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All-Ukrainian Scientific Research Institute for Civil Defense of population and territories from technogenic and natural emergences.

«Twenty-five Years after Chornobyl Accident: Safety for the Future»

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LIST OF CONVENTIONAL SIGNS AND ABBREVIATIONS

AC_605	Administration of Construction № 605 MCM of USSR – specialized building organization set up to make sarcophagus
ACB	Administration control building
ACS DB DEMOSMONITOR P	Automated control system of data bases of monitoring of medical and demographic consequences of Chernobyl catastrophe
ADR	Analytical rated dose reconstruction
AELT	Average expected lifetime
ALARA	As Low As Reasonably Achievable
AMSU	AMS – Academy of Medical Science of Ukraine
AOR	Adjusted Odds Ratio
ARDIET	All_union Research and Design Institute of Energetic Technology of Minseredmash of USSR
ARS	Acute radiation syndrom
ARS NC	Acute radiation sickness no-confirmed by experts in 1989
ASRCC	Automatic System of Radiation Condition Control
ATR	Attributive risk
AZF	Active Zone Fragments (Core Fragment)
BD	Birth Defects
BSS	International safety standards
BSR – 72/87	Edition of basic sanitary regulations accepted in USSR in 1987
BSSR	Belorussian Soviet Socialist Republic
BSRRSU_ 2005	Basic Sanitary Regulations of Radiation Safety of Ukraine
Bq (kBq, MBq, GBq, TBq, PBq)	Becquerel ($Bq*10^3$, $Bq*10^6$, $Bq*10^9$, $Bq*10^{12}$, $Bq*10^{15}$), radioactivity unit
CCC	Chronical lymphoid leucaemia
CDC IA «Combinat»	Council of Dosimetric control of Industrial Association «Combinat»
CDP	«Chernobyl Decommission Plan»
CEC	Commission of European Communities
CER	Clinical and epidemiological register
CEZ «Slavutych»	Special economic zone «Slavutych»
CFR	Chain fission reaction
CHD	Coronary heart disease,
CHNPP	Chornobyl Nuclear Power Plant
CHC	Chernobyl catastrophe
CIL	Current interventional levels
CI	Confidence interval
CIRS	Complete engineering-radiation survey
CL	Control Level
CMU	Cabinet of Ministers of Ukraine
CMV	Cytomegalovirus

CMZ	Critical mass zone
CNSDU	Council of National Security and Defence of Ukraine
COLD	Chronical Obstructive Lung Disease
CPMCCRWS	Complex for production of metal and ferroconcrete containers for of radioactive wastes saving
CP NSC	Conceptual project NSC
CPRD	Chernobyl Program of Remediation and Developing
CRMEZ	Center of Radiologycal Monitoring of Exclusion Zon
CSNFSF	SNF Storage Facility
DA	Deficiency anemia
DCCP	Definitive closure and conservation project
DCS	Diseases of the circulatory system
DECOMMISSIONING	Removal of ChNPP from usage
DS	Drum separator
EAR	Excess of absolute risk
EDC	Exposure Dose Capacity
EDLC	Extremely dangerous labour conditions
EBRD	European Bank of Reconstruction and Development
ECHNPPAC	Elimination of ChNPP Accident Consequences
EH	Essential hypertension
EPR	Electron paramagnetic resonance
EPC	Extreme permissible content
ESS	Ecologically Safe System
ESCUN	Economical and Social Council of UN
EZ and ZAR	Exclusion Zone and Zone of Absolute resettlement
EZ	Exclusion Zone
FC	Fuel channel
FCM	Fuel Containing Materials
FE	Fuel element
FGI	French-German Initiative for Chernobyl
FIP	Facilities for personal protection
FPC	Fuel and Power Complex
FSISC	Feasibility study of investments into storage construction
Grey (Gy)	Grey, unit of absorbed dose
HLRW	High level radioactive waste
IACS	Integrated automated control system
IAE	Kurchatov Institute for Atomic Energy
IAEA	International Atomic Energy Agency
IBDSO	Integrated database for «Shelter Object»
ICC	Information crisis Center
ICD	International Classification of Diseases
ICMRW	Industrial complex for management of solid RW
IDD	Iodine Deficiency Diseases
IEG NASU AND ME	Institute for environmental geochemistry of NASU and ME
INSAG	International Consultative Group on Nuclear Safety
IPHECA	International Program on Health Effects of the Chernobyl Accident
IQ	Intelligence Quotient

IRL	International Radiological Laboratory
IRSA	Interim report on safety analysis
IS NASU	Institute for sociology of NASU
ISP NPP	Institute for safety problems of nuclear power plants NAS of Ukraine
KIEP	Kyiv Institute «Energy project»
LC-1 NSC	The first launching complex of NSC
LFCM	Lava_like fuel containing materials
LGW	Level of ground waters
LMAW	Low and medium active wastes
LRWTP	Liquid radioactive wastes treatment plant
LRW	Liquid radioactive wastes
LRWSF	Liquid radioactive waste storage facility
MAPU	Ministry of Agrarian Policy and Food of Ukraine
MPI	Medical and prophylactic institutions
MD	Ministry of defence of Ukraine
MDSS	Modernised Dust Suppression System
ME of Ukraine	Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chernobyl catastrophe
MHU OF UKRAINE	Ministry for Health of Ukraine
mR, (R)/hour	(Roentgen) per hour, exposure radiation dose capacity
MIAU	Ministry of Internal affairs of Ukraine
Minseredmash (MPEI)	Ministry of Power Engineering Industry of USSR
NASU	National Academy of Sciences of Ukraine
NAASU	National Academy of Agrarian Sciences of Ukraine
NCRPU	National Commission on Radiation Protection of population of Ukraine
NEC	Nuclear energy complex
NSC	New Safe Confinement
NULESU	National University of life and environmental sciences of Ukraine (UIAR of former UAA, NAU)
ODR	Official Dose records of military liquidators of ChNPPAC in State registry of Ukraine
OG	Operations Group
OR	Odds Ratio
ORR	Operate reactivity reserve
PC_a	Permissible concentration of substance in air
PL – 97	Permissible Levels of 137Cs and 90Sr radionuclides concentration in food and drinking water, valid at the moment
PL – 2006	Permissible Levels of 137Cs and 90Sr radionuclides concentration in food and drinking water, valid at the moment
PLEA	Plans for localization and elimination of an accident
PSTTE	Points for special treatment of technical equipment
PTSD	Posttraumatic Stress Disorder
RADRUE	Realistic Analytical Dose Reconstruction and Uncertainty Analysis
RALE	Reduction in anticipated life expectancy
RBE	Relative biological efficiency

RBMK -1000	Model of Reactor (high power capacity, channel) -1000 MWt
RCSS	Report on conformity to sanitary standards
RCM	Radio_contaminated materials
RCT	Radio_contaminated territories
RDIPE (NIKIET)	Research and Development Institute of Power Engineering
REA	Report on Environmental action
REM	Rad equivalent man – outdatednon-system unit for effective expose dose (1 rem=0,01 Sv)
RIA „Prypiat'»	Research-Industrial Association „Prypiat'»
RIAR (RIARAE)	All-Union research Institute of Agricultural Radiology, Obninsk (since 1991 Russian research Institute of Agricultural Radiology and Agroecology)
ROW	Recovery operation workers (clean-up workers, liquidators)
RR	Relative risk
RS	Radiation sources
RSA	Report on safety analysis
RSSU_97	Radiation Safety Standard of Ukraine_97
RTL	Relative telomere length
RW	Radioactive wastes
SA	Supplementary absorbers
SAC	Soil absorbing complex
SAD	Small anomalies of development
SBRW	Sites for burial of radioactive wastes
SCS	State committee of statistics
SDF	Spent Deffective Fuel
SE	State Enterprise
SEC HGS NASU	Scientific-engineering centre for radio-hydro-geo-ecological polygon studies NASU
SE NNEGC «Energoatom»	SE National Nuclear Energy Generating Company «Energoatom»
SE SCRM	State Enterprise «Scientific Centre for Radiation Medicine» AMSU
SFA	Spent Fuel assembly
SFSNF	Storage facility for spent nuclear fuel
SFSNF -1	Storage facility for spent nuclear fuel of wet type
SFSNF -2	Intermediate storage for spent nuclear fuel of dry type
SIP SO	Shelter Implementation Plan SO
SLSW	storage for liquid and solid wastes
SLW	Short-living wastes
SNF	Spent Nuclear Fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SO	Shelter Object
SR	Safety rods (System of control and safety of reactor)
SRISBC	State Research Institute for structure, building units
SRU	State Registry of Ukraine
SRW	Solid radioactive waste
SRWSF -1	Solid radioactive waste storage facility first type
SRWSF -2	Solid radioactive waste storage facility second type
SSCDCH ME of Ukraine	State scientific Center for defence of cultural heritage from

	technogenic emergencies of Ministry of Emergencies of Ukraine
SSDW	Sites for storage of deactivation wastes
SSE ChNPP	State specialized enterprise Chernobyl Nuclear Power Plant
SSE «Complex»	State Specialized Enterprise «Complex»
SSE «Technocentre»	State Specialized Enterprise «Technocentre»
SSRI «**Chernobyl Center**»	State Scientific and Research Institution « Chernobyl Center for Nuclear Safety, Radioactive Waste and Radioecology»
SSRW	storage for solid RW
SSSIE «Ecocentre»	State Specialized Scientific – Industrial enterprise «Ecocentre»
SSTC NRS	State scientific and technical Center for nuclear and radiation safety
STC CMRW	Scientific-and-technical center for complete management of radioactive wastes, Zhovti Vody
STLRW	Sites for temporal localization of RW
Sv (mSv)	Sivert (milisivert), effective dose unit
TB	Technological building
TC	Thyroid cancer
TD	Thermoluminescent dosimeter
TF	Factor of radionuclides in natural chains
TF-92	Aggregated transfer factor «soil-milk»
The USSR	The Union of Soviet Social Republics
TG	Thyroid gland
TISNO	Technogenic intensified sources of natural origin
TPL-91	Temporal Permissible Levels, acted up to 1997
TSF HAW LMA LLW	Temporary storage facility for high-active and low-medium active long living wastes
TSF SRW	Temporary storage facility for solid radioactive wastes
TUE	Transuranium elements
UACOS	Ukrainian/American Chernobyl Ocular Study
UIAR	Ukrainian Institute for Agricultural Radiology
Ukr SA «Radon»	Ukrainian state association «Radon»
UkrSSR	Ukrainian Soviet Sicialisr Republic
UNDP	United Nation Development Program in Ukraine
URHMI	Ukrainian Research Hydrometeorological Institute under the Ministry for Emergencies and NAS
UNICEF	United Nations International Children's Emergency Fund
UN SCNRA	UN Scientific Committee on Nuclear Radiation Activities
URTC	Ukrainian Radiological Training Centre
USRICD	ll-Ukrainian Scientific Research Institute for Civil Defense of population and territories from technogenic and natural emergences, ME of Ukraine
UTC	Educational and training Center
WBC	Whole body counter
WHO	World Health Organization
WHO-CIDI	Composite International Diagnostic Interview
WMR	Water_moderated reactor

1. CHERNOBYL CATASTROPHE. IMPLEMENTATION OF FIRST-PRIORITY MEASURES ON MITIGATING ITS CONSEQUENCES

1.1. Reasons and scale of the accident at ChNPP

During testing of design conditions of power supplying Power Plant's own needs in the event of external SOURCES loss, on April 26, 1986, a nuclear accident with catastrophic consequences happened at Chernobyl NPP Unit No. 4. The similar tests were performed earlier too at Chernobyl NPP Power Unit No. 3 in 1982, and then at Power Unit No. 4 in 1984 and 1985. But all of them turned out to be failed due to unsatisfactory characteristics of generators' actuation systems.

The reasons of the accident were analyzed by organizations and individual experts both in the former USSR and abroad. One can formulate three main reasons set conditions for pre-accident reactor status and its catastrophic power runaway:

– Before the accident the reactor facility was in such physical and thermo-hydraulic state of stability which could be disturbed even by minor excitations. Such state of the reactor was caused by personnel actions and occurred prior to the tests of generator running-out operation. All reactor parameters before start of the tests, except for operating reactivity margin, were within the limits authorized by the process regulations;
– A direct impulse for the accident occurrence was emergency reactor shutdown system activation that due to defective design of control and protection rods led to positive reactivity insertion and start of reactor power excursion;
– This runaway reached disaster proportions because of a large steam coefficient of reactivity peculiar to high power channel-type reactors (RBMK-1000), and impact of which is notably strong at a low level of power (small void fraction).

Thus, the direct causes of the accident became neutron and physical, and design peculiarities of RBMK-1000 reactor implementation of which was promoted by personnel actions. To the main shortcomings of RBMK-1000 reactor in its operation as of 1986 one should relate:

– Low speed efficiency of reactor control and protection system (control and protection rods were inserted into the reactor for 18 seconds, while at reactors of other types it took 2-4 seconds) that did not allow the control and protection system to deal with transient processes;
– Design of control and protection rods which led to the fact that under certain circumstances the emergency protection did not shut down a reactor, but inserted a positive reactivity into the reactor and became an initiator of reactor power excursion;
– Unacceptably high coolant density (steam) reactivity coefficient as a result of which, firstly, at some operations the reactor total coolant density coefficient of reactivity became positive and, secondly, the decrease of coolant density in the reactor, regardless of the reason, led to catastrophic power rise;
– Double-peak throughout the height power density field which together with shortcomings of reactor control and protection system predetermined formation at reactor's bottom half of quasi-individual reactor core with unacceptably high speed of power rise in case of actuating reactor emergency protection under the condition of low operating reactivity margin.

These particular shortcomings of RBMK-1000 reactor caused the accident at Chernobyl NPP Power Unit No. 4 on April 26, 1986. They were the consequence of the made deviations by reactor's creators from safety requirements formulated in ПБЯ 04–74 («Nuclear Safety Rules for Nuclear Power

Plants») and ЗПБ–73 («General Provisions on Safety Assurance of Nuclear Power Plants during Design, Construction and Operation»). Both documents were in force during designing the Chernobyl NPP's Second Generation.

To all of this one should add that RBMK-1000 reactor and a Design of the Chernobyl NPP on the whole also contained other considerable departures from requirements of normative documents. In particular, the NPP's Design envisaged the limited accident containment system the sealed circuit of which included only a part of the reactor and systems of its cooling. Also, that is more important, the Design did not envisage control and information devices for an operator regarding the operating reactivity margin, to say nothing about automatic reactor protection under the conditions of deviations of this parameter from the fixed limits. This particular parameter in the event of its decreasing lower than a certain value transformed the emergency protection, which in any circumstances must have shut down the reactor, into the instrument of its power runaway.

Analysis of personnel actions disputes concerning which are still underway revealed that the personnel in fact made some mistakes, but a level of their guilt was consciously overestimated in information provided by the USSR to IAEA in 1986. The accident which in virtue of its scales concerned many countries demolished a myth about impeccability of the soviet nuclear science and engineering. One failed in concealment of the accident scales and consequences. It was necessary to find reasons which would to the least give the low-down on state of affairs and not challenge a quality of the soviet engineering. Thus the slogan «personnel is guilty» appeared. This approach was authorized by the state political leaders.

A critical part in initiating and developing the accident was played by creators of RBMK-1000 reactor, who, having known about its shortcomings, had not informed about this the operating personnel and not instructed them about how they must have acted to prevent their appearances. As a result, the process regulations and instruction on reactor operation specified directions the actions pursuant to which at certain operations could have led to disaster consequences. For example, following the completion of generator running-out tests at night on April 26, 1986, it was strongly forbidden to shut down the reactor by pushing AZ-5 button as it was envisaged by the process regulations on RBMK-1000 reactor operation, but the personnel did not know about this. Unfair practices of RBMK-1000 reactor creators to conceal information on its shortcomings known to them caused inadequate preparation of the personnel for actions during unscheduled situations.

The results of investigation of the organization – Chief Designer of RBMK-1000 reactor, published in 1993, make it possible to stop disputes on technical reasons of the accident. The reactor's designers showed that nuclear-physical and thermo-hydraulic characteristics, as well as design defects led to destruction of RBMK-1000 reactor even in the event of design-basis accident at low power. Also it was confirmed that solely «implementation of measures, carried out after the accident at the Chernobyl NPP, leads to the fact that at all range of initial power, being under study, a maximum design-basis accident with de-energization does not give rise to a dangerous change of power, and a fast emergency protection shuts down the reactor». Thus, the Chief Designer confirmed that the reactor was doomed by virtue of its design characteristics and only waited for implementing the respective initial conditions. On April 26, 1986, such conditions were created by personnel actions.

Specific details of the accident can be defined more exactly, but the main conclusions will remain the same. The accident was caused by underestimation and disregard to the possible negative effects of the known physical phenomenon. It's overwhelmingly important with the objective to learn lessons for future to understand what led to the possibility of multi-years operation of the nuclear facility with the shortcomings that caused the disaster, and to realize what one must do in order to prevent an accident in future.

The shortcomings of RBMK-1000 reactors were known long before the accident. And this fact has been confirmed by many documents. There were plans for upgrading such reactor facilities.

However, they either had not been implemented, or were implemented very slowly. For instance, a positive overshoot of reactivity during insertion of control and protection rods into reactor core, been a trigger for the disaster, was experimentally specified and documented in December 1983 during commissioning tests of Ignalina NPP Unit No. 1 and Chernobyl NPP Unit No. 4. This effect and its possible consequences for safety had been considered by the I.V. Kurchatov Atomic Energy Institute (Scientific Manager of RBMK-1000 Design) and Scientific and Research Institute of Energy Technologies (RBMK-1000 Chief Designer) and the results of this discussion had been known to managers of all NPPs with RBMK-1000 reactors and higher organizations.

However, neither the Scientific Manager, nor the General Designer bore responsibility for the NPP safety. In the USSR at that time there was not operating organization, defined by civilized world, absolutely responsible for the safety. In the state including the high national level was absent that nowadays recognized worldwide as «safety culture». The importance of occurring concerns regarding the safety was underestimated. The measures that could have prevented the disaster were not implemented.

The USSR undoubtedly achieved considerable success in developing nuclear science and engineering, especially in military industry. However, this success was too much politicized. At the same time, shortcomings and errors that led to large disasters both at civil (Leningrad NPP, 1975, Chernobyl NPP, 1982, etc.) and military nuclear facilities (Cheliabinsk, 1957, Chazhma Bay, 1985, etc.) were concealed. There was not a proper state control over the activity of nuclear institutions (actually, such control was absent until 1984). All this resulted in the fact that infallibility moods become firmly established in the nuclear engineering. Their best closest main point is presented by the formula «The Soviet nuclear reactors are the best in the world». This was also eloquently seen in response to the accident happened at the American «Three Mile Island NPP» in 1979, when the leaders of the USSR nuclear industry announced that «such accident was impossible under socialism». The state political prestige dominated and strangled the basic condition for a peaceful use of nuclear energy that is the assurance of its safety.

At the beginning of 1980's, after the accident at the American «Three Mile Island NPP», tendencies for a critical overestimation of NPPs' safety emerged in the USSR. But, objective safety assessments of national reactors were blocked by authorities and leaders of the soviet nuclear science and engineering. The role of peer review first of all from the state nuclear safety regulation bodies was almost null. Prior to the accident of 1986 a strong and independent nuclear regulation authority that is the basis for the state nuclear safety system was almost absent.

Politicization of the USSR nuclear science and engineering, image of its exclusiveness and infallibility, created by years, absence of independent nuclear regulation and efficient state control over the nuclear power engineering are the fundamental reasons of the Chernobyl tragedy.

The myth, that the nuclear science and techniques of USSR had unlimited financial and material resources continues to exist till now. It is fair if to speak about what has been intended for the military purposes. Really the nuclear power felt chronic shortage of funds, first of all for exploratory developments for a safety and reliability substantiation, experimental try-out of the equipment etc. It is enough to say, that expenses for the Nuclear Power Plants Safety substantiation in USSR were more than in 10 times lower, than in USA – but it became known only after «Iron Curtain» falling. Absence of funds for creation of experimental testbed base, procurement of modern computing techniques, to perform researches and try-out of technology for Radioactive Waste and Spent Nuclear Fuel Management, creation of qualitative dosimetric equipment, creation of training simulators – all that to some extent appeared during the accident and in process of its consequences liquidation. It can be absolutely soundly stated that economic bases for Nuclear Safety assurance in USSR haven't been arranged and the reason of such position was misunderstanding of a problem or absence of funds it doesn't matter. It is important, that Nuclear Energy Safety hasn't been provided economically.

True causes of the accident have been formulated for the first time by the Governmental commission on investigation of the accident causes at Chernobyl NPP and liquidation of its consequences. Really, Governmental commission named Chernobyl NPP managers as responsible for accident, who «have made serious errors in the plant operation and haven't ensured its safety». However, only these conclusions became known to the USSR's population and to wide world community – the commission's deed has been hush-hushed. In fact, the Governmental commission also named as responsible for the accident:

- Ministry of Energy and Electrification, which has tolerated malpractice to perform various tests and not regulated works in night time, and absence of control for these works; tolerantly reacted to physical and technical lacks of RBMK-1000 reactors; hasn't insisted the Chief Structural Engineer and the Research Adviser for realization of actions to improve these reactors reliability; hasn't provided appropriate training for operational staff;
- Ministry of Medium Machinery Manufacturing, which hasn't taken timely measures for RBMK type reactors reliability improvement in full conformity with the requirements of «General provisions of Nuclear Plants safety assurance during designing, construction and operation»; hasn't provided sufficient technical solutions for the reactor safety assurance;
- State Nuclear Supervisor, which hasn't provided appropriate control of nuclear and technical safety rules and norms execution; not in full exercised the provided to it rights; acted irresolutely, hasn't stopped violation of safety norms and rules by the employers of ministries and departments, nuclear plants, enterprises supplying the equipment and devices.

Governmental commission has considered engineering and technical aspects of the accident. In particular, the Commission has noted that the reactor protection emergency system hasn't executed its functions and the accident has occurred because of reactor lacks, in particular:

- presence of positive steam reactivity factor;
- occurrence of the positive general power reactivity factor, which should be negative at normal and emergency operation;
- unsatisfactory design of a reactor control and protection system roads, which entered positive reactivity during their initial movement to core;
- absence in the reactor installation design of the device showing value of an operative reactivity allowance and preventing about approach to dangerous border.

In essence, Governmental commission even in May 1986 recognized that the RBMK-1000 reactor had the serious constructive lacks, which became the reason of its explosion with catastrophic consequences.

Bitter and hopelessly tardive confession of the accident causes, political assessment of occurred were given by last CPSU congress (the newspaper «Pravda» dated 7/14/1990): «In the conditions of administrative and command system the former country leaders made the great miscalculations in scientific and technical policy development in the field of nuclear power and population protection in extreme conditions. Ministry of Energy, Ministry of Medium Machinery Manufacturing, State Committee of Hydrometeorology, State Nuclear Energy Supervisor, Academy of Sciences, Civil Defence have shown inability to secure population's life and health, were unprepared to apply necessary urgent actions... Overconfidence and irresponsibility of some leading scientists, heads of the ministries and the departments involved in Nuclear Power Plants designing, construction and operation, their statement about absolute safety of Nuclear Power Plants, have led to real absence of the state system of works in emergency situations».

Decision of the commission of Ministry of Medium Machinery Manufacturing (May 1976), created after the accident at Leningrad NPP in 1975 is acknowledgement of the fairness of Governmental commission deed and the resolution of last CPSU congress. At that time the commission has come to a conclusion that the problem of positive steam effect of reactivity isn't resolved, there are no means for immediate moderation chain reaction of fission which could compensate the positive reactivity released under condition of fast growth of steam content in reactor core. The position of Kurchatov institute about necessity to introduce additional faster emergency protection is stated at the same document. Thus, the main reasons which have caused accident have been named ten years before the accident.

But elimination actions have not been realized and designers haven't prevented operational personnel about consequences of the miscalculations realization made during designing of the reactor and haven't provided recommendations to the personnel how to act in critical situations, till the actions excluding design defects of the reactor will not be realized.

It is difficult to explain sluggishness in elimination of the revealed deficiencies in RBMK-1000 safety, but set of negligence and self-confidence with a lack of knowledge became one of key causes of the accident. An incontestable fact is also that important details for safety consciously weren't communicated to the personnel. The personnel practically knew nothing about the accident at Leningrad NPP in 1975 and about other operational incidents at this main NPP from a series with RBMK-1000 type reactors. One of the most important safety principles – taking into account operating experience of the same Units was ignored.

IAEA General Director has created the International Nuclear Safety Advisory Group (INSAG) for the analysis of Chernobyl accident reasons. Its first Report pursued this purpose. The emphasis in it has been made on personnel errors. Obviously INSAG didn't carry out independent collection of materials about the accident and was guided by the mispresented information given by the Soviet side in 1986. Later, on the basis of the researches carried out by the Soviet and foreign experts, Report INSAG-1 has been revised and the new report, INSAG-7, which is recognized today around the world as the most true-to-life document about Chernobyl accident reasons and circumstances was issued in 1993.

Coming back to the accident, it needs to provide in brief the information about course of events on April 25-26th 1986 at Chernobyl Unit 4 led to the accident. Decrease in Unit's capacity for planned repair performance has been started at about 1 o'clock in the morning on April, 25th and up to 4 o'clock in the morning power unit's capacity has been stabilized at the level of 50 % from the nominal. It has been started preparation of the unit for testing and repair. However, the command of the power supply system dispatcher at 14.00 has arrived to continue operation at the level of 50 % from nominal till overcoming of maximum loadings. The permission of the dispatcher shutdown unit has been obtained only at 23.10. It should be noted that throughout several hours, approximately from 7 am till 14 pm designed operative reactivity margin was a little below admissible, but the NPP's Chief Engineer on the basis of the available at the moment information about the equipment status and being guided by operating procedure, permitted to continue unit operation under capacity.

At 00.28 during regular operation of transition from one control system to another the Senior Engineer of the reactor control (SERC) was not capable to make it and capacity of the reactor has decreased up to 30 Mwatt thermal. Near one SERC renewed automatic control of the reactor and stabilized its capacity at the level 200 Mwatt thermal established by the head of tests. That was a deviation from the tests program which should be carried out at the capacity 700 Mwatt thermal. However, operation at the capacity 200 Mwatt thermal wasn't forbidden by operating procedure for RBMK – 1000 reactor.

Till now heated discussion proceed, attempts to find the one who has given a command about renewal of the reactor capacity, considering, what namely this command has led to the accident. Such command wasn't necessary. The operator has made a mistake and tried to correct it. From a today's position it should be noted that it was the fatal decision – it would be correctly to stop the reactor.

Tests were started at 1.23 under the stable parameters of the reactor confirmed by last records of parameters registration by computer complex «Skala». At 1.23,40 ' in the absence of any deviations in an operating mode of the reactor and warning or alarm system signals, tests were completed and according to the Unit Shift Supervisor command SERC performed regular action – presses AZ-5 button to reactor shutdown. Last record in operative log of the reactor operator: «01.24. Hard knocks. CPS roads have stopped without reaching bottom trailing edges. The key of a muffs feeding is removed».

Pushing of AZ-5 button became a direct impulse to start emergency process. The imperfect design of control and protection roads has caused introduction of positive reactivity in a reactor core. Speeding up of its capacity has started. It became catastrophic because of big (approximately 5β eff.) steam factor of the reactivity, which influence was especially high under condition of close to zero steam content in reactor core.

Low value of ORM not only worsened condition of the reactor control, which was known to the personnel, but also has left the reactor without emergency protection, that wasn't known to the personnel. The device for ORM control hasn't been provided by the design. The regular system of ORM calculation according to «Prisma» program didn't provided the operator with information as worked unstably at low capacity level – ORM value at the moment of AZ-5 button pressing has been identified by calculation already after the accident. The operator could make ORM assessment on poisoning curves which has been provided in the reactor operation instruction. Such assessment would provide him with ORM value at one o'clock in the morning on April 26th – MC 15–16 roads (unit unloading was starved in April 25 at 23.10 under condition of ORM in 26 MC roads).

Low reactor power and high coolant flow, which is close to zero-point core inlet subcooling of coolant, conditioned high sensitivity of reactor to external impacts. Thus, the proximate reasons of the accident were neutron-physical, thermal-hydraulic and structural peculiarities of RBMK-1000 reactor, and personnel actions make their realization possible. It is obvious that reactor was doomed due to its design characteristics and just waited for implementing corresponding post-conditions. On April 26, 1986, these conditions were created. The details of accident process can be specified, but main conclusions remain the same.

Personnel really took some actions, which worsened the situation. Stability of connection system for accessory main circulation pumps was highly affected. But this operation was not prohibited by the process regulations, and it was provided by the testing program. Prohibition for such operation appeared already after the accident. The USSR information provided to IAEA contained personnel accusation in deactivating some shielding. As it is, whole reactor shielding was activated by physical parameters, including power overshoot and expanding capacities rates. The linings of process shielding were in positions prescribed by 1986 operational documentation. The only deviation is that shielding setting regarding water level in drum-separators was changed, but this did not influence on neither initiation nor development of the accident.

Personnel really made the emergency core cooling system out of operation. However, first of all, this was provided by the testing program and, secondly, this was not prohibited by the process regulations. But emergency core cooling system had to be put into normal operation mode upon condition to postpone time for shutdown and Unit testing upon the command of energy system supervisor.

It should be mentioned that even if all actions incriminated to personnel by USSR information provided to IAEA in 1986 were actually taken, they by no means would not influence on initiation and development of the accident process.

According to Item 10.12 of Reactor Operation Regulations and Item 12.4 of Process Regulations, the reactor is stopped by pressing AZ-5 button. Lead engineer for reactor control did just the same thing having received the command to stop reactor after testing completion. And just this regulation action was fatal one. Reactor protection system in case of low operative reactivity margin played the part of launching trigger for accident, and high positive density effect of reactivity led to accident development of catastrophic magnitudes. Incontrovertible fact is that high-level emergency protection not only did not save the reactor, but also caused the accident.

Neither Management of nuclear power plant, nor operational personnel particularly chose the equipment they should use. The NPP's staff had to master the provided equipment and learn to control this equipment. But the time has come when operator was not able to cope with the reactor. The reactor developers did not provide him with required information. Those limitations, ignorance of which was referred to personnel fault later, were not indicated in the process regulations and instructions. Operators fell into a mode, which was not described and was not prohibited by any acting document until the accident.

Some primary reasons of accident were already mentioned above. There should be added some more. There was no nuclear legislation in USSR. Only at the end of 80's of the last century, understanding became forming that the law is required, which regulates activity in nuclear field, including authorization system, rights and commitments of its participants. But this law was never accepted in USSR.

Fewer claims could be laid to the regulatory framework available at that time. But also it contained many concessions for RBMK reactor. Moreover, its developers could not meet a lot of regulatory requirements mentioned above. Attempts to denote them and also any criticism to RBMK-1000 were blocked by Management of the Ministry of Middle Engineering. The deserts of this Ministry, especially in military field and in creating nuclear shield of the country are indisputable. The Ministry included intellectual elite of the country, outstanding scientists and specialists. But to convert it into state in the state, actually leave without control, and make its managers infallible oracles is a great mistake of the country's leaders, which resulted in tragic consequences.

The security system, in which Soviet nuclear science and machinery existed, should also be referred to root causes of the accident. Undoubtedly, first of all, the Soviet party suffered from this system. Creating peculiar «iron curtain» around national nuclear power industry, USSR was losing ability to compare its developments with those in other countries of the world, being behind more and more from the most important trends.

It is sufficient to make one example. In the world's practice in the 60's of the last century, prior to decision-taking about NPP construction, to analyze its safety comprehensively became a practical activity. The American standard RG 1:70, regulating requirements to the structure and content of a report summarizing results of such analysis, became an example for the world nuclear community. No such matter was in USSR, and practice in licensing nuclear power plants in USSR was lacking. The State greatly fell behind in creating methods of safety analysis and their mathematical support. The world advanced in analysis methodology for not only design accidents, but also beyond design basis ones. Chernobyl tragedy opened eyes to this unpleasant fact, and only in the middle of 80's the practice in NPP licensing, developing and providing substantiation of safety for new and active nuclear units began developing.

Not only international self-isolation played the negative part in creating conditions resulted in catastrophe. Nuclear energy for all intents and purposes was closed from public control in its own country. And this is also one of the root causes of the accident.

The accident magnitudes were very large. Vast resources are spent and being spending for their elimination. A lot of territories are lost for a long time for common economic activity. Tens of villages have lost their inhabitants and transformed into silent monuments of the catastrophe. It affected fates of million people. Tens of thousands people lost their health, and many of them lost lives. This is terrible price for mistakes made when creating RBMK-1000 reactors.

The accident inflicted the great loss to nuclear energy industry in the whole world and deferred its development for many years. The accident showed that consequences from error of an operator or NPP creators go beyond the international boundaries. Responsibility for national nuclear energy safety is transforming into responsibility to world community. And this regards not only to nuclear facility creators and its operating personnel, but also to national regulators and high level state authorities.

Chernobyl accident gave one more lesson learned, i.e. need in supporting efficient international safety measures for nuclear energy. The world community promptly learned this lesson that is confirmed by IAEA activity, conclusion of certain international conventions, first of all, the convention on nuclear facility safety.

The important lesson learned is a necessity for independent state and public control for nuclear energy safety. Only society has a right to take decision on nuclear energy development to be precisely documented in legislation. But for such responsible decision, population should be prepared appropriately. It has to know what NPP is, what its potential hazard is, and what is done to have this hazard so minor to neglect it. It is required to have routine and methodical public relations.

Availability of independent and competent regulatory authority is an indicator of nuclear safety culture in the country. Lack of such authority or financial and human resources sufficient for performing its functions, lack of actual independence in taking important safety-related decisions mean the lack of nuclear energy safety culture in the country and violation of its international safety measures.

Equally important lesson learned from Chernobyl accident is compulsory availability of qualified operating organization, which is able to solve nuclear energy problems and has the potential for safety assessment and control of nuclear facilities being under operation.

Finally, one more lesson learned is continuous NPP safety analysis, revelation of safety deficiencies and their elimination. This should include intensive scientific research of factors influencing on NPP safety; continuous improvement of regulatory framework; creation of specific safety-oriented psychological climate in the operators' teams; continuous advanced training of personnel and sense of responsibility for accident-free operation of nuclear power units.

The analysis of the thing happened on April 26, 1986 at Chernobyl NPP is not a goal in itself and should not be retrospective. The primary goal is to learn lessons for nuclear safety today and in future, and to prevent the potential for accident repetition having significant radiological consequences. All who in some or other way are involved in nuclear safety assurance, whose decisions could directly or meanly have an effect on nuclear safety, should understand why one was able to operate the facility, which did not meet the safety requirements, why deficiencies were not eliminated for years, which were known and resulted in accident with catastrophic consequences. This should be recognized, and appropriate conclusions should be made.

1.2. Measures on limiting radioactive substance releases into the environment

After the first major release of radioactivity due to reactor explosion, radioactivity release did not stop.

The rate of this release was determined by the following processes:

1. Residual heat release by means of radioactive decay of fission products generated in reactor.

Considering release of volatile fission products, this value amounted to ~230 kWt/tU [7] after the explosion, and decreased hereafter.

2. Heat release due to chemical reactions (mainly in oxidation-caused graphite) [8].

The release intensity from April 26 to May 2 was gradually decreasing, and from May 2 to May 6 it was increasing, probably due to generating a combination of isolated cells into single flux [9], and after May 6 it decreased suddenly (Figure 1.1.) [3].

Hereafter, estimates were made based on reconstruction of release dynamics on density of territory contamination with ^{137}Cs and considering meteorological conditions during accident [10], according to which the release rate was steadily increasing from 26 to 28 April as a result of nuclear fuel heating.

In order to reduce impact of releases from the destroyed reactor into environment, the Government Commission created on April 26 decided to start dropping the materials from helicopters into the reactor vault to contain release sources. Starting from April 26, about 5,000 t of different materials [11] were dropped onto Unit 4 for two weeks. To provide fuel cooling – 2,400 t of lead, to prevent potential self-sustained chain reaction – 40 t of boron carbide, to cease graphite burning – 800 t of dolomite, to filtrate release of fission products – 1,800 t of sand and clay. Total for April and May

1986, about 15,000 t of following materials were dropped: lead pellets – 1,500 t, lead bars – 5,220 t, marble aggregates – 3,532 t, dolomite – 1,167 t, baron carbide – 42 t, rubber resin – 489 t, zeolite – 1,890 t, polymerizing liquid – 140 t and tri-sodium phosphate – 1,536 t [12]. Unfortunately, as shown in [12], the significant amount of materials dropped onto destroyed unit did not reach reactor vault. In the Central Hall, the top height of hill consisting of dropped materials is about 15 m over floor near the wall of destroyed southern drum separator. Average height of the hill in the center of the hall is about 7 m. It can be explained that smoke source was located, approximately, 25 m eastwards from reactor vault. Moreover, the upper plate of biological shielding located almost vertically covered reactor vault from above together with water pipeline fragments. Dropping of backfill materials from top height led to a destruction of Turbine Hall roof plates and deaerator stack, and intensive dust-generation led to radiation contamination northwards [9]. The backfill materials coming into Central Hall extinguished inflammation source being outside reactor vault, and covered there high-level fragments of the core with thick layer mitigating radiation hazard for builders and personnel.

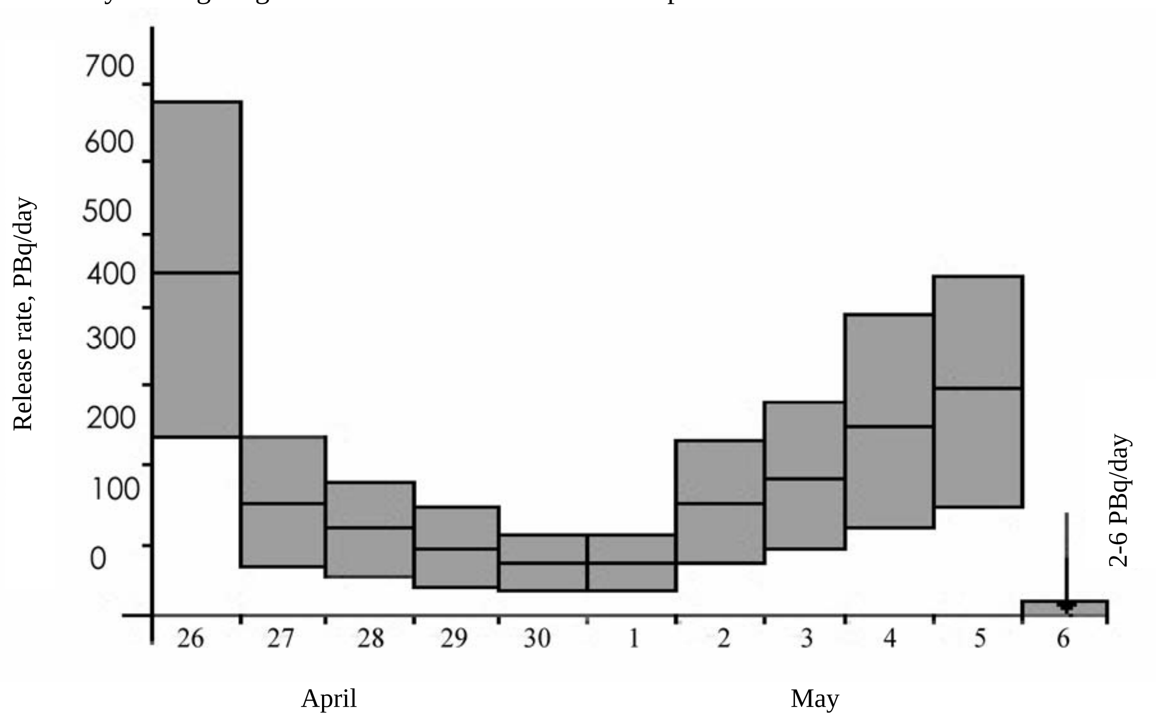


Fig. 1.1. *Daily release of radioactive substances into environment during Chernobyl accident (not considering inert gases). The values are estimated as of May 6, 1986, including radioactive decay. Activity released on April 26, 1986, amounted to 740–890 PBq. The uncertainty limit for all releases ± 50%*

Generally, further release reduction was conditioned by natural processes inside the reactor: finishing of graphite burning and temperature decrease of generated lava-like fuel-containing materials due to decrease of residual heat release and heat removal by means of atmospheric wind convection.

There was one more hypothetic hazard – significantly large amount of nuclear fuel could penetrate floor structure under reactor compartment, foundation plate and contaminate ground waters with high-level activity. To eliminate this potential hazard, the Government Commission decided to construct reinforced concrete under-foundation plate of 30x30 m size and 2.5 m thickness, which is cooled by water owning to valiant job of miners in extremely complicated conditions. Works on construction of this plate were completed on June 28. However, when calculating the interaction of melted fuel with structural materials of reactor compartment, it was not considered that during this interaction fuel would be mixed or dissolved in their flux, as a result of which a volume would be significantly increased and heat removal conditions would be improved. Thus, the real hazard of melting was only for floor structure between premise 305/2 and steam distribution corridor [13] (see Section 5.1.1.).

When it was not clear actually what processes take place in the destroyed unit, limited time for their modeling, incapability to obtain reliable information due to the highest radiation backgrounds near and inside the unit, as well as psychological impact of catastrophe scale made impossible to take optimal decisions in some cases.

1.3. Activities on population protection

During some hours after the 4th Power Unit destruction the ChNPP firemen and personnel managed to liquidate numerous inflammations at the Unit that prevented the threat of fire spreading to other Power Units. Just after the accident at first the 3rd Power Unit, which along with the 4th Power Unit makes the second ChNPP generation, and then the 1st and 2nd Power Units were shutdown. The Government Commission on Investigation of Causes of the Accident at the Chernobyl NPP was established under the order of the USSR Council of Ministers. The main tasks of the Government Commission were determination of the accident scales, development and implementation of measures on its localization and overcoming its consequences, health protection and population aiding, as well as the detailed study of the accident causes and the development based on the carried out analysis of immediate and long-term measures on preventing such accidents in future. The activity of the Government Commission was carried out in extreme conditions caused both by complexity of the problem occurred and lack of experience of actions in such situations. [2]

One of the first issues faced by the Government Commission was determination of destiny of the town of Pripyat located 4 km from the ChNPP. Since morning of April 26 a permanent monitoring of radiation situation was established in the town. By evening of April 26 the radiation levels increased and in some areas reached hundreds of milliRoentgens per hour. In this connection the Government Commission took the decision on preparation for evacuation of Pripyat residents. On the night of 26th/27th April 1390 buses and 3 railway trains arrived from Kyiv and other neighbor's towns. Regions and settlements were specified to accommodate the evacuated people. The order of their registration and settling was determined. The special groups to solve the urgent problems were organized. The evacuation began at 14.00 on April 27, 1986, and was conducted for about 3 hours. That day around 45 thousand people were transported out of the town. Within first hours after the accident the population of the ChNPP adjacent (10-kilometer) zone was evacuated. On May 2 the decision on the evacuation of population from the Chernobyl NPP 30-km zone and some settlements beyond the bounds of it was approved. Later on by the end of 1986 about 116 thousand of people were resettled from 188 settlements (including the town of Pripyat). [2, 3] In total, since the moment of government decision making on the evacuation and resettlement of the victims from the radioactively contaminated territories, more than 52 thousand of families (164,7 thousand people, 90784 people out of them during 1986-1990) were evacuated and resettled.

It was forbidden to take belongings along. Many people were evacuated in playclothes. In order not to spread panic it was communicated that the evacuated persons would come back home in three days. It was forbidden to take domestic animals along (later the majority of them were killed). The safe roadways for movement of the evacuated population in columns were specified considering the radiation survey data having been already obtained. In spite of this, neither on April 26, nor on April 27 the people was warned about the existent danger. No recommendations were given about a way of behaving in order to decrease radioactive contamination effects.

On May 7, 1986, the Decree of the CC CPSU and Council of Ministers of the USSR for the issues of job placement and domestic arrangements of the population evacuated from the dangerous areas was approved. It specified specific measures on the placement of families of the Chernobyl NPP workers in Kyiv and other settlements, construction of domestic buildings and facilities used for economic activities for relocatees from a rural area, job placement and wage conditions of the evacuated people. In particular, it was envisaged to allocate for these purposes 7500 apartments in Kyiv and 500 apartments in Chernigiv.

The first official announcement about the accident at the ChNPP was made on TV on April 28. In a rather scholastic report it was communicated about a fact of the accident and two died. Later the actual scales of the accident started to be communicated. At the beginning of May the radiation background at the streets of Kyiv exceeded by tens or even by hundreds times the natural one. Though the medical and other administrations persuaded people using mass media that in the city the radiation background was not changed and did not exceed 0.15 mR/h, and if was exceeded somewhere to 0.34 mR/h than it was due to radiation of granite by which basements of some buildings were trimmed up. Somebody from the Ministry of Health management notified that because of more frequent cleaning of the streets the radiation conditions in Kyiv became even better than it was before the accident. While all foreign mass media informed about the danger to people life and the map of air streams in the Central and Eastern Europe was presented by TV screens, in Kyiv and in other cities of Ukraine and Belarus demonstrations and open air celebrations devoted to the First of May were carried out. Hiding of information on the accident from the public was initiated by the State leaders. Concerns for prevention of panic among population were adduced as an argument for the accident secure classification. Such concerns indeed were not unfounded. However, the accident scales were such that it appeared to be impossible to classify it. The fact of resettlement of the residents of the towns of Pripyat and Chernobyl (April 27, 1986 and May 06, 1986 respectively) promptly became known to the population of Ukraine, Belarus and Russia. At the same time by the middle of May 1986 doctors of the Ministry of Health and mass media were forbidden to inform the USSR people about the activities performed regarding the liquidation of the accident consequences, about protection methods and scales of the accident. It resulted in the fact that a great part of population, especially it concerned countrymen, used gardens and farms products, particularly, milk. Due to this the people were additionally exposed, in particular it affected thyroid gland. Maps of radiation contamination and radiation levels were classified until 1990. The hiding of the Chernobyl accident information led to formation and spread of unbelievable rumours about the possible consequences of the accident. This, in its turn, caused a very large social and psychological tension among the population and distrust to official information. The hiding of the Chernobyl accident information, undoubtedly, was a mistake. [4]

As a result of the accident at the Chernobyl NPP a large radioactively contaminated territory was created that only in Ukraine makes 54.6 thousand km^2, including more than 2.5 thousand km^2 of the created Exclusion Zone. As was stipulated by the Law of Ukraine «On Legal Regime of a Territory Affected by Radioactive Contamination as a Result of the Chernobyl Catastrophe» the zone combined two special territories, namely – the Exclusion Zone and Zone of Absolute (Obligatory) Resettlement. This very Law declared the Exclusion Zone as the territory which the residents were evacuated from in 1986, while the Zone of Absolute Resettlement – as the territory contaminated by long-lived radionuclides. Soils of these zones were removed from economic use, isolated from the adjacent territories and attributed to radiation-dangerous categories. As of today there are 76 settlements within the Exclusion Zone and 92 settlements within the Zone of Absolute (Obligatory) Resettlement. The Exclusion Zone is a specific security territory enclosed with barbed wire that is always under guard. One of the tasks of the guarding is to prevent distribution of radioactive substances outside.

The first-priority tasks faced by scientists and specialists during the first postaccident months were first of all the issues on stabilization of radiation situation at the territory from which the population had been evacuated, elimination of secondary contamination sources, carrying out of large-scale decontamination activities, creation of conditions for the future NPP safe operation [5, 6, 7]. To solve these and many others tasks in October 1986 an Association «Kombinat» was established. It comprises the ChNPP and all enterprises and organizations engaged in the first-priority activities on the liquidation of the Chernobyl accident consequences within the territory of the actual Exclusion Zone. In December 1989 the decontamination of the industrial site was mainly completed and the required life support utilities of the Plant and Exclusion Zone were renewed. The Association «Kombinat» was reformed into a Scientific and Production Association «Pripyat». The new association within the Exclusion Zone was assigned the tasks on radiation and dosimetric control, radioactive waste management, research and development, maintenance of infrastructure of the Exclusion Zone.

Since March 1992 the Exclusion Zone began to be managed by a special subdivision of the Ministry of Chernobyl of Ukraine – the Zone Administration. In January 1996 this body was renamed into the Administration of Exclusion Zone and Zone of Absolute (Obligatory) Resettlement. Later in December 1997 the transfer of the first line of the Zone of Absolute (Obligatory) Resettlement territory under the jurisdiction of the Administration of Exclusion Zone and Zone of Absolute (Obligatory) Resettlement of the Ministry of Emergencies of Ukraine was completed. In 2000 pursuant to the active Law «On Legal Status of a Territory» and the Edict of the President of Ukraine «On Administrative Reform in Ukraine», and other standard acts this structure was reorganized into the State Department – the Administration of Exclusion Zone and Zone of Absolute (Obligatory) Resettlement with the objective of state regulation and management of all measures on elimination of the Chernobyl accident consequences within the Exclusion Zone. Work activity within the zone is performed under two directions – the Chernobyl NPP decommissioning (until 2000 – operation of the Plant) and carrying out of activities on the liquidation of the Chernobyl accident consequences. The Zone Department manages and coordinates carrying out of all actions within its territory. Today within the Exclusion Zone there are more than 800 facilities for a temporary radioactive waste containment with a total volume of about 1 million m^3 and total activity of 380 thousand Ci. The State Enterprises «Complex» and «Technocentre» are dealing with the activities on radioactive waste management. They consist of a Complex for Radioactive Waste Processing and Disposal «Vektor», RAW Disposal Facilities «Buriakivka», «Pidlisnyi», «Kompleksnyi». Within the zone there are also two sites of radioactive machinery used during the elimination of the accident consequences in 1986–1987.

With the objective to develop safe and efficient technologies for management of RAW, generated as a result of the ChNPP accident, the complex of facilities for RAW decontamination, transportation, processing and disposal named «Vektor» was established. Thus, in Ukraine the possibility of RAW disposal following all requirements of reliable protection of population and natural environment from radioactive effects was created. Analysis of the situation proves that all radioactive waste disposal facilities, including Shelter Object containing nuclear fuel residuals, give rise to serious concerns of specialists concerning the negative processes associated with conversion of radionuclides into soluble and mobile forms, in particular, the conversion of Plutonium-241 into Americium-241, and their possible penetration into groundwater. One of the most important areas of activity on the elimination of the ChNPP accident consequences are the measures on radiological monitoring at the Exclusion Zone territory. Periodically, the summarized materials and study results in the form of maps, prediction calculations, references etc. were systematically submitted to the Government Commission, republican headquarters of Ukraine and Belarus. Based on these data the decisions on people evacuation and carrying out of decontamination activities were made, the limits of radioactive contamination (permanent resettlement, temporary resettlement, strict radiation control) and levels of social protection of the citizens, inhabited or worked within the contaminated territories, were specified.

After the establishment of the Ministry of Chernobyl of Ukraine and the following establishment of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of the Chernobyl Accident the planning, coordination and analysis of activities on creation of radiation monitoring system and refinement of radiation situation of the territories became the priority directions of their activity. [8] Currently, the radiological control within the Exclusion Zone is performed by the State Enterprise «Chernobyl Radioecological Centre». The radioecological monitoring within the

Exclusion Zone is an integral component of the State Monitoring System. Health physic research is carried out under six main directions, namely, radiogeochemical monitoring of soils; surface water monitoring; groundwater monitoring; air monitoring; monitoring of biological entities; monitoring of unauthorized habitation areas.

As a result of Chernobyl accident, 4.4 million ha of forests are contaminated in Ukraine with radioactive decay products. The government authorities had to recall 157,000 ha of forests from circulation (including 110,000 ha within Exclusion Zone). [9, 10] The conceptual provisions for safe forest management, envisaging clean product receipt, were finally approved in Autumn 1991. Dosimetric control network is established to perform measures on safe forest management and prevention of realizing the products with prescribed standards exceeded. Owing to forest areas, which during the accident played a part of shielding of radionuclide accumulator, wide spreading of radioactive contamination was certainly limited. It means that forest became a major natural factor for stabilizing radioecological situation within Exclusion Zone. State Specialized Production and Complex Forestry Enterprise «Chernobyllis» (later on «Chernobyl Puscha») started its activity in 1992 within Exclusion Zone. The task of this enterprise is to protect forest areas of the Exclusion Zone from fires, poachers, to protect trees from insects, deceases, and the important thing is to plant young forests to bind radionuclides in biological chain.

A hazardous factor leading to repeated radioactive contamination of territories is forest fires. Mineralized zones are arranged, availability of specialized fire-chemical stations for forest fire fighting is maintained and other measures for forest protection are performed within Exclusion Zone in order to improve sanitary-protective functions of forests, prevent repeated radioactive contamination of area due to fires, prevent radionuclide release to the clean areas.

As statistics showed, 90% of radionuclides are released from the Exclusion Zone by waters. Water is contaminated, mainly, due to radionuclide wash-off from contaminated areas. [11] A major hazard of radionuclide wash-off to Prypiat River, and then to Dnipro River, occurs during flooding in the rivers of the Exclusion Zone. The Government of Ukraine decided to establish Chernobyl Administration for Operation of Water-protective Structures in Prypiat River Basin in October 1987 for operation of security facilities. Later on, State Specialized Production and Complex Water-protective Enterprise «Chernobylvodekspluatatsiia» (Chernobyl Water Operation) was established in 1993. The whole activity of the enterprise is aimed at reduction of radionuclide release from contaminated areas of Exclusion Zone by waters. Particularly, this is reached by establishing scientifically based complex of hydro-technical facilities, which isolated radionuclides of the most contaminated areas of Exclusion Zone and created barriers on the way of radionuclide migration, e.g. after construction of protective dam on the left bank of Prypiat River, the carry-over to the river was reduced for 100–150 Cu.

In order to minimize spreading of radioactive substances within the territory of population habitation, the following activities are carried out in Exclusion Zone:

- Shelter Object transformation into ecologically safe system;
- Sanitary and fire-protection measures in forests and fields;
- Radiological control of workers in Exclusion Zone;
- Processing and disposal of radioactive waste;
- Water-protective measures;
- Support of the Exclusion Zone infrastructure;
- Physical protection of the Exclusion Zone perimeter;
- Scientific support of works and scientific-research activity.

Immediately after Chernobyl NPP accident occurred in 1986, a compensation policy relating to all categories of people suffered from Chernobyl accident was introduced in Ukraine. Compensations were implemented as payments, free and extraordinary access to different services causing significant increase of costs in the state budget. When country’s independence gained, the political institutes being at initial stage, on behalf of their electorate, actively addressed the problems caused by Chernobyl accident. As a result, the Parliament repeatedly agreed for recovery of damages without appropriate assessment of resource abilities. A lot of liabilities were not fulfilled, and «Chernobyl payments» fell onto state budget. [12]

The national policy of Ukraine is based on following principles in comprehensive protection of people suffered from Chernobyl NPP accident consequences:

- The priority of life and health of people suffered from Chernobyl accident, full responsibility of the State for establishing safe conditions for living and working;
- Integrated solution of tasks on health protection, social policy and use of contaminated territories based on national programs;
- Social protection and full recovery of damages caused to suffered people;
- Use of economical methods for improving life through policy of preferential taxation for citizens suffered from Chernobyl accident and their unions;
- Implementation of measures on occupational reorientation and advanced training for suffered population;
- Cooperation and consultancy between state authorities and suffered people (their representatives, social teams) when taking decisions on social protection at local and state levels;
- International cooperation on health protection, social and radiation protection, occupational safety, use of the world's experience for arranging activities on these matters. [27]

There was no reasonably perfect legal framework before 1990 on protection and status of citizens suffered from Chernobyl accident. The decrees of the Central Committee of the Communist Party of the USSR, the Council of Ministers of the USSR, the orders of branch ministries and authorities had the effect. Most of mentioned documents had a security classification limiting their application range. The Law of Ukraine «About Legal Status of the Territories being Radioactively Contaminated due to Chernobyl Accident» implements the legislative determination of legal status for territories having different radioactive contaminations and measures on its provision. The principles for legislative provision of protecting suffered people are laid in the Law of Ukraine No.796-XП dated February 28, 1991, «About Status and Social Protection of Citizens Suffered from Chernobyl Accident», which determines basic provisions for implementing constitutional right of the citizens suffered from Chernobyl accident, for protecting their lives and health. A single procedure for determining status of suffered people is developed. Corresponding subordinate acts are developed and put in force based on the Laws.

1.4. Establishment of state management system on overcoming the consequences of the Chernobyl catastrophe

The accident at the Chernobyl NPP on its scales did not confine itself to the parameters of the accidents considered as possible in regulatory documents of the Soviet Union. The global distribution of a great spectrum of radioactive isotopes of Chernobyl origin happened. It set to the USSR governmental and administration authorities the completely new tasks associated with localization and mitigation of the catastrophe consequences. The problems occurred as a result of the accident at the ChNPP and managerial decisions pertaining to their liquidation were made based on decrees and directions of the Central Committee of the Communist Party of the Soviet Union (CC CPSU) and Council of Ministers of the USSR, orders of ministries and government agencies, decisions of the state committees. They were taken classified as «Top secret», «Secret» or «Official use only» that restricted field of their application. In the Ukrainian SSR (Soviet Socialist Republic) on their basis the decrees of the Central Committee of the Communist Party of Ukraine and Council of Ministers of Ukraine were made. These documents were published in 1990 within the composite book prepared for the deputies of the Verkhovna Rada of Ukraine. [1]

With the objective to ensure the radiation protection of population the USSR Ministry of Health (USSR MH) right from the first days of the accident started to enact the regulations on temporary emergency levels of contamination for environmental compartments, body, constructions, roads, public irradiation doses, permissible levels of radioactive substances content in foodstuffs, agricultural raw materials, etc. Application of these regulations made it possible to carry out organizational and managerial arrangements which helped to ensure people protection from the ChNPP radioactive releases. In 1987 revised versions of Radiation Safety Standards (NRB-76/87) and Basic Sanitary Rules (OSP-72/87) were enacted in the USSR taking into consideration the refined data regarding ionizing radiation impact on human body, experience of radiation control assurance and carrying out of preventive measures, including the measures on liquidation of the accident consequences at the ChNPP [2]. The issues of population medical assistance within the areas of NPPs location and during radiation accidents were regulated by special regulatory documents. [3, 6]

A principally new in NRB-76/87 was the division of normative standards for each category of radiation-exposed citizens into three classes: principal dose limits, permissible levels and reference levels. The maximum permissible dose per year (MPD) was referred to the principal dose limits for Category A (personnel), while for Category B (restricted part of population) – maximum dose per year (MD). Exposure of the restricted part of population according to NRB-76/87 should have been controlled by measurements of releases, field dose rate, and environment radioactive-contamination levels (air, water, soil, foodstuff, etc.) with the following dose calculation. Individual effective exposure dose for Category B citizens should not have exceeded 0.005 Sv per year. In 1996 almost all documents and materials related to the accident at the ChNPP become available for public and were published in a special composite book [7]. The documents, been a part of this composite book (508 documents dated from 1967 until 1996), are the confirmation that the problems, associated with the accident at the ChNPP, from the first day were in the spot of the governmental and administration authorities of the former USSR, as well as Ukraine, Belarus Republic and the Russian Federation. The Supreme Soviet of the USSR in its Decree dated April 25, 1990, acknowledged the accident at the ChNPP as the greatest catastrophe of modern age, nationwide disaster dealt with the destiny of millions of people populated the large territories.

A political assessment was given to the catastrophe at the ChNPP and to the activities on liquidation of its consequences at the XXVIII CPSU Congress. The Congress acknowledged the measures on the liquidation of the ChNPP catastrophe consequences as unsatisfactory and insufficient. In Ukraine the overall assessment of the activities on the liquidation of the Chernobyl catastrophe was given in the Statement of the XXVIII Congress of the Communist Party of Ukraine «On liquidation of the consequences of the Chernobyl catastrophe and protection of population from its effect» dated July 1990, and in the Decree of the Verkhovna Rada of the Ukrainian SSR dated August 1, 1990. These documents become a starting point for transition to the breakthrough way of overcoming the catastrophe consequences.

The Verkhovna Rada of the Ukrainian SSR during 1990 [8] discussed twice at its sessions the ecological situation and urgent measures on population protection from the Chernobyl catastrophe consequences. The Committee of the Ukrainian SSR Verkhovna Rada on the Issues of the Chernobyl Catastrophe was established. A year of 1990 was announced the rehabilitation year of the children who lived within the territories affected by the ChNPP accident. With the objective to ensure the scientifically grounded approach in solving the problems of population radiation protection and to expand the international cooperation on these issues the decision to establish the National Commission for Radiation Protection of the Population of Ukraine and the State Committee of the Ukrainian SSR on the Issues of the Chernobyl Catastrophe was taken. The territory of the Republic was declared a zone of ecological catastrophe. The authority of the First Deputy Chairman of the Council of Ministers of the

Ukrainian SSR was delegated to the Head of Government Commission on Emergencies. It was accepted as necessary to establish the special subdivisions for the assurance of organizational work on overcoming and liquidating the Chernobyl catastrophe consequences in the staff of the Government and some Ministries, in Zhytomyr, Kyiv, Rivne, Chernigiv, Volyn, Cherkasy, Vinitsa Regions and, if necessary, in other regions. [9]

On March 29, 1990, the Presidium of the Ukrainian SSR Verkhovna Rada, taking into consideration the proposals of People's Deputies of Ukraine and general public regarding perpetuating in people memories the tragic events associated with the ChNPP accident, as well as with the objective to prevent nuclear catastrophes, declared the 26th April the «Day of Chernobyl Tragedy» by its Decree (No.8985-XП).

Since 1990 the decisions, taken at the state level, on the assessment of the performed measures on the liquidation of the catastrophe consequences and proposals pertaining to their elimination in future started their implementation. «The State Soviet and Republican Program of Urgent Measures on the Liquidation of the ChNPP Accident Consequences for 1990–1992» was approved [8]. It also specified those measures which were planned to be performed in Ukraine.

Thus, Kyiv, Zhytomyr, Rivne and Chernigiv Regional Executive Committees were authorized to ensure the people resettlement from the territories faced radioactive contamination as a result of the accident at the Chernobyl NPP by Decree of the Council of Ministers of the Ukrainian SSR and the Ukrainian Republican Council of Trade Unions No.115 dated May 21, 1990.

Until 1991 the Program's tasks were implemented by all-union efforts. From the date of the USSR collapse the accident consequences were liquidated by each state separately that created many difficulties.

In general the State Union and Republican Program and the adopted decrees envisaged a number of large-scale state measures targeted at ecological safety assurance, protection and promotion of health, social and legal protection of victims suffered from the Chernobyl disaster and population inhabited the contaminated territories.

The Government of Ukraine, local governmental and administration authorities performed the measures targeted at the mitigation of radioactive contamination impact on public health. During the period of 1987–1990 the Government of Ukraine enacted 116 decrees and orders on the issues of the liquidation of the ChNPP accident consequences. The State Program of Urgent Measures on the Liquidation of the ChNPP Accident Consequences in the Ukrainian SSR for 1990–1992 was developed and implemented. In spite of this, the situation within the contaminated areas remained highly complicated. The problems associated with the lack of detailed territory survey, radiation situation assessment, wide and impartial provision of information to the public concerning the radiation situation were escalated. The development of the Republican Concept for safe habitation of people within the radioactively contaminated territories was delayed unjustifiably. Up to that time the status of 30 km zone and other contaminated territories was not specified. The responsible social protection of the victims was not secured. The decision regarding the provision of the population from the «contaminated» areas with «clean» foodstuff and dosimetric equipment, people rehabilitation and medical treatment, construction of housing, social facilities and other urgent tasks was not implemented.

During decision-making the executive authorities followed the basic criterion of temporary specified levels of contamination by radionuclides approved by the USSR MH in May 1986, that is density of contamination.

The Supreme Soviet of the USSR by its Decree No.1452-1 of April 25, 1990, emphasized that the measures, performed to liquidate the accident consequences, appeared to be insufficient. A highly stressed social and political situation occurred within the areas that were faced the radioactive contamination. It was predetermined by contradictions in recommendations of scientists and specialists on radiation safety problems, the delay in taking the required measures, and, as a result, loss of trust to local and central authorities by a part of population.

At the end of 1990 the Committee of the Verkhovna Rada of Ukraine on the Issues of the Chernobyl Catastrophe, the Government of Ukraine, the Academy of Sciences, public association «Union of Chernobyl» prepared the drafts of the Concept for habitation of population within the territories of higher levels of radioactive contamination as a result of the Chernobyl catastrophe, as well as the Law drafts «On legal regime of a territory affected by radiation contamination as a result of the Chernobyl catastrophe» and «On status and social protection of citizens who suffered as a result of the Chernobyl catastrophe».

The Concept was developed based on the materials of the Scientific Report of the Council for the Study of Productive Forces of the Ukrainian SSR under the Academy of Sciences of the Ukrainian SSR. This Report was prepared for the Council of Ministers of the Ukrainian SSR [10]. In the Report the Radiation Safety Concept was proposed. It specified and justified the criteria and normative standards of people habitation and life support. The international radiation safety practice, which is mainly based on the non-exceedance of safety normative standards and implementation of all necessary measures on minimizing human exposure, laid the foundation for the Concept.

The basic principle of the Concept is that for the critical group of population (1986 year of birth children) the value of effective dose of additional exposure, connected with the Chernobyl catastrophe, should not exceed 1.0 mSv per year and 70.0 mSv per all life besides the doses received by the population during a pre-accident period in specific natural conditions [11]. The division of all the territory, contaminated by the accident releases, into zones is envisaged in the Concept and subsequent Laws «On legal regime of a territory affected by contamination as a result of the Chernobyl catastrophe» and «On status and social protection of citizens who suffered as a result of the Chernobyl catastrophe». [12]

Taking into account a social importance of the draft laws, the Committee on the Issues of the Chernobyl Catastrophe took the decision on their nation-wide discussion. The drafts were published in the central newspapers. Thousands of citizens of Ukraine, ministries, government agencies and organizations submitted their proposals. The scientists of the Academy of Sciences of the Ukrainian SSR, staff of the Ministries of Health, Agro-industrial Complex, Labor, and Justice, public organizations, local Soviets of the suffered regions were engaged in the development of the law drafts for a long time. On February 5, 1991, the draft laws were introduced for consideration by the Verkhovna Rada of the Ukrainian SSR in the first reading. And on February 27 and 28, 1991, they were finally adopted by the great majority of people’s deputies.

During consideration of the draft laws at the session of the Verkhovna Rada of the Ukrainian SSR the attention was paid to the fact that according to the calculations of the Ministry of Finance the annual expenditures for the implementation of the prescribed benefits made up more than 4 billion Soviet roubles. If proceed from all decrees and decisions have been adopted and acted as of the time of the consideration of the draft laws, regarding a differential system of labour remuneration, additional payments, rehabilitation, free nutrition of children and others than this sum amounted to 580 million Soviet roubles. Thus, scarcity of funds for the implementation of the laws exceeded 3 billion Soviet roubles. These funds were envisaged to be received from the Soviet budget.

Since the collapse of the Soviet Union the possibility to receive the funds from the Soviet budget was lost, and the financing of all measures, envisaged by the Chernobyl legislation, laid completely on the Ukrainian budget. Notwithstanding the fact that in the course of the years of independence Ukraine spent more than 10 billion US dollars on the liquidation of the Chernobyl catastrophe consequences, in price equivalent the laws were not financed by more than 57%.

Adoption of the Concept and the Laws of Ukraine «On legal regime of territories affected by radioactive contamination as a result of the Chernobyl catastrophe» and «On status and social protection of citizens who suffered as a result of the Chernobyl catastrophe» made it possible to fix by law the radioactive contamination zones depending on the rate of a possible negative impact on public health, establish the criteria of top-priority resettlement, create the system of monitoring over the safe habitation and the regime of habitation within the contaminated territories. Provision of benefits and compensations depending on the prescribed category is guaranteed by the state to each person suffered as a result of the Chernobyl catastrophe. [13]

To raise the status of the state administration body, which was dealing with the Chernobyl problems solving, the Ministry for the Issues of Population Protection from the Consequences of the Chernobyl Catastrophe was established on the base of the State Committee on the Issues of the Chernobyl Catastrophe by Law «On a list of ministries and other central state administration bodies of the Ukrainian SSR» dated May 13, 1991, No.1030б-XII at the suggestion of the Committee of the Verkhovna Rada of Ukraine on the Issues of the Chernobyl Catastrophe.

The abovementioned allows referring the function of the state in overcoming the Chernobyl catastrophe consequences to the one of the major.

The most important factor to refer one function or another to the number of the main is its constitutional entrenchment. Unlike in the constitutions of other states of the former USSR, the function of the state with respect to the Chernobyl catastrophe is represented in the Constitution of Ukraine: «… overcoming of the consequences of the Chernobyl catastrophe – a catastrophe of global scale, and preservation of the gene pool of the Ukrainian people, is the duty of the State» (Article 16).

After acceptance of Chernobyl laws and collapse of the Soviet Union, an issue emerged on financing of the whole Chernobyl program. According to the Order No.206 of the Verkhovna Rada of Ukraine «About Republic Draft Budget of Ukraine for Q1 1992» dated December 20, 1991, a Fund for Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population was created as part of Republic Budget for 1992. This Fund received fees from enterprises and economic organizations irrespective of subordination and proprietary forms in amount of 19% of payroll allocating transferred sums to the product (works, services) costs. According to the Order No.2147-XII of the Verkhovna Rada of Ukraine «About Order of Putting into Force the Law of Ukraine «About Income Taxation of Enterprises and Organizations» dated February 21, 1992, the allocations to the mentioned fund were assessed at amount of 12%, starting from March 1, 1992.

According to Law of Ukraine «About Fund Formation to Implement Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population» (1997), a fee amounted to 10% from tax entity allocating paid sums to gross expenditures of production. [14] By Decree No.857/98 of the President of Ukraine «About Some Changes in Taxation» dated August 7, 1998, starting from January 1, 1999, fee allocation to the Fund for Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population was stopped. The Decree established that financing of the expenditures from the Fund for Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population is carried out at the expense of State Budget of Ukraine, particularly at the expense of increased budget receipts coming from extended taxation base. Formation, procedure of filling and using assets of the Fund for Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population were determined by appropriate Law of Ukraine No.1445-Ш dated February 10, 2000. It was defined that financing of expenditures related to mitigation of Chernobyl accident consequences and social protection of population is carried out at the expense of the Fund for Measures on Mitigating Chernobyl Accident Consequences and Social Protection of Population, which is established as a part of State Budget of Ukraine. The Fund's assets are counted to a separate account of State Budget of Ukraine. The Ministry of Ukraine for Emergencies and Affairs on Population Protection from the Consequences of Chernobyl Catastrophe (ME) was determined as Fund Administrator. [15]

Therefore, a legal base for implementing national policy on protection from Chernobyl accident consequences was gradually formed.

The experience in applying the requirements of Law of Ukraine «About Status and Social Protection of Citizens Suffered from Chernobyl Accident» showed that strategic tasks relating to social protection of affected citizens were determined correctly. This protection covers the liquidators of accident consequences who are liable to hazards, i.e. children and invalids, inhabitants of settlements located within radioactive contamination areas.

This very Law determines the main provisions regarding implementation of constitutional right of citizens suffered from Chernobyl accident for protecting their lives and health, and a single procedure for determining status of suffered people is developed. When this Law is accepted, the Government started to work on preparing and putting into force subordinate legislation to implement provisions determined by the legislation and, first of all, regarding determining status of suffered people and organizing their social protection. It also should be mentioned that a significant part of measures prescribed by the Law were never performed and did not meet expectations for expected outcome.

During 1996–2004, the Verkhovna Rada of Ukraine made some changes to the effective Law of Ukraine «About Status and Social Protection of Citizens Suffered from Chernobyl Accident», many of which concerning specifying norms of the law and expanding social protection for suffered people. By changing revision of the Law dated June 4, 1996, a new procedure for determining categories of suffered people is implemented and list of privileges and compensations for suffered children, whose invalidity relates to Chernobyl accident, is extended. [16]

Totally for 1990, regulatory and legal framework on Chernobyl accident amounts to more than 800 documents enabling to regulate different aspects of Ukrainian citizens' vital activities as a result of Chernobyl accident.

The Verkhovna Rada of Ukraine paid specific attention to the study of theoretical and practical issues of legal regulation of social protection for citizens who had radiation exposure from Chernobyl accident. The analysis of legislation regarding social protection of citizens and practice of its application, annually conducted by the Verkhovna Rada of Ukraine under Parliament proceedings or «The Ukrainian Government's Days», gives an opportunity to define new problems and propose methods for improvement.

During the Parliament proceedings devoted to 23rd anniversary of the accident, it was stated that problems occurred from Chernobyl accident don't disappear over the years, but transforming. Some of them, first of all social and economic ones, are focused and require integrated solutions and system approach in the activity of executive authorities for their solutions. It was emphasized that financing of Chernobyl programs is characterized by nonconformance of calculated volumes in the budget request to the volumes approved in the State Budget for corresponding year. It was also decided to create at top level Interdepartmental Commission on integrated solutions of Chernobyl problems, activity of which is planned to aim at solving issues associated with social protection of Chernobyl people. The positive change, first of all in assuring safety of Chernobyl NPP, was made by the Verkhovna Rada of Ukraine accepting two laws regarding radioactive waste management in Ukraine and above all – Law of Ukraine «On National Program for Chernobyl NPP Decommissioning and Shelter Object Transformation into an Ecologically Safe System». [17]

On January 15, 2009, the President of Ukraine has approved «National Program for Chernobyl NPP Decommissioning and Shelter Object Transformation into Ecologically Safe System» (No.886-VI), which gained the status of Law of Ukraine since January 1, 2010. This Program defines common activities on Chernobyl NPP decommissioning and Shelter transformation into ecologically safe system, approximate scopes for their financing, organizational and technical tasks.

The objective of the National Program is to ensure implementation of the state policy regarding:

- Preparation to decommissioning and Chernobyl NPP decommissioning and the Shelter transformation into ecologically safe system;
- Ensuring protection of personnel, population and environment from ionizing radiation exposure.

The completion of Chernobyl NPP decommissioning and Shelter Object transformation into ecologically safe system requires about 100 years, therefore the Program contains primary measures to be implemented during 2009–2012 at the stage of Chernobyl NPP shutdown and Shelter transformation into ecologically safe system.

The Program envisages the following main activities:

1. Shutdown, preparation to decommissioning and decommissioning of Chernobyl NPP;
2. Shelter Object transformation into ecologically safe system;
3. Management of Chernobyl NPP radioactive waste accumulated during operation and to be generated during Chernobyl NPP decommissioning and Shelter Object transformation into an ecologically safe system;
4. Scientific-technical and informational support of activities on preparation to Chernobyl NPP decommissioning and Shelter Object transformation into ecologically safe system, ensuring transparency of decisions for community regarding safety assurance of activity envisaged by the Program;
5. Social protection of Chernobyl NPP personnel and Slavutych citizens due to pre-schedule decommissioning of Chernobyl NPP.

State legal mechanism for mitigating Chernobyl accident consequences is the main constituent of state legal mechanism of Ukraine. As mentioned in normative legal acts of the Verkhovna Rada of Ukraine, the structure of state legal mechanism for mitigating Chernobyl accident consequences is not balanced in Ukraine to date. On one hand, regulatory support system is developed enough, but not implemented. On the other hand, there is no system activity of the central and local executive authorities in this area.

Initially, the Ministry of Chernobyl of Ukraine addressed the issues on mitigating Chernobyl accident consequences, and since 1997, according to the Decree of the President of Ukraine No.1005/96 dated October 28, 1996, it is the Ministry of Ukraine for Emergencies and Affairs on Population Protection from Consequences of Chernobyl Catastrophe. It was the major institution in the system of other central executive authorities on ensuring implementation of state policy on mitigating Chernobyl accident consequences. Later on, upon implementing a reform of central executive authorities, in 2004 the functions of population social protection were transferred to a Ministry of Labor and Social Policy. This complicated the coordination on ensuring the state policy implementation in the area of solving the complex of Chernobyl problems. The analysis of ME activities shows that comparing with the Ministry of Chernobyl it was not able to solve full-scale problems of interaction with other state administration bodies, control their activities on implementing the programs for mitigating accident consequences. It should be mentioned that when Chernobyl NPP generated the electric energy, a lot of issues relating to mitigation of Chernobyl accident consequences were succeeded. After shutdown of Chernobyl NPP Units, the situation of issue solving on mitigating accident consequences became worse.

Mitigation of Chernobyl accident consequences is not a temporary, but purpose-driven activity of the State intended for long-term period. Scientific feasibility and stability should become the specific features of state management in mitigating Chernobyl accident consequences. Nowadays, it is required to create such management system for mitigating Chernobyl accident consequences, which could combine all directions of social protection, rehabilitation and development of population suffered from the accident consequences, ecological remediation of radioactively contaminated territories, as well as to generalize and create efficient regulatory framework, which could regulate and ensure solving of all problems associated with mitigation of Chernobyl accident consequences enabling to come to new phase, i.e. renewal and development phase. The main assessment of efficiency should be defined as ability to achieve desired goal within scheduled terms using provided resources. In its turn, an increased attention should be paid to the rehabilitation of suffered people. The State policy should be aimed at reducing «victim» feeling. One should diverge from the stereotypes that only the State could solve all issues associated with mitigation of the accident consequences. Suffered people should try to overcome occurring obstructions by their own. Also, it is necessary to transit from risk compensation policy to the compensations for damage done in fact.

1.5. Shelter Object construction

As a result of the accident the reactor core, considerable part of the technological equipment and constructions of ChNPP's Unit 4 (fig. 1.2 look the coloured inset) have been destroyed. Safety barriers and systems protecting environment from the radionuclides, containing in irradiated nuclear fuel, have been destroyed.

Therefore an issue about long-term preservation of Unit 4 by construction of a structure which would restrict release of radioactive substances and ionizing radiation outside the destroyed power Unit was arisen directly after the accident.

«Works on disposal of ChNPP Unit 4 and constructions referred to it» had been charged to the Ministry of medium mechanical engineering of USSR by Resolution of the Central Committee of CPSU and Council of Ministers of USSR No 634–188 dated 29.05.86. The facility has received the name «Shelter of ChNPP Unit 4».

Another Resolution of the Central Committee of CPSU and Council of Ministers of USSR No 663–194 dated 05.06.86 assigned functions of the General Designer of works on disposal of ChNPP Unit 4, radioactive waste and decontamination of ChNPP industrial site equipment on VNIKIET (St.-Petersburg). Kurchatov INE performed a scientific management of works on ChNPP Unit 4 disposal.

Peculiarities and complexity of works on the emergency power unit preservation consisted in absence of experience in national and in world practice in overcoming of such large-scale accident consequences and in absence of the special normative documents at that period of time for design decisions development.

In view of critical importance of the Shelter object it was developed at conceptual level eighteen options of the design, stipulated, in particular, formation of a hill from crushed stone and concrete, construction of a huge structure in the form of a curved arch or a spherical vault and other options. But the majority of the proposed solutions required considerable construction materials consumption, and the main thing – enormous efforts and exposure doses for the personnel and long time for their construction, that didn't correspond to the main requirement – as soon as possible to liquidate accident consequences. Separate decisions couldn't be realized at existed at that time level of the equipment.

Taking into account material expenses and dose loadings on the personnel and tight schedule for the construction it has been accepted the final option of a protective construction which provided the maximum use of the remained supporting constructions of Unit 4 as part of the Shelter object constructional system.

Thus, building constructions of the Shelter object is a combination of «old» constructions of the destroyed Unit 4 and «new» constructions erected after the accident.

Owning to such combination it has been erected the unique structure which constructions carry out extremely important function of a physical barrier on ways of radioactive substances and ionizing radiation release into environment.

The basis of physical barriers is composed of the external protective constructions built after the accident: Cascade Wall, Buttress Walls, covering of the reactor block, deaerator stack and Turbine hall (Fig. 1.3 look the coloured inset).

Relatively undamaged constructions of the Unit 4 create a basic contour supporting load bearing elements of the covering of the reactor block and deaerator stack. First of all these are Northern and Southern exhaust shafts, a monolithic wall on an axis 50 with an abutting frame (fig. 1.4 look the coloured inset). The main units of beams B1 and B2 lean on these constructions. These beams together with a pipe covering create roof of the central part of the reactor block (in particular, above the Central Hall). Beam «Mammoth» and «Octopus» are supported by the deaerator stack constructions.

Realization of such option of a protective encasement required to resolve two the most difficult tasks:

- Survey of a technical condition of the remained constructions of Unit 4 in extremely difficult radiation conditions and assessment of possibility of their use as constructional elements of Shelter object;
- Choice of such constructional and technological decisions which would allow to reduce as much as possible terms of Shelter object construction and to minimize radiation impact on the personnel and environment.

Besides VNIPIET, design works in various directions were carried out by a number of design institutes, in particular, LenPSK (St.-Petersburg), TSNIIPSK (Moscow), UKRNIIPSK (Kiev), DneproPSK (Dnepropetrovsk) and other institutes.

To perform building and installation works on the emergency Unit preservation and Shelter object construction in the system of the Ministry of medium mechanical engineering of USSR it has been specially created Construction Management No 605.

Supporting facilities were constructed within the shortest terms: bases of supply, base on maintenance of motor transport and construction machinery, concrete plants, points of building materials acceptance and unloading and other facilities.

Children pioneer camp, recreation facilities, schools have been adapted for accommodation of the working personnel, tent towns and promptly mounted construction were created. Canteens and sanitary-and-hygienic facility have been organized.

These facilities were located taking into account radiation condition of territories and availability of transport communications. The personnel were daily delivered by «clean» transport to change point to special transport maintaining restricted area. All motor transport left a restricted area, was subject to a radiation control and, if necessary, decontamination at specialized entry-exit points.

To ensure efficiency and safety of works on preservation of the emergency Unit prior to the major constructional and installation works it has been performed the complex of measures for decontamination of surrounding territory. Fragments of the reactor core (fragments of fuel assemblies, graphite and constructional materials of the reactor), fire fighting vehicles and other equipment, elements of the destroyed constructions and the technological equipment, the top contaminated layer of earth have been removed. These works were carried out using the special engineer vehicles created on the basis of tanks and equipped with protective shielding, clamshell, technical television and devices for detection of local ionizing radiation sources and the bulldozers equipped with protective shielding. After completion of works on removal of a radioactive waste the territory around the emergency power unit was covered with a concrete layer in the thickness up to 0.5 m.

The construction along the perimeter of the emergency power unit so-called pioneer walls which with shielding function was other essential factor of radiation conditions improvement. Besides, the space behind pioneer walls was used for disposal of a radioactive waste, collected from surrounding territory.

Works on decontamination of surrounding territory and creation of protective pioneer walls allowed to start performance of the main complex of constructional and erection works for the Shelter object construction.

Construction of the Shelter object in extremely difficult radiation conditions required to develop and introduce such organizational and technological decisions which as maximum as possible would provide radiation protection of the personnel.

The main actions for radiation protection of the personnel consisted in realization of radiation survey of working areas, use of various types of shielding and application of remote controlled technologies for performance of works in the most hazardous radiation conditions.

The technology of installation with use of the large-sized constructions, which were assembled in «clean» zone was extremely effective and permitted remote installation. Constructions were designed with connection units for which it wasn't need to perform the operations connected with presence of people directly in an installation zone.

To manage installation process the central operative station was established. The information from the television cameras mounted directly at levers of cranes and special at towers installed in places with the maximum overlook come to this station.

Special technologies of timbering installation and concreting with remote use of pumps for concrete mix submission have been also introduced.

To ensure radiation protection of the personnel the complex of organizational, radiological and hygienic and technical measures was carried out, in particular:

- permanent monitoring of radiation conditions at ChNPP area and at adjacent territories;
- the organization of a sanitary access control;
- personnel provision with necessary individual protection equipment (working clothes, respirators and another);
- individual radiation control;
- shielding of a vehicle cabs and devices;
- dust suppression in works performance zones and at surrounding area;
- decontamination of vehicles and mechanisms;
- arrangements for nutrition in «clean» zone.

Construction and erection works were carried out with use of unique for that time vehicles and mechanisms, in particular: caterpillar cranes «Demag» with weight-lifting capacity on the main lever up to 650 tons and on auxiliary lever – 112 tons with out-in 78 m; automobile cranes «Liebherr«, pumps for concrete mix submission of firms «Schwing», «Putzmester», «Worthington» and other cars and the mechanisms which have been equipped additionally with remote control and protection frames [1].

The general view of the Shelter object construction is provided at Fig. 1.5 (look the coloured inset).

In process of Shelter object construction it has been laid down about 345 thousand m^3 of concrete mix and mounted 7 thousand tons of metal constructions [1].

Beside the construction and erection works the considerable scope of works has been executed for creation of necessary systems for Shelter object safe operation (ventilation, power supply, firefighting system, monitoring system and others).

Designing and construction of the Shelter object have been carried out for record short term – only for half-year. The Certificate of the State Commission about Shelter object acceptance for maintenance has been signed on November 30th, 1986.

Construction of the Shelter object became the essential result of urgent measures implementation for minimization of the consequences of beyond designed accident at ChNPP Unit 4.

At the same time the Shelter object isn't the facility created according to designing, construction, commissioning and operation rules and norms referring not only to nuclear installations or Radioactive Waste Management facilities, but also to usual industrial facilities. Its building constructions don't meet the safety requirements specified in normative and technical documents in terms of structural integrity and reliability and have uncertain term of operation.

Following basic demerits are characteristic to Shelter object building constructions:

- supporting constructions of support contour (remained constructions of Unit 4) and connection joints are significantly damaged, overloaded by the weight of the dropped constructions and the equipment, and by materials used during the accident liquidation. The bared armature of reinforced concrete constructions and metal constructions are exposed to corrosion;

- reliability and durability of supporting constructions of a support contour can’t be credibly identified in the absence of access to many elements and units and hazardous radiation conditions doesn’t allowing to perform their detailed survey;
- the structures constructed after the accident are separated – not connected among themselves, freely lean on the supporting constructions without physical connection and are kept in designed position (welding or bolted connections of supporting parts of constructions are absent);
- difficult access to metal constructions elements and units for periodic survey and corrosion-resistant coating refreshment.

These lacks lead to the Shelter object safety level decreasing in time. Process of building constructions degradation continues. There is a high probability of constructions collapse, which can lead to considerable radioactive contamination of surrounding environment, and personnel and population exposure.

All that demands permanent supervision for the status of Shelter object constructions, important for safety, and intrusion in case of threat occurrence of their condition dangerous deviation from stable. Therefore surveys of building constructions condition and implementation of urgent measures for their strengthening have been started immediately after completion of Shelter object construction.

2. RADIOECOLOGICAL CONSEQUENCES. RADIOACTIVE CONTAMINATION DYNAMICS OF TERRESTRIAL ECOSYSTEMS AND PROTECTIVE MEASURES EFFICIENCY

2.1. General characteristics of radioactive contamination in atmosphere, soil, surface water and groundwater

2.1.1. Scales and characteristics of the area contamination by Chernobyl fallout radionuclides

As a result of the Chernobyl disaster, a considerable territory of the Soviet Union, particularly of Belarus, Russia, and Ukraine, as well of Western Europe, primarily the Scandinavian countries and the Alpine region, was the most severely contaminated. High levels of radioactive contamination in the areas outside the Chernobyl NPP Exclusion Zone are preconditioned by the following: release of contaminated masses into the atmosphere to a height of 2000 m and their intense movement at these altitudes; rainfalls; presence of complex landscapes that dictated changes in directions and altitudes of the contaminated air masses travelling.

The height of radioactivity release stipulated a global character of contamination, rains and landscapes conditioned heterogeneity (spottiness) in contamination of the lands [1].

The precipitation falling during movement of contaminated clouds over the territory of Ukraine, particularly in Narodytskyi and Lugynskyi districts (rayons) of Zhytomyr Oblast (province), southern districts of Kyiv Oblast, in Cherkasy Oblast, in Podillia and Prykarpattia preconditioned formation of areas with elevated levels of ^{134,137}Cs. The same weather event caused washout of radioactive substances and aerosols from the troposphere and formation of areas with high levels of radioactive contamination on the territory of Belarus, Russia, Sweden, Finland, Germany, Austria, Switzerland, Slovenia, Greece, Bulgaria, Romania, and Georgia [2].

Formation of ^{131}I and ^{137}Cs local contamination maximum in the foothills of the Alps, the Balkans, i.e. at a distance of 800 – 1 400 km from the Chernobyl NPP, was also caused by vertical movement of air flows that are typical for mountain groups.

The overall area of Western Europe countries, where levels of ^{137}Cs contamination exceeded 20 kBq·m^{-2} (almost 10-fold higher that the global background) due to the Chernobyl disaster, amounted to approximately 280 000 km^2 [2].

Almost 75% of Ukraine’s territory suffered from radioactive contamination by ^{137}Cs, which exceeded the pre-accident levels more than twofold. The total activity of ^{137}Cs that was located outside the Shelter Object (excluding the activity that was located in the form of radioactive waste in the appropriate storage facilities and on temporary storage sites) exceeded 13 PBq [1, 2]. Analysis of ^{131}I and ^{137}Cs correlation in the damaged reactor releases and study of its spread during the early stage of accident allowed to state that over a half of Ukraine’s child population were subject to adverse effects of iodine radioactive isotopes [3].

The natural processes of radionuclides decay, which were taking place in the course of 25 years after the Chernobyl accident, substantially corrected a pattern of radionuclide distribution over Ukraine’s territory (Fig. 2.1–2.10). Over this period, the area of localities, where ^{137}Cs contamination levels exceeded 10 kBq·m^{-2}, reduced almost twofold (Table 2.1). The area of sites, where ^{90}Sr contamination exceeded 4 kBq·m^{-2}, is now more than 3 times less, i.e. practically 90% of Ukraine's territory is characterized by the pre-accident levels of ^{90}Sr contamination [3].

Table 2.1.

The area of Ukraine's territory contamination by ^{137}Cs in 1986 and in 2011, thousand km^2

Republic, Oblast	Oblast area	Year	Area of the territory with the following ^{137}Cs contamination density, kBq·m^{-2}					
			< 2	2 – 10	10 – 40	40 – 185	185 – 555	> 555
Autonomous Republic of Crimea	27.0	1986	0.3	26.1	0.6			
		2011	14.8	12.2				
Vinnytsia	26.5	1986	0.3	16.9	7.6	1.7		
		2011	2.7	19.0	4.6	0.2		
Volyn	20.2	1986	0.3	12.7	7.0	0.2		
		2011	2.0	14.9	3.3			
Dnipropetrovsk	31.9	1986	8.2	18.9	4.8			
		2011	15.5	15.5	0.9			
Donetsk	26.5	1986		11.6	14	0.9		
		2011		20.7	5.8			
Zhytomyr	29.9	1986	0.5	9.5	8.9	8.7	1.7	0.64
		2011	2.3	13.6	6.2	6.3	1.1	0.33
Zakarpattia	12.8	1986	0.5	11.0	1.3			
		2011	3.9	8.8	0.1			
Zaporizhzhia	27.2	1986	0.9	24.6	1.7			
		2011	11.1	16.0	0.1			
Ivano-Frankivsk	13.9	1986	0.1	5.1	8.3	0.4		
		2011	1.6	8.4	3.8	0.1		
Kirovohrad	24.6	1986	0.1	17.8	6.5	0.2		
		2011	1.3	21.4	1.9			
Kyiv	28.9	1986		3.4	14.1	8.8	1.6	1.0
		2011		8.3	14.4	4.6	0.9	0.70
Lugansk	26.7	1986		1.6	25.1			
		2011		19.2	7.5			
Lviv	21.8	1986	2.2	19.6				
		2011	17.5	4.3				
Mykolaiv	24.6	1986		23.4	1.2			
		2011	7.7	16.7	0.2			
Odesa	33.3	1986	0.1	29.7	3.5			
		2011	4.7	28.0	0.6			
Poltava	28.8	1986		26.5	2.3			
		2011		28.8				
Rivne	20.1	1986		6.4	5.8	7.8	0.1	
		2011		8.6	7.9	3.6		
Sumy	23.8	1986	0.1	16.4	6.5	0.8		
		2011	1.5	18.0	4.0	0.3		
Ternopil	13.8	1986	3.6	7.2	2.7	0.3		
		2011	7.9	4.1	1.8			
Kharkiv	31.4	1986		14.0	17.4			
		2011		29.1	2.3			
Kherson	28.5	1986	0.9	27.4	0.2			
		2011		7.3				
Khmelnytskyi	20.6	1986	1.7	14.2	4.4	0.3		
		2011	8.6	10.3	1.6	0.1		
Cherkasy	20.9	1986		7.6	8.2	4.9	0.2	
		2011	0.5	11.3	7.2	1.9		
Chernivtsi	8.1	1986		3.8	3.9	0.4		
		2011		5.8	2.2	0.1		

Republic, Oblast	Oblast area	Year	Area of the territory with the following ^{137}Cs contamination density, $kBq \cdot m^{-2}$					
			< 2	2 – 10	10 – 40	40 – 185	185 – 555	> 555
Chernihiv	31.9	1986	0.6	16.5	12.6	2.1	0.1	
		2011	5.3	17.1	8.3	1.2		
Exclusion Zone	*2.6**	*1986*				*0.8*	*0.9*	*0.86*
		2011			*0.5*	*0.8*	*0.8*	*0.5*
Total, in Ukraine	*603.7*	*1986*	*20.4*	*371.9*	*168.6*	*37.5*	*3.7*	*1.6*
		2011	*130.1*	*367.4*	*84.7*	*18.4*	*2.0*	*1.1*

* – area of the Exclusion Zone and the zone of mandatory resettlement located in Kyiv Oblast.

Actually, the level and scale of Ukraine's territory contamination by Pu isotopes have not changed. ^{241}Am activity is gradually increasing due to ^{241}Pu decay; and the area of its distribution, where levels exceed 0.2 $kBq \cdot m^{-2}$, shall be 30% wider than the area of plutonium isotopes fallout having the same density [3]. The Ukraine's area contaminated by ^{90}Sr, ^{241}Am, Pu isotopes [1, 3] is substantially smaller than the one contaminated by ^{137}Cs. Since an overwhelming majority of these radionuclides has penetrated into the atmosphere during the first (explosive) and the third (high-temperature) phases of the accident and were associated with hot particles [4], they are the most widespread within the Exclusion Zone boundaries [3].

Polissia (northern districts of Volyn, Rivne, Zhytomyr, Kyiv, and Chernihiv Oblasts) is referred to the worst affected areas in Ukraine in terms of negative effects produced by radioactive contamination. The effective legislation states that in 1991–1993 2052 settlements or almost 90% of a total number of habitats on the abovementioned territory were classified as radioactive contamination zones (Table 2.2).

Table 2.2.

Quantity of settlements that may be referred to radioactive contamination zones as per zones demarcation criteria stipulated by the effective legislation

No.	Oblast	Per dosimetric rating						Per radionuclides contamination density						Classified as the zones
		I	II	III	IV	V	total	I	II	III	IV	V	total	
1	Vinnytsia					89	89				31	58	89	89
2	Volyn			76	90		166				9	157	166	166
3	Zhytomyr			80	126	490	696		11	45	371	307	734	734
4	Ivano-Frankivsk					5	5				4	1	5	5
5	Kyiv			4	20	446	470	20	11	54	189	286	560	560
6	Rivne		1	75	167	96	339				133	206	339	339
7	Sumy			1	1	9	11				6	5	11	11
8	Ternopil					10	10				5	5	10	10
9	Khmelnytskyi					9	9				6	3	9	9
10	Cherkasy				1	102	103				57	46	103	103
11	Chernivtsi					14	14				10	4	14	14
12	Chernihiv			1	42	210	253			1	80	172	253	253
	Total		***1***	***237***	***437***	***1480***	***2165***	***20***	***22***	***96***	***901***	***1250***	***2293***	***2293***

Whereas an average predicted effective equivalent dose of human exposure was the main criterion for classification of the settlements as referring to zone III (of guaranteed voluntary resettlement), the most part of habitats belonging to zone II (of absolute (mandatory) resettlement) were respectively classified by the Resolutions of Ukraine's Governments adopted in 1989–1990 basing on contamination density assessments and estimated exposure dose and with due regard to geographical and administrative links. The key criterion for compiling a list of the population centres referred to zone IV (of enhanced radioecology monitoring) was the density of ^{137}Cs contamination in the area. The Exclusion Zone, or zone I, was established on the territory, from where people were evacuated in late

April and in the first week of May in 1986 (mainly out of the 30-km zone surrounding the ChNPP). The evacuation was grounded on the estimated exposure dose rates and on the uncertainty about an absolute stoppage of releases from the destroyed ChNPP Unit 4.

A high level of radioactive contamination is not always a reason of radioecological problems. Such a conclusion may be justified by a comparison of the dosimetric rating results and contamination density data. Since, in the case there are soils with greater bioavailability of ^{137}Cs, the areas with relatively moderate (even less than 37 kBq·m^{-2}) levels of ^{137}Cs contamination may become critical for living activities. For instance, a large part of woods is referred to the areas, where low-level ^{137}Cs contamination caused excess content of ^{137}Cs in forest grass and food stuff (mushrooms, berries) that surpasses the levels stipulated by PL-2006 [5].

With a glance to the fact that radioactive contamination density has significantly decreased over the years, as a result of radionuclide natural decay, the positioning of population centres has also changed as far as zoning criteria are concerned (Table 2.2).

In 25 years after the accident, the radioecological conditions improved significantly, as compared to 1986 and 1991. In the meantime, within the boundaries of zone III (today encompassing the area of almost 200 population centres) still necessary are the measures aimed at reduction of the exposure doses potentially absorbed by public due to consumption of locally produced food.

Severely contaminated (over 1.5 MBq·m^{-2} of ^{137}Cs) localities (almost 300 km^2) within the boundaries of Exclusion Zone shall remain uninhabitable for hundreds of years. These water-producing areas shall remain a long-term source of surface water and groundwater contamination due to surface washout and vertical migration, respectively.

Radioactive contamination of the atmospheric boundary layer

After a rapid increase in air contamination in April 1986 resulting from radionuclide release from the damaged reactor and starting from 1989, a total β-activity of atmospheric aerosols is being primarily caused by naturally-occurring radioactive elements, which activity in the atmospheric boundary layer is now almost an order of magnitude higher than the man-caused component (Fig. 2.11–2.12). Recently, a total β-activity in terms of absolute values is even slightly lower than the one during the pre-accident years due to a reduced lift of soil particles by wind caused by the area overgrowing [6].

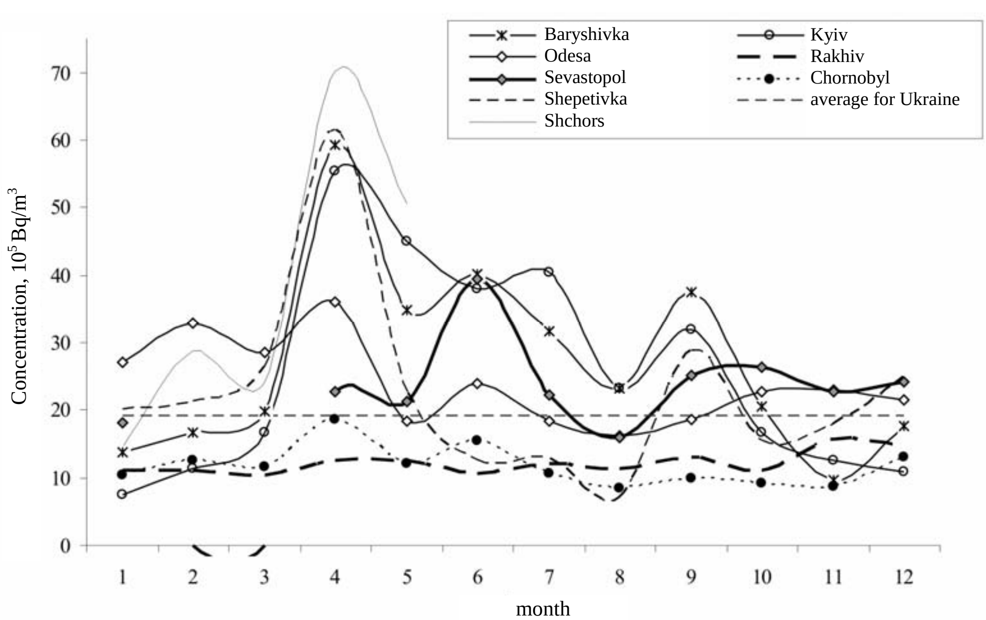


Fig. 2.11. *Fluctuation of levels for a monthly average value of specific total β-activity (10^{-5} Bq·m^{-3}) in the atmospheric boundary layer on Ukraine's territory*

Therewith, seasonal variability limits of volumetric radioactivity levels are single-order in some years. These differences (Fig. 2.12) in the levels of aerosols' natural radioactivity depend on many factors, and not least is the Earth's tectonic activity, as well as weather conditions and a state of soil surface layer, its susceptibility to wind erosion, and other factors [7].

In the areas subject to radioactive contamination resulting from the Chernobyl disaster, where lands were removed from agricultural use and farming operations (ploughing, harrowing, etc.) are actually not performed, thereby increasing susceptibility of the soil surface layer to erosion (Chernobyl), the total β-activity is 2–3 times less than the one observed in the areas that are not classified as the radioactive contamination zones (Shchors, Shepetivka), even under adverse weather conditions.

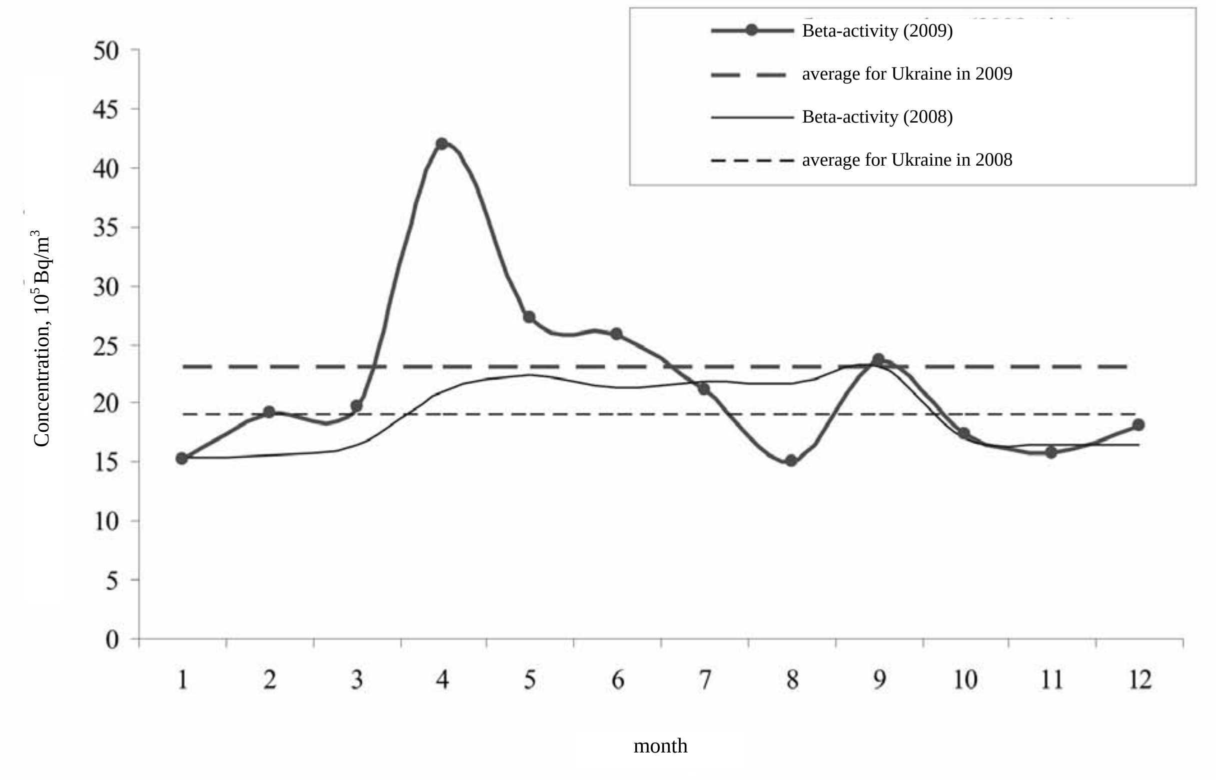


Fig. 2.12. *Seasonal variations of a value for a total volumetric beta-activity of aerosols in the air on average in Ukraine in 2009 compared to 2008.*

At the same time, resuspension in the near-surface air layer has produced high levels of man-caused radionuclide concentrations in the structure of aerosols in the contaminated areas, if compared to the rest of Ukraine (Fig. 2.13).

In case of intense works involving destruction of a soil surface layer, where ^{137}Cs contamination level is 370–555 kBq·m^{-2}, the radionuclide volumetric activity in aerosols at a height of 3–5 m may exceed the permissible limits established by NRSU-97 [8].

Starting with 1998, average annual concentrations of ^{137}Cs and ^{90}Sr in aerosols are varying within the range similar to the pre-accidental one, i.e. $0.08 \cdot 10^{-5}$ Bq·m^{-3} [9]. At the same time, absolute levels of air contamination by ^{137}Cs and ^{90}Sr are 4–5 orders of magnitude lower than the permissible concentrations (NRSU-97).

In due course, concentrations of accidental radionuclides in the air will be slowly decreasing due to both their natural decay and further penetration into soil.

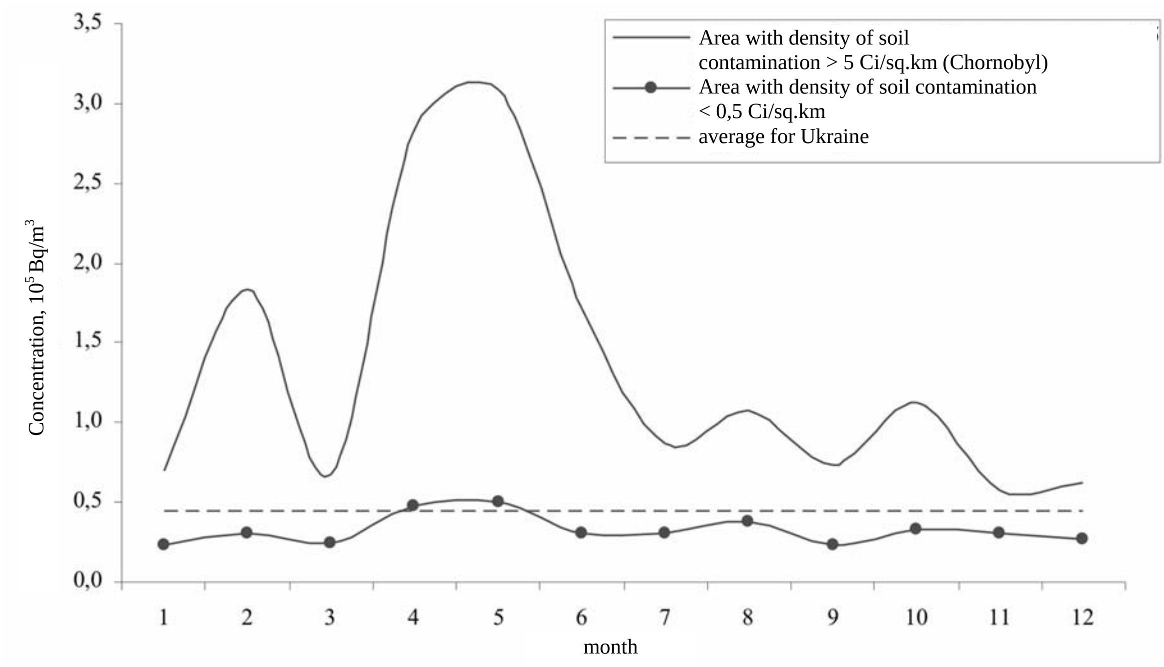


Fig. 2.13. *Annual course of ^{137}Cs concentrations in aerosols, averaged for the areas with different soil contamination levels*

In most of the country, the exposure dose rate of γ-radiation (γ-background) is within the levels driven by natural radioactive isotopes and cosmic radiation, and in various areas it amounts to 5–21 μR·year^{-1} (depending on natural differences). At the check pints located in the area contaminated as a result of the ChNPP accident (outside the Exclusion Zone and the zone of absolute (mandatory) resettlement), the average monthly level of γ-background varied within a range of 7–33 μR·year^{-1}, the maximum levels were observed in Korosten (33 μR·year^{-1}).

During a year, γ-background in Kyiv was recorded within a range of 8–18 μR·year^{-1}, amounting to 12 μR·year^{-1} on average. i.e. it was within the limits of natural background.

Radioactive contamination of surface and underground waters

Since initial period followed the accident, implementation of water protection activities have been considering as a priority for the Governmental action plan. In a history of post-Chernobyl protective took place an effective as well as the incorrect actions, which have not achieved the purpose – to decrease the radioactive contamination of the surface water bodies and consequently radiation risks due to water consumption and water use by the people leaving at the affected areas. A number of reviews and scientific studies were devoted to the detailed analysis of these actions.

In the first years after the accident the number of water protective dams having adsorption filtering body, have been constructed at the many small rivers, the sediment traps at the Pripyat river have been constructed downstream of the contaminated floodplain near outlet of the Pripyat river to the Kiev reservoir.

However, since several years after the accident, the most of small dams installed at the small rivers were demolished because, dose reduction effects of these facilities have been estimated as very low and have been evaluated as inefficient in terms of radiological risk reduction and economical factors.

During the initial post-accidental period, a relatively significant contribution to the human exposure associated with aquatic pathways was primarily caused by high ^{131}I content in the water, and in particular in the Kyiv water intake [10–12]. Eventually, such radionuclides as ^{137}Cs and ^{90}Sr, which have been washed out from the contaminated catchments and river flood plains and transported over considerable distances (up to 1000 km), become predominated in the surface water contamination. Direct fallouts of aerosols to the surface of Kiev and other reservoirs and deposition of the contaminated suspended particles from the river's flows onto the bottom, have been formed the initial picture of the bottom sediment contamination in the Dnieper's reservoirs. The most of ^{137}Cs activity that has inlet to the Dnipro cascade has been accumulated in the bottom sediment of Kyiv Reservoir, while dissolved ^{90}Sr was relatively easily transported by water flows into the Black Sea [10, 13].

The radiation monitoring studies at the surface water and groundwater in the affected areas due to Chernobyl accident has been carried out during all whole period passed after the accident [10, 14, 15]. The mathematical models to predict possible long-term consequences and calculate potential exposure doses for the variety of potentially affected population groups that use water from the Dnipro reservoirs were developed [12, 14, 16]. Analysis of estimated long-term radiological risks caused by contamination of the water indicated that critical groups, in terms of potentially increased exposure through the waterways, included only fishermen's subject to their consumption of fish from the closed lakes located in the contaminated areas close to the damaged reactor. The estimated radiological risks for Ukrainian population due to water consumption were assessed to be relatively low [10, 14].

At the same time, due to Dniper river contaminated occurred to be psychotically sensitive for the million of peoples leaving along the Dnieper's cascade and created inadequate perception of the radiation risks forming, the limited number of priority water protective actions, which have been executed in the Chernobyl exclusion zone, appeared quite justified taking into consideration social and economical expediency.

For justification of the water protection strategies in the Chernobyl exclusion zone the methodology based on collective dose assessment over 70 years of potential exposures due to all actual aquatic pathway, probabilistic models for long-term water system trend estimation have been applied [12, 14, 16]. The strategy such as most contaminated flood plain damming at the Chernobyl exclusion zone has been chosen taking into account radiological, social and economic criteria of its expected efficiency.

A perfect example of comprehensive justification and social appropriateness of the actions were construction at the Chernobyl close-in zone the flood protection dams. In 1992–1994 and then during 1999–2000, the dams were built around the most contaminated floodplain sites within the Chernobyl exclusion zone. The dams made possible to control the most contaminated lands flooding and the radionuclide washout from the left and right banks of the riverside.

No large-scale water protection activities were performed within the Exclusion Zone after 2000. With-in the objective to mitigate further contamination of water bodies after 2000 the only hydrological remediation actions were carrying out: such as runoff regulation by means of hydraulic engineering facilities in the most severely contaminated areas, support of anti-erosion measures through forestation of the rivers' catchments and flood plains, installing the barriers to prevent radionuclide migration into the groundwater from the radioactive temporary waste disposal sites, development of observation networks for the groundwater contamination, and maintenance of the existing dams and water protective activities.

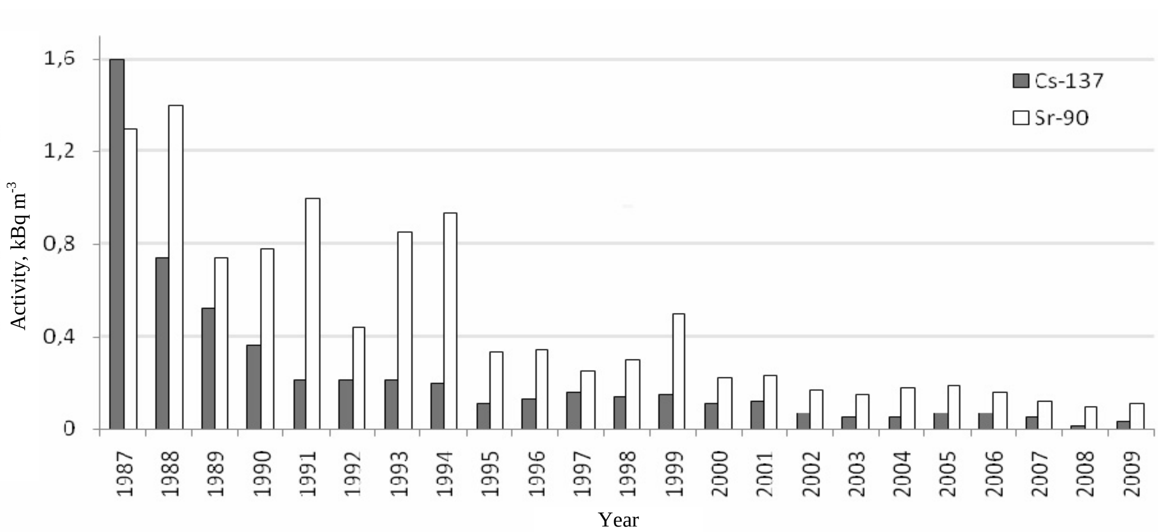
The long-term radioecological studies within the Chernobyl exclusion Zone demonstrate that natural attenuation processes at the contaminated areas are the major factors contributing to reduction in the aquatic system radioactive contamination [18, 19].

Radioactive contamination of surface water

Results of observations confirm that radiation condition of the water bodies located in the area affected by the ChNPP accident has become steady and is predictable now. With regard to all water bodies, a strong tendency towards a decrease in radionuclide ambient activity and its fluctuations are of seasonal nature. Relatively high levels of radionuclide activity are still observed in the Pripyat River and in other waterways within the Chernobyl Exclusion Zone (50–300 $Bq \cdot m^{-3}$ for ^{90}Sr, 20–80 $Bq \cdot m^{-3}$

for ^{137}Cs). At the same time, ^{90}Sr content in the Pripyat River is about 1.0–1.5 orders of magnitude lower than allowable levels of radionuclides for the drinking water (2000 Bq·m^{-3}) established in Ukraine. The data on Fig. 2.14 presents the temporal variation dynamics of ^{137}Cs and ^{90}Sr activity in the Pripyat River (at the Chernobyl exclusion zone).

The data provided by Central geophysical observatory, which belongs to Hydro-meteorological service of Ukraine, reports that during 2008–2009 the radionuclide concentrations in the Kyiv Reservoir for ^{90}Sr varied in range 40 and 100 Bq·m^{-3} and for ^{137}Cs the values were observing as 10–20 Bq·m^{-3}, while in the Kakhovka Reservoir (lowest in the cascade of Dnieper reservoirs) the activities of ^{137}Cs varied in range 0.5–1.0 Bq·m^{-3}. For the period followed the Chernobyl accident (1986) up to 2000-2004, the content of ^{137}Cs in most of Ukrainian rivers (lower reservoirs on the Dnipro River, the Desna River, the Pivdennyi Bug and the Danube River) have reduced to a pre-accident level such as 0.5–1.5 Bq·m^{-3} [20]. This fact demonstrates the effects of natural attenuation process such as radionuclide vertical migration and its irreversible fixation by soil particles, which annually reducing the content of radionuclides in the upper superficial layer of soil. Accordingly, radionuclides washout in the rivers is constantly decreasing.



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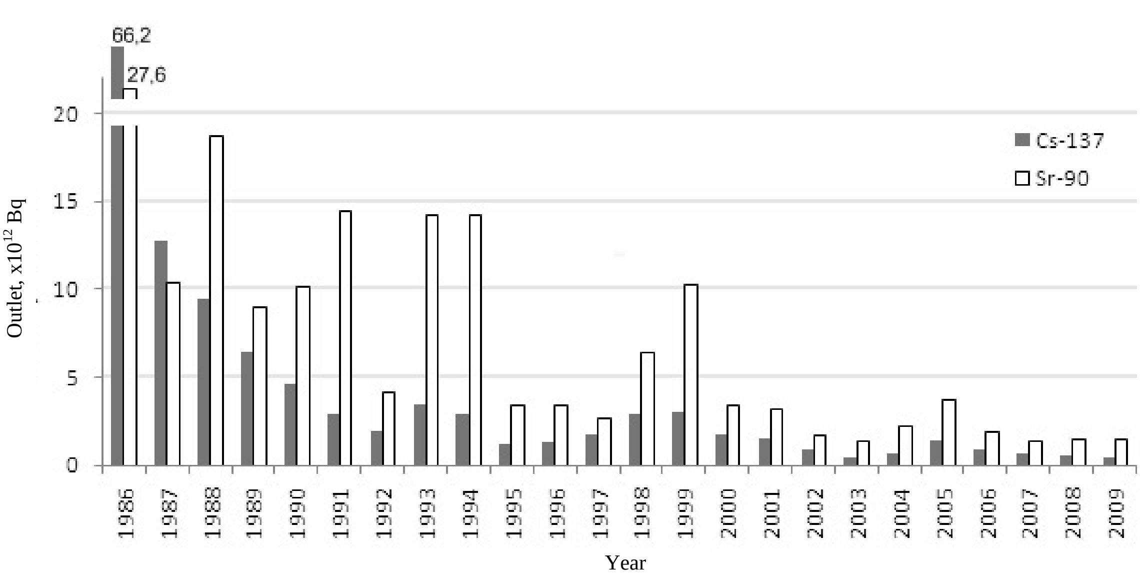
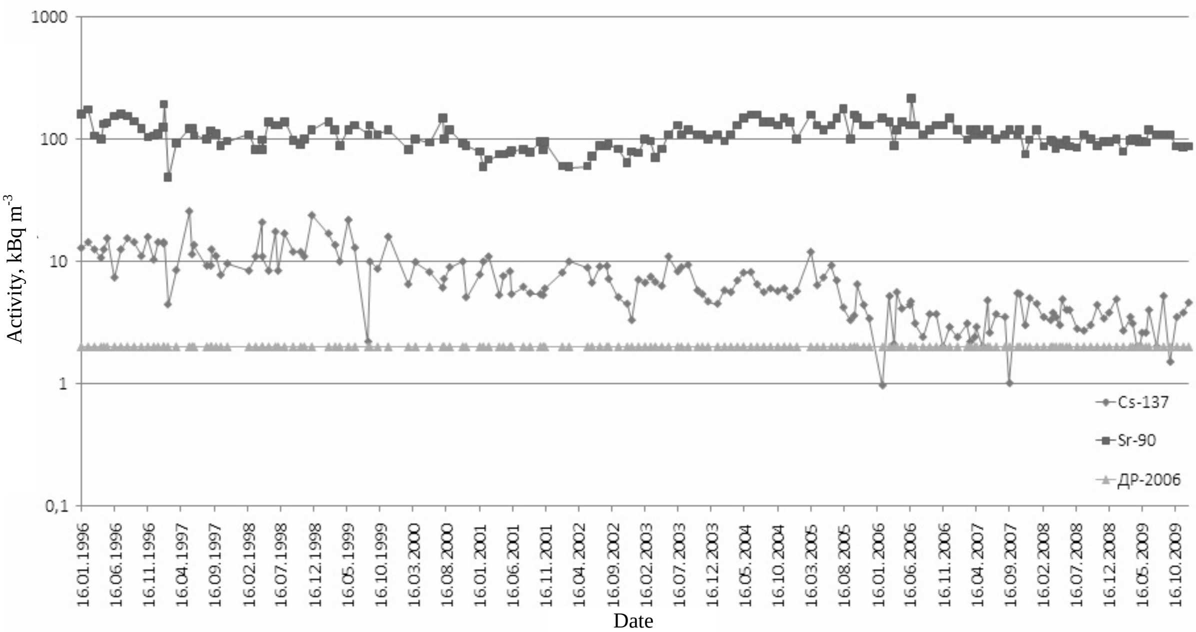


b

Fig. 2.14. *Annually averaged activities of ^{137}Cs and ^{90}Sr in the Pripyat River (a) and annual values of radionuclides inlet to the Kyiv reservoir (b) Data of the Chernobyl 'Ecocentre' and UHMI)*

On a background of reduction of carrying out radionuclides by surface runoff, the annual infiltration outlet of contaminated water from the Chernobyl cooling pond remains more or less stable, making its relative contribution to the Pripyat River contamination in comparison to surface runoff higher. However, the infiltration flux of radionuclides from the cooling pond to the Pripyat River and the Kiev reservoir remains insignificant [20, 21].

A Significant increase the radionuclide inlet to the Pripyat river with groundwater at the most contaminated part of the Chernobyl exclusion zone is not expecting in the coming years. Relatively high contamination is still remains in the lakes situated in surrounding area around ChNPP [21, 22]. Particularly, there are no significant reductions of ^{90}Sr in the Gluboke Lake and in the cooling pond over the last decade (Fig. 2.15).



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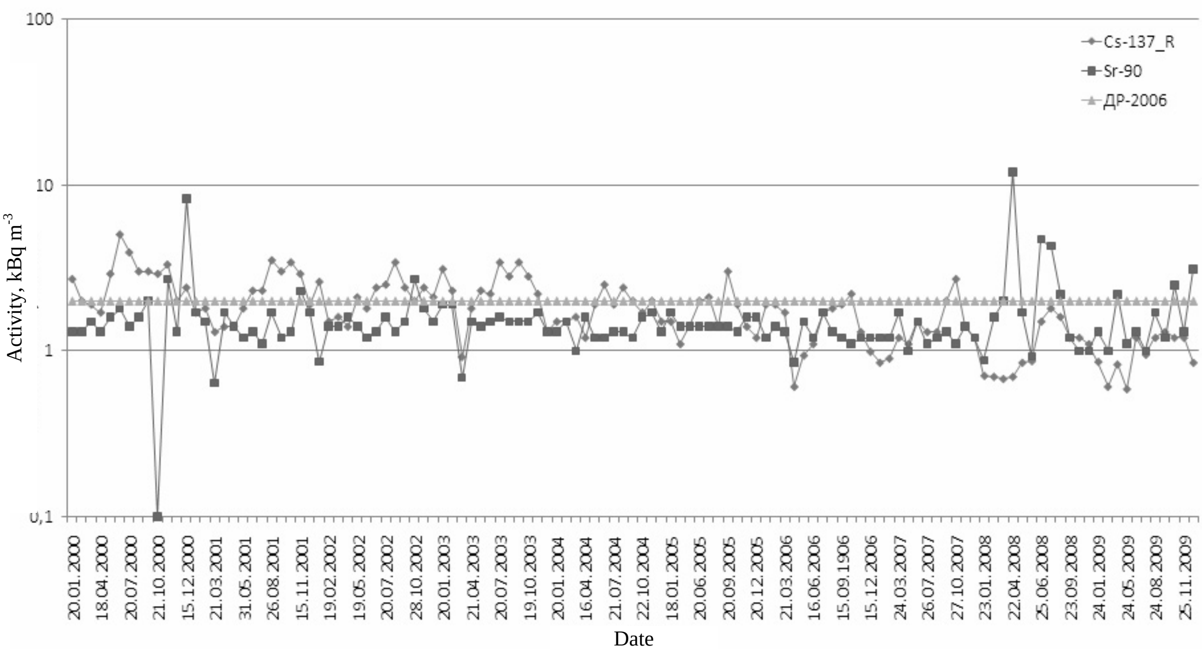


b

Fig. 2.15. *Dynamics of ^{137}Cs and ^{90}Sr activity (kBq·m^{-3}) concentrations in the Glyboke Lake (a) and in the Chernobyl cooling pond (b).*

Nevertheless in the future some increase of ^{90}Sr can take place at the closed water bodies (mainly lakes situated flood plain and area adjacent to Chernobyl NPP industrial site), in which bottom sediments a significant amount of nuclear fuel particles still well preserved till to now) [23].

Therefore at present time the only regulation of the runoff and water drainages at the contaminated areas in order to prevent its significant inundation such as the forestation at the most contaminated catchments and floodplains, and also controlled natural attenuation process at the most contaminated wetlands and lakes can be considering as reasonable achievable remediation actions [19].

Enhancing and optimization of the monitoring network at the most contaminated areas around ChNPP industrial site such as extension of the automatic hydrological stations and developing specialized groundwater observational wells have been carried out and to be continued as part of remediation strategy in the Chernobyl exclusion zone. The analytical laboratory of Chernobyl Ecocentre is also under its developing. These actions as it expected will allow improving the quality and consistency of the monitoring data needed for efficient safe management at the Chernobyl exclusion zone. Supporting the environment monitoring network and reliable data collections in the future will be needed if consider the Chernobyl exclusion zone at this late post-accident period also as unique test site for validation and development of radionuclide transport and radioecological models.

Drawing up and Evaluating Remediation Strategies for Chernobyl cooling pond. Subsequent to the last reactor Unit of ChNPP shutdown in 2000, the need in the cooling pond water decreased to a minimum. The cut-off of two canals used to join the pond and ChNPP, and using the canals as fire-protective ones ensures satisfaction of the NPP's current demand for cooling water. At the same time, the annual expenses needed to maintain safe condition of the pond is rather high (estimating about 2 millions of UA hryvna per year). The expenses on maintaining stable state of the dam, repairs of pumping equipment and drainage systems, cost of electric power, etc. are expected to be increased in the future. Therefore, the ChNPP top managers in agreement with the Regulatory bodies decided to begin preparation to decommissioning the cooling pond. At the moment the preparedness actions include developing FS (feasibility studies) EIA (environment impact assessment) and modernization of the observational network on in the cooling pond and surrounding areas, which will become invalid within few several years after declining of water level.

Due to significant radioactive contamination of the bottom sediment its safe decommissioning should be well justified and also regulatory and socially approved. The accident-caused fallout of a great amount of dispersed nuclear fuel particles, which were fallen down in aerosols to the surface of the cooling pond from the damaged reactor and discharge of heavily contaminated process water from the ChNPP industrial site through the sewage system have been a reason of a significant radioactive contamination of the cooling pond [24–29]. The assessments carried out by the UHMI during recent decade indicate that silt at the cooling pond bottom contains approximately 280 TBq of ^{137}Cs, 42 TBq of ^{90}Sr and 0.75 TBq of Pu isotopes.

It is expected that as result of stop of the water pumping to the cooling pond from the Pripyat River, the water level in the pond will be reduced on 6–7 m due to natural filtration of water through the dam's body to the river and its evaporation from the surface. The process may last for about 5–6 years. Afterwards, the water level in the submerged floodplains and lakes that will occur in natural lowlands of the river's former floodplain instead of the presently existing cooling pond will depend on the water level in the Pripyat River bed, because they will be hydraulically connected.

As a result, in place of the currently existing cooling pond there should emerge three specific zones, including: a completely drained one (the bottom surface, with absolute altitude ranging between 103–104 and 110.5 m); a transition zone that will be like wetland in high water periods and almost dewatered during dry summer and low-water seasons; and also lakes, which will be created in place of the former floodplain lakes submerged by the elevated water level in the existing cooing pond water body. (Fig. 2.16 look the coloured inset). The totally drained area will occupy about 10-12 km^2 (50–60 % of the current area of the cooling pond's bottom) presently containing almost 15–17 % of ^{137}Cs, 20 % of ^{90}Sr and 12 % of Pu isotopes.

Simulation results of the new expected landscape to be created after declining of the cooling pond, indicate that as result of decommissioning of the pond, most of the radionuclides (75–85 % activities) will remained in the bottom sediment of the new created lakes and wetlands and only about 20–25% of the existing amount of radionuclides in the bottom sediment at present condition will be potentially exposed for potential wind re-suspension and external expose on the dried bottom surface.

The carried out assessment show that the relatively high contaminated water of the cooling pond, which will inlet to the Pripyat River as result of its natural infiltration will not create additional contamination of the rivers and also will not produce any significant negative ecological effects for the Kiev reservoir aquatic ecosystem.

The total amount of water which is as expected will outlet from the cooling pond due to natural filtration is estimated to be approximately 60–70 million m^3 having activities of ^{137}Cs and ^{90}Sr about 2–2.5 $kBq{\cdot}m^{-3}$. These waters will be dissolved in the huge amount of the Pripyat and Dnieper water and will not be detectable as increasing of existing low and safe level of the radionuclides in Kiev reservoir. A loss in the cooling pond's water volume may result in some activity increase (mainly ^{90}Sr) in residual water masses, and subsequently in the small water bodies that will form subject to the bottom topography and water levels. Anyway, once the cooling pond's water level starts lowering, the annual seepage discharge of activity into the river will be continuously decreasing.

A possible wind re-suspension and dispersion of the potentially high contaminated dust particles from the dried bottom sediment and potential fire of the dried vegetation, which as expected will be naturally covered the dewatered bottom sediment relief of the cooling pond are considering as a major risk factor to be assessed at the stage of justifying possible needs in application of mitigate measures to prevent negative effect the cooling pond decommissioning, when water level will be declined.

A feature of the case, which was taken into account, are phenomena of fine fuel particles presents in the bottom sediments that are associated with a silt particulate phase of bottom sediments, which have fairly well preserved their structure and integrity over the post-accident period [26–28] in comparison to the «hot particles», which already almost dissolved in the soils at the lands adjacent to the cooling ponds. It is expected that once the cooling pond's bottom is partially drained the preserved till now «hot particles» will be exposing by weathering condition and will rapidly fail [26]. Consequently it will increase their availability for re-suspension and dispersion by wind to adjacent areas. Preliminary assessment of radiological risks for the people, working within the exclusion zone during possible wind storms condition, which was carried out as a part of preliminary EIA (Kashparov at all, 2001) show that contribution of radionuclide dispersion to the additional contamination of the adjacent area due to aerosol fallout having specific origin at the cooling pond dried area will be insignificant as well as its expose effects [27]. Gradually, the cooling pond's surface will overgrow with herbaceous vegetation and with wild willow species that are typical for the area [28], thus mitigating transport of radioactive dust particles from the water surface by wind.

Bottom sediment of the Dnipro river Reservoirs. Throughout the whole post-accident period, ^{137}Cs and ^{90}Sr transport delivering into the Kyiv Reservoir by the Pripyat and Dnipro Rivers water have been monitored [13, 23, 30]. The spatial distributions of ^{137}Cs and amounts of ^{137}Cs accumulated at the bottom sediment have been studied and estimated for each particular reservoir, based on implementation of the number of sampling surveys performed by the UHMI during first decade followed the accident (1989–1996) [13, 30].

The carried out assessment published [30] show that total inventory of ^{137}Cs and ^{90}Sr in the bottom sediment of reservoirs is gradually reducing since 1990, due to radioactive decay which become dominated natural attenuation process in surpasses the annul income of radionuclides with river's runoff inlet and continues partly removal of radionuclides from water column to the bottom due to adsorption sedimentation process.

During the first decade followed the accident, approximately 70 % of ^{137}Cs and 90 % of ^{90}Sr total income to the Dnipro reservoirs system, were accumulated by the bottom sediment of the Kyiv Reservoir and in particular in its upper section which accept major part of inlet from the Pripyat River sediment load. The suspended particles being delivered by the river's to the upper part of the Kiev Reservoir have been deposited at the local bottom depressions or old river channels and as result the area, where contaminated silt particles have been accumulating, become a local hot spots having local formation of the relatively high radioactive contamination. The years with low-water runoff, that observed during period since 1986 till 1993 have contributed to steady local processes of radionuclides accumulation in the upper part of the reservoir. Instead, during later period having relatively high floods in 1994 (summer rain flood), and specially as a result of high spring flood, which took place in 1999, and in 2005, a number of sites, which characterized by relatively steady accumulation rates in the low water seasons, were flushed by water high floods. Impacted by flash river's floods, the most contaminated fine silt particles have been suspended and transported to the middle and lower parts of the Kyiv Reservoir, where these particles deposited again in the deepened sites become unavailable for significant hydrodynamic stressing.

The recent carried out studies of the radionuclide vertical distribution in the accumulated bottom sediment columns t the sites with typical condition for sedimentation have indicated a significant change in spatial distribution of radioactive contamination at the Kiev reservoir, which took place during passed 15–20. The UHMI survey carried out during 2008–2009 show, that the deposited silt sediments layers in the central and lower sectors of the Kyiv Reservoir were increased on deep water sites significantly up to 25 sm. Accordingly the radionuclide accumulation density per a unit of the bottom area has also augmented (Fig. 2.17). Consequently, caesium-137 contamination densities at some particular areas have been increased from 185 kBq·m^{-2} in 1994 to 610 kBq·m^{-2} in 2009. Simultaneously, *the sites in the upper sector of the reservoir, where the highest contamination levels were observed during the first years of the contamination formation, were subject to a significant cleanup due to hydrodynamic factors impact.*

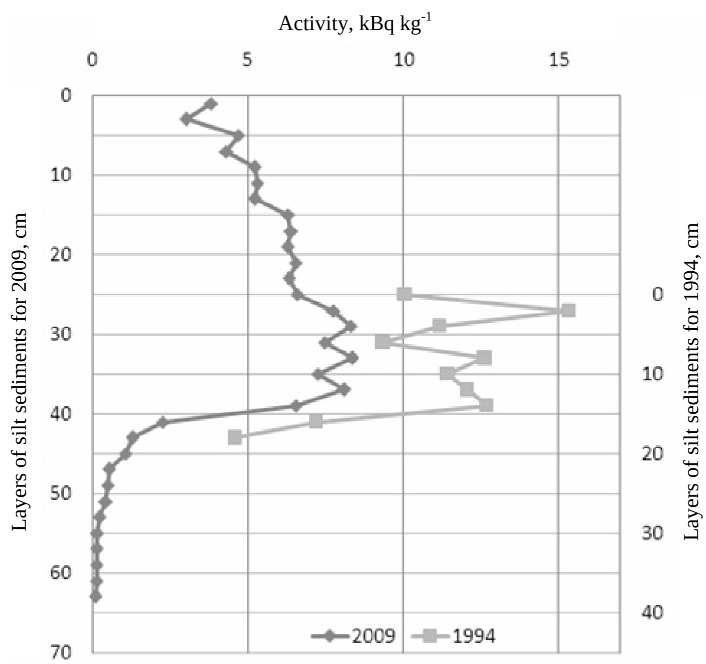


Fig. 2.17. *Vertical distribution of ^{137}Cs in the silt sediment located at the lower section of the Kyiv Reservoir in 1994 and 2009*

Generally, a radioactive contamination pattern of the reservoir bottom became more contrast. Shallow water sites of the bottom (0–5 m) became cleaner; on medium depth sites (5–9 m) the contamination density is approximately the same as it was in early 90^{th}; and on deep water sites the total amount of Chernobyl-originated radionuclides has increased.

The total radionuclide activity is still reducing due to radioactive decay. Actually, the nuclides that are strongly occluded in bottom silt particles no longer impact contamination of the water masses.

Beneficial is the fact that current *status of the bottom silt radioactive contamination has verged towards a steady equilibrium condition, as most of the sludge contaminated during the initial post-accident period has moved to the zones of steady (stable) accumulation*.

Presumably, a process of contaminated sediment covering with a layer of more clean materials, which will be delivering to the most contaminated bottom sediment area, will play a role of natural attenuation processes as well. The sources of relatively clean particulate materials suspended materials contributing due to coastal and catchments erosion. In the next decade sedimentation factor will play a predominant role to create relatively clean sediment layer forming above the buried radioactive contaminated particles at the deepest areas of the Kiev reservoir. It is very important now to fix the current situation by a repeated survey of the bottom sediment contamination picture as an intermediate phase on the way of achieving the end-sate of the natural attenuation in self remediation of the Kiev reservoir bottom. Results of such the survey will also assist in making more accurate calibration of the mathematical models for radionuclide migration in such system as «catchment-water – suspended particles – bottom sediment» as a basis for developing tools for safety assessment and radionuclide transport modelling in such complex catchment – river reservoir environmental system. The new spatial distribution mapping of radionuclides in the bottom sediment of Kiev Reservoir is also needed to justification of dredging strategies and techniques at the reservoir, which should be considered as a natural trap for radionuclides delivering to the reservoir from huge Dnipro river basin. Therefore in respect of sedimentation as a key natural attenuation process in the Kiev reservoir, it should be monitored – means controlled.

Therefore, *monitoring of the bottom sediment radioactive contamination in the Kyiv Reservoir and other reservoirs should be continued*.

Radionuclides in the groundwater

A specific groundwater observational well network to monitor condition of the groundwater after the ChNPP accident was significantly developed only within the Exclusion Zone and in the localities for temporary residential areas for personnel working within the Exclusion Zone.

Observation results indicate that radioactive contamination levels of the groundwater are remain relatively low, excluding sites around temporary waste disposal site and some radioactive storage facilities situated at the ChNPP industrial site. Groundwater also significantly contaminated in close adjacent areas to the contaminated water bodies (cooling pond, lakes and wetlands at the most contaminated area of the Exclusion Zone). In the worst contaminated areas of the Exclusion Zone, the level values vary in range from 0.1 and less to 1.0 $Bq{\cdot}L^{-3}$ for ^{137}Cs and between 1 and 10 $Bq{\cdot}L^{-3}$ for ^{90}Sr. A spread rate of the contaminated groundwater aureole in the direction of its discharge into rivers is very slow, even for strontium-90 [31], mostly up to 20 m per year.

Generally, contamination of the groundwater in the Exclusion Zone and adjacent areas has not produced catastrophic effects that were expected by the most conservative predictions during the first years after the accident. *The cumulative flow of radionuclides caused by the groundwater discharge into the rivers of the Exclusion Zone is relatively low and will remain the same in the future, if compared to surface water transport of radionuclides in the contaminated areas. It can not produce any significant radiation risks to the people of Ukraine living beyond the boundaries of the ChNPP Exclusion Zone* [32, 33].

At present, relatively high levels of water contamination (in some cases, the levels, which in 10 – 100 time exceed critically allowable concentrations (CAC) for drinking water supply) are only registered exactly within the bounds of radioactive waste storage facilities that have been constructed with no special filtration-proof geochemical or other engineering barriers, as well as on some specific sites in the area having the clearly marked depression morphological landforms.

Predictive estimates [34] indicate that the groundwater will start discharging into the Pripyat River no earlier than in 40-50 years from now. During the forthcoming years, a maximum discharge may be estimated as to 100–120 GBq (3.0–3.5 Ci). If compare the estimated transport of ^{90}Sr by the surface water to the Kiev Reservoir, the contribution of radionuclides delivering by the total ground water flux to the Pripyat river will not exceed 10–15 %.

The model calculation results indicate that *the groundwater flow from the Shelter Object site will hardly reach the Pripyat River, as even in 100 years ^{90}Sr front shall spread no further than 600 meters*. Therefore, during the period of the water arrival to the riverbed, the water contamination levels shall become practically insignificant [21, 31]. Both ^{137}Cs and ^{90}Sr contamination of the groundwater in the first aquifer under the surface registered beyond the Exclusion Zone boundaries does not exceed 0.3 $Bq{\cdot}dm^{-3}$.

Within the 25 years have passed after the Chernobyl release, we can make a general statement that the processes of radionuclide migration in the aeration zone and in saturated soil, unlike their behaviour in the air and in surface water, are characterized by significant retardation and inertia. The radiation monitoring system covers the groundwater of Quaternary, Eocene, Cenomanian, and Lower Cretaceous aquifer systems. The groundwater monitoring is ensured at RAWDS (radioactive waste disposal sites), major RAWTSS (radioactive waste temporary storage near surface sites), water retaining structures, and regionally within the entire Exclusion Zone. The radiation condition of groundwater in aquifer system of Eocene sediments (sources of centralized water supply to the ChNPP) is monitored at the operating ChNPP's water intake facility (the city of Pripyat); the one of Cenomanian and Lower Cretaceous aquifer systems is monitored at the operating water intake facility in the city of Chernobyl. Results of research conducted in 1986–2010 indicate minimal contamination of the groundwater by the ChNPP release radionuclides (significantly lower than the required limits). ^{137}Cs and ^{90}Sr specific activities in the drinking water used at the ChNPP and at the Chernobyl City water intake facilities do not exceed 0.001 $Bq{\cdot}L^{-3}$.

The groundwater monitoring results reveal ^{90}Sr contamination in aquifer system of the Quaternary sediments, which is progressing over time and distance due to the radionuclide migration from accidental RAW temporary storage near-surface sites, i.e. trenches (clamps), and the Shelter Object industrial site. Migration of the radionuclide to the hydro-geological medium is caused by infiltration of atmospheric precipitation as well as by direct continual or seasonal groundwater under-flooding of RAW. ^{90}Sr specific activity in poral solutions of the trenches' bodies, under and around the waste dumps, is 100–1000 times exceeding the permissible limits for drinking water (PL-97). The aquifer system contamination is several dozen of meters deep, as the groundwater flow runs.

The maximum intensive radionuclide migration was fixed at observation wells in the 'Red Forest', in the former Stroybaza and Yanivsky Lake locations. As of summer 2010, the following values are true for the water in the wells equipped for the Quaternary aquifer system: ^{90}Sr volumetric activity in the vicinity of the former Stroybaza varied between 32 $kBq{\cdot}m^{-3}$ and 130 $kBq{\cdot}m^{-3}$, and near Yanivsky Lake it was in the range between 0.77 $kBq{\cdot}m^{-3}$ and 36 $kBq{\cdot}m^{-3}$.

In the vicinity of the cooling pond PK-14, the following ^{90}Sr volumetric activities were registered in the observation wells' water: about 1.3–18 $kBq{\cdot}m^{-3}$ in the upper section and 1.2–4.3 $kBq{\cdot}m^{-3}$ in the medium and lower sections. ^{137}Cs volumetric activity amounts to 0.007–0.14 $kBq{\cdot}m^{-3}$. In K-3 observation well water (Sandy Plateau, RAWTSS, Semykhody Lake location), ^{90}Sr volumetric activity was registered to be at a level of 22 $kBq{\cdot}m^{-3}$, while the water level occurrence depth was 3.2 m.

The values of ^{90}Sr and ^{137}Cs volumetric activities in the water of the observation wells included into 'Pidlisnyi' RAWDS monitoring network were as follows: ^{90}Sr – 0.18–0.49 $kBq{\cdot}m^{-3}$, ^{137}Cs – 0.009–0.091 $kBq{\cdot}m^{-3}$, while the water level occurrence depth varied between 1 and 6.5 m. In the water of the regulatory observation wells located within the bounds of 'Buriakivka' RAWDS, ^{90}Sr volumetric activity was 0.26–1.8 $kBq·m^{-3}$ and ^{137}Cs volumetric activity was 0.009–0.12 $kBq·m^{-3}$. At the Pripyat water intake facility, ^{90}Sr volumetric activity was registered as varying between 0.31 and 2.3 $kBq·m^{-3}$ and for ^{137}Cs it was 0.006–0.05 $kBq·m^{-3}$.

In the water of Cenomanian and Lower Cretaceous aquifer system, ^{90}Sr and ^{137}Cs volumetric activities have not exceeded 0.01 $kBq·m^{-3}$.

The results of research conducted within the near-ChNPP zone enveloping major RAWTSS («Red Forest», «Budbaza», Yaniv Station, etc.), the ChNPP industrial site, the Shelter Object, as well as «Pidlisnyi», «Kompleksnyi» and other radioactive waste disposal sites indicate that *the long-term, i.e. during 100–300 forthcoming years, lateral distribution of ^{90}Sr dangerous concentrations from the trenches will be limited to several hundred of meters from the dumps down along the groundwater stream*. Local hydro-geological conditions and geological barriers ensure a rather safe occlusion and decelerate migration of radioactive strontium and caesium, therefore limiting a spread of radionuclides by the groundwater.

However, *for a long time will the contaminated groundwater surrounding RAWTSS be a steady source of radiation risks within the near-ChNPP zone*. As far as radionuclide potential transport and migration pattern are concerned, the dumps located in the Yanivsky Lake area (due to its location in the Pripyat River floodplain) pose a real danger of surface water contamination.

The dominant factors of radionuclide migration intensity variations throughout a year include specific features of hydro-geological and climate conditions, structural features of disposal sites, as well as the conditions and intensity of interactions between surface flows, water bodies and groundwater. Beyond RAW disposal sites, the conditions of groundwater radioactive contamination formation depend on 'diffused' sources of radionuclide migration.

The data provided by the Institute of Geological Sciences under the NASU indicate that up to 40 TBq (1000 Ci) of ^{137}Cs annually penetrate into the geological environment including local sites, i.e. RAWTSS, RAWDS, and the Shelter Object. An amount of ^{90}Sr annually penetrating into the geologic environment is well above ^{137}Cs. Consequently, *total activity of ^{137}Cs and ^{90}Sr absorbed by the geological environment is 4–20 times as high as annual export of the activity by the Pripyat River beyond the boundaries of the Exclusion Zone.* As per the data provided by the ISTC «Shelter», about 120 MBq of U and Pu and nearly 1.5 TBq (40.5 Ci) of ^{137}Cs and ^{90}Sr can be annually transported into the geological environment by the Shelter Object waters.

2.1.2. Radiation monitoring system for the environment

The existing legislation for environmental protection, health and disease control, Chernobyl and nuclear issues envisages functioning of a rather extensive radiation monitoring system in Ukraine. The system is to reliably ensure accomplishment of central tasks for radiation protection of public and the environment, including radioactively contaminated areas affected by the Chernobyl accident. Today, monitoring of radionuclide content in various objects of the natural environment, food, and in people is mainly ensured by radiology departments in the organizations and enterprises subordinate to the ME, the MH, the Ministry of Agricultural Policy, the Ministry of Energy, the State Water Management Committee, the State Forestry Management Committee, according to areas of their responsibility and authority.

The SSSPE «Ecocentre» is ensuring monitoring within the Exclusion Zone and zone of absolute (mandatory) resettlement at the expense of the State Budget of Ukraine.

The monitoring schedule covers 146 observation centres for various environmental objects (surface waters including sewage, atmospheric boundary layer, landscape), 138 wells for groundwater observation, personnel operation sites, 11 centres of population. Annually, over 5,000 samples are taken and more than 10,000 analytical studies of the samples are carried out. The radiation conditions are continuously monitored by means of the computer radiation monitoring system in 39 observation stations, including the ChNPP industrial site and the city of Slavutych. With the objective to prevent man-caused transport of radionuclides beyond the boundaries of the Exclusion Zone, radiation monitoring of vehicles and cargoes is ensured at monitoring and dosimetry check points.

The radiological service under *the Ministry of Agricultural Policy* ensures radiation monitoring of agricultural products obtained in the centres of population referred to radiation contamination zones, as per the Chernobyl program. However, the service suffered a substantial loss in recent years. Also, a considerable scope of work under the agricultural lands passportization programs is being carried out by the oblast (province) state design & process centres for soil productivity protection. The centres have conducted radiation surveys of over 5 million hectares of lands. A level of food contamination caused by the Chernobyl disaster consequences is reducing year after year.

The radiation monitoring service subordinate to *the State Forestry Management Committee* ensures: latest updates on radiation conditions in forests, at production facilities and private premises; dosimetry monitoring in forestry work locations, sampling and measurements of standard radionuclides in forest products; support to maintaining the radiation databank; information of top managers at enterprises, local authorities, and local communities on radiation situation in the forests located in corresponding areas and on the content of standard radionuclides in the branch products. The annual output of radiological monitoring under the State Forestry Management Committee's system amounts to 30000 samples per year. However, the scope is gradually reducing because of a gap in budget financing.

It is noteworthy that along with normalization of radiation situation in forest ecosystems and gradual reduction of a share of products contaminated beyond the permissible limits, radionuclide content in forest foods, especially in Ukrainian Polissia, is still rather high. Permissible limits for ^{137}Cs content are exceeded in up to 80 % of the monitored forest foods.

The surveillance over the levels of radioactive contamination executed by the radiation monitoring system under the *State Hydro-Meteorological Service* covers the entire territory of Ukraine, inclusive of the area classified as radioactive contamination zones formed as a result of the Chernobyl disaster.

The monitoring results indicate that during the previous 5 years radiation background practically in all oblasts (provinces), including the radioactive contamination zones, was stable, within the limits equal to the pre-accident levels, i.e. 6–33 μR·hour^{-1}, and driven primarily by natural radionuclides and cosmic radiation. At the Chernobyl check point, where a current density of soil contamination by ^{137}Cs is about 330 kBq·m^{-2}, γ-background was driven by the Chernobyl NPP accident consequences and varied within a range of 15–27 μR·hour $^{-1}$. Higher γ-background levels (18–33 μR·hour $^{-1}$) at the Korosten check point are caused by both soil radioactive contamination of Chernobyl-origin (presently, about 165 kBq·m^{-2}) and peculiarities of the local geologic framework, particularly by a cropout of granitoids that is close to the earth's surface and is characterised by high concentrations of natural radionuclides of kalium, uranium, thorium. Monitoring of the contaminated areas is ensured by way of daily measurements of γ-radiation exposure dose rates at 70 check points, collection and analysis of the following: atmospheric fallout samples at 26 points, airborne particulate samples at 5 points, surface water samples at 3 points in the Kyiv and Kaniv Reservoirs.

The following are the common problems of all radiological services subordinate to a variety of agencies: non-availability of implementation programs for the state-of-the-art quality assurance systems; inadequate financing of radiation monitoring programs, and first of all under the budget program entitled 'Radiological Protection of Public and Ecological Recovery of Radioactively Contaminated Areas', which in 2009–2010 was reduced more than 20-fold, if compared to 1998. A failure to carry out dosimetry and radiation monitoring programs as well as programs for radiation monitoring of the products produced in the contaminated areas has actually made impossible ensuring constitutional rights of nearly 2 million of Ukrainian citizens, i.e. residents of the localities classified as radioactive contamination zones, with regard to accurate information on contamination levels of the environment and locally produced food, and their adverse health effects.

2.1.3. Recovery of ecosystems affected by radioactive contamination

The Chernobyl accident was characterised by a relatively short-time pulse release. As a result there was created an artificial time marker which can be used for estimation of the rate of the following processes. The fixed date of the fallout, exclusively artificial origin of contamination, high sensitivity of radiometric measurements, a wide variety of landscape and geochemical conditions within Ukrainian Polissia determined the reliability of the obtained data and possibility of their generalization for a wide range of artificial pollutants.

The concept of natural recovery of radioactively contaminated ecosystems. Spatial expansion of radioactivity as well as lack of techniques designed for soil decontamination provided the requirement in researches on natural decontamination of the environment within the area affected by the Chernobyl Catastrophe. Considering that the locally produced food (potato, milk) prevail in the diet of the rural population residing in radioactively contaminated lands, the oral intake of radionuclides predominates in formation of the irradiation dose. Consequently, along with a significant reduction in annual doses, as early as in 1988, a portion of exposure caused by peroral intake increased up to 80% [35]. This predetermined a crucial role of the ‘soil – plant’ trophic chain in the process of radiation exposure and determined the urgently need for a conceptual review of an idea of the ecosystem’s natural recovery.

In the context of ecological safety, *natural recovery of an ecosystem* includes natural processes facilitating excretion of a contaminant out of a trophic chain. In contrast to the concepts developed in geochemistry [36–38], the processes of a contaminating agent’s prolonged fixation by the soil absorbing complex play a key role in ecosystem *natural recovery*. These processes are not necessarily accompanied by destruction of the contaminant or its removal outside a landscape. Therefore, studying the processes of radionuclide biogenic migration within ecosystems of contaminated areas has become a matter of special concern.

^{137}Cs and ^{90}Sr are the most dangerous dose-forming radionuclides in medical and biological sense. The long-term dynamics of Ukraine’s rural population radiation exposure demonstrates that the radiation exposure decrease rates are significantly higher than the rates of the radionuclides physical decay (Fig. 2.18).

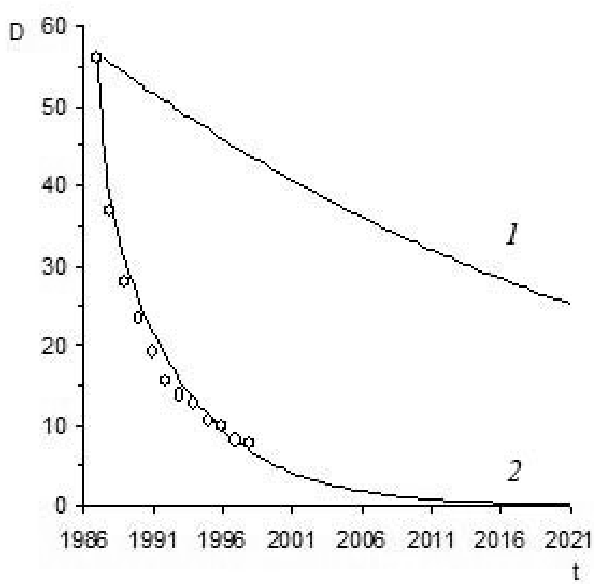


Fig. 2.18. *Dynamics for the dose-forming radionuclides decay (1) and rates of total (caused by various sources) normalized annual exposure dose reduction, $\mu Sv \cdot year^{-1}$ per 1 $kBq \cdot m^{-2}$ (2), (dots indicate experimental and estimated data).*

Having fallen on the surface, the radionuclides join the abiogenic transformation processes resulting in formation of mobile (water-soluble and exchangeable) forms that are the most accessible to vegetation (Fig. 2.19).

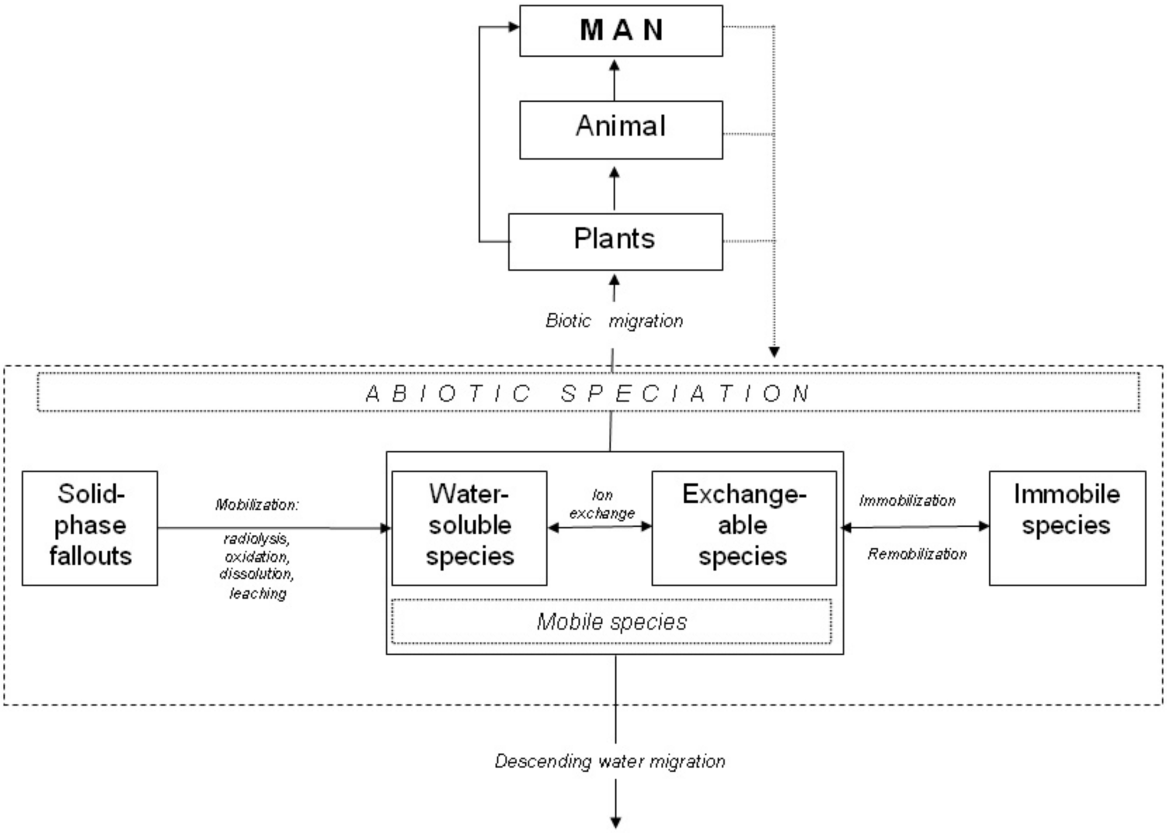


Fig. 2.19. *Biogenic and abiogenic processes of radionuclide forming and migration.*

The concept of the natural recovery of the environment based on speciation has been formulated in the following way [39, 40]:

– the non-equilibrium thermodynamics of an initial artificial form of being of element in the outer shell of the Earth is a driving force behind the abiogenic transformation of agents;
– speciation of the man-caused elements is accompanied by the intermediate product generation, i.e. a mobile form, which content synchronically stipulates an intensity of biogenic and abiogenic water migration;
– the kinetic model of transformation determines content of the mobile form as a function of time elapsed since the moment of an element's artificial form fallout to the Earth's surface.

Natural decontamination of trophic chains. The synchronism of dynamics between radionuclide abiotic speciation and biogenic migration has been render the possibility to regard parameters of radionuclide speciation in soil as a «*geochemical chronometer*».

A radionuclide removal out of the biological cycle owing to immobilization at the geochemical barrier does not exclude its contribution to the external exposure dose.

Rating parameters of radionuclide removal out of the root nutrition, i.e. an initial link in a trophic chain, may be regarded as efficiency of impact of a number of geochemical processes' on the decontamination. (Table. 2.3).

Comparing constants of the rates for geochemical processes contributing to annual natural decontamination of plant products in terrestrial ecosystems demonstrates that during the post-accident period a key role is played by ^{137}Cs immobilization process, as on the average its rate is one order of magnitude greater than the one of radioactive decay.

Table 2.3.

Periods and constants of semi-decontamination rates for terrestrial ecosystems and their components caused by various geochemical processes

Process	**^{137}Cs**			**^{90}Sr**		
	$T_{1/2}$, years	**k, $year^{-1}$**	**k/λ**	**$T_{1/2}$, years**	**k, $year^{-1}$**	**k/λ**
Physical decay	30	0.023	1.0	29	0.024	1.0
Lateral migration	> 1000	0.0005	0.02	> 300	0.0015	0.06
Immobilization	0.10–1.5	0.45–7.0	20–300	1.2–69	0.01–0.60	0.42–25
Downward migration	70 –>300	0.001–0.01	0.043–0.43	25–45	0.015–0.028	0.65–1.0
Biogeochemical migration into meadow grass	2.0–10	0.07–0.32	3.0–14	≈ 2.0	0.29–0.38	13–17
Biogeochemical migration into cow's milk	2.0–10	0.07–0.32	3.0–14	N/D	N/D	N/D

Note: *$T_{1/2}$ is a semi-decontamination period (removal from the root nutrition), k is a process rate constant, λ is a radioactive decay constant, N/D – not determined.*

As for ^{90}Sr, the immobilization processes in mineral soils does not play a significant role in decontamination of trophic chains. During the first years after the accident, an increase in ^{90}Sr activity in annual biomass product of terrestrial ecosystems, which was caused by the mobilization processes, took place in the areas, where dispersed fuel fallouts have predominated. Later, annual decontamination of products in the terrestrial ecosystems was determined by a high migration ability of radiostrontium in Polissia soils.

The data obtained allow estimation of the periods for radionuclide semi-removal of an ecosystem and a trophic chain due to the processes of abiotic transformation and abiogenic and biogenic migration. The data presented in Table 2.1.3 demonstrate the difference between the natural recovery capacity of a landscape, i.e. radionuclide transport out of a trophic chain, and the natural attenuation, i.e. decontamination of a landscape's abiogenic component. The latter takes place due to the three main processes, including radioactive decay, lateral and vertical migration of radionuclides, and depends on the physical decay for ^{137}Cs, and for ^{90}Sr the decontamination occurs twice as fast as the decay. The natural decontamination of meadow ecosystems occurs 3–10 times faster than the decay; due to the abiogenic transformation, particularly ^{137}Cs fixation in the soil absorbing complex and ion exchange under ^{90}Sr biologic uptake.

Natural decontamination of forest ecosystems. The biogeochemical flux of radionuclides in forest biogeocenoses are characterized by significantly more complicated patterns. This caused by the multilevel structure of the ecosystem, different time periods, biological peculiarities of plant lifecycles, etc. With identical density of soil contamination, intensity of ^{137}Cs biogeochemical flow in a pine tree's ecosystem increases with biomass gain determined by landscape and geochemical conditions. The natural decontamination capacity of forest ecosystems increases contrariwise, and for the most of ecotopes it is governed by a radioactive decay rate. A pine tree biological natural recovery period is 15–250 years [41, 42].

Natural decontamination of surface water systems. Radionuclide water transfer through the Dnipro River system is at the top, alongside with the risks of radioactivity spreading from RAW dump sites or beyond the excluded area boundaries due to a partial damage of the Shelter Object [43].

However, a steady trend towards a decrease in the annual radionuclide transfer to water reservoirs of the Dnipro Cascade is observed (Fig. 2.20).

The analysis of average annual dynamics of ^{137}Cs and ^{90}Sr concentrations in the water of the Pripyat River demonstrates the availability of two periods in the surface water natural decontamination (Fig. 2.21):

in the accident phase the natural decontamination depended on radionuclide fallout forms, therefore the rate of this process was almost an order of magnitude higher than in the subsequent years;

since 1989, the processes of radionuclide transfer through the Chernobyl Exclusion Zone drainage system have depended on the rate of radionuclide mobilization in soils within water catchment. Currently, the water masses natural decontamination rate is almost 5 times as high as the corresponding rates of isotopes decay. ^{137}Cs transfer is primarily determined by the hydrological regime of the rivers. And ^{90}Sr transfer depends to a great degree on a water regime of soils, and to a lesser degree on dryness of a year.

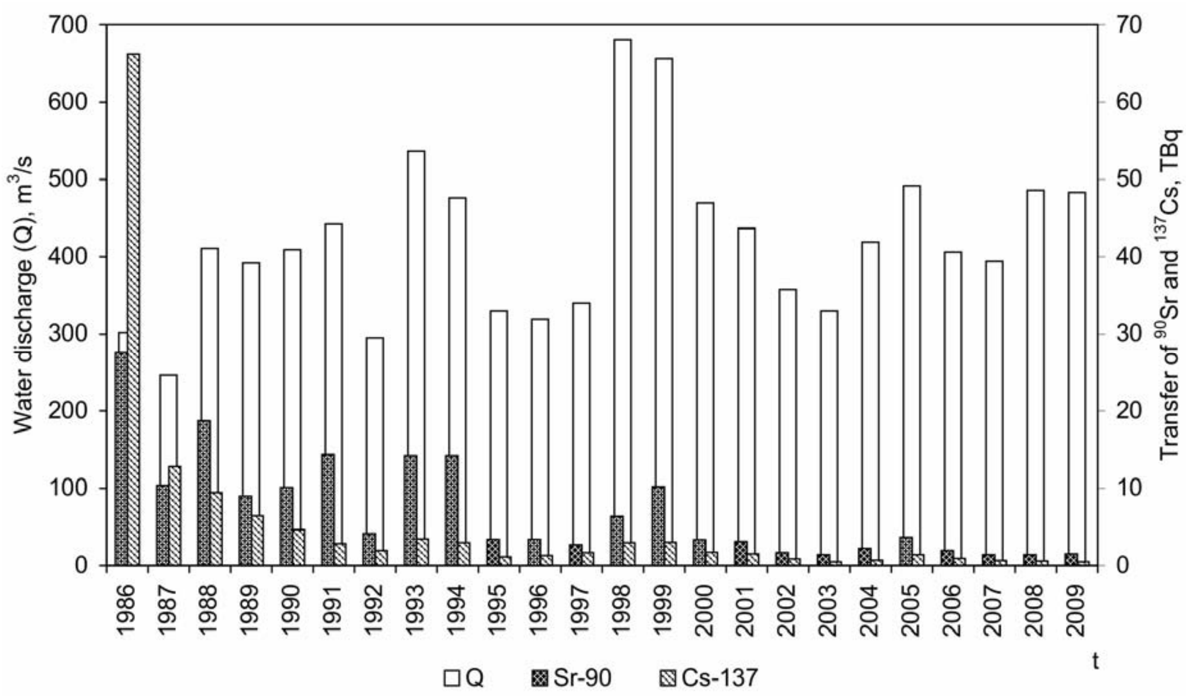


Fig. 2.20. *Post-accidental Pripyat River water flow and radionuclide transfer.*

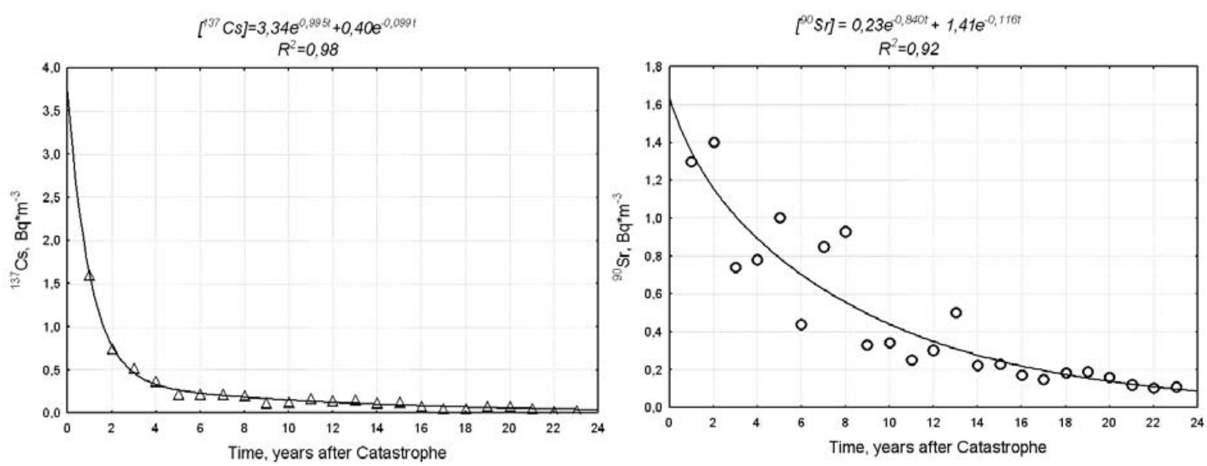


Fig. 2.21. *Temporal dynamics of ^{137}Cs (a) and ^{90}Sr (b) concentrations in the water of the Pripyat River.*

Simultaneously with a decrease in water contamination, evident is a change in the radionuclide speciation towards increasing of conditionally dissolved species and decreasing of suspended ones. The transformation rate in terms of size corresponds to the rate of radionuclide mobilization in soils, which indicates *a uniform geochemical mechanism for water migration of radionuclides in the environment*.

In the past decade the annual transfer of ^{137}Cs to the Kyiv Reservoir amounted to $6{\cdot}10^{11}$ Bq and that of ^{90}Sr to $7{\cdot}10^{12}$ Bq. Studying the dynamics of radionuclide speciation in the surface water systems makes possible to assess the total transfer into the Black Sea amounting to 20 TBq of ^{137}Cs and 200 TBq of ^{90}Sr. The reason is that ^{137}Cs is firmly trapped by solid phase of bottom deposits, and ^{90}Sr is almost completely washed out from the bed silt by the Dnipro River system [44].

2.1.4. Environmental regulation issue

The system of hygienic regulation existing in the country and in the world does not settle the problem of ecosystems biota safety found within the zone of radioactive accidents and fallouts effect. The experience of assessment of radionuclides impact on biota as in the case of the Kyshtym and especially Chernobyl accident has shown that such telling impacts are observed. Accordingly, published paper 103 of the International Commission for Radiological Protection has finally posed the problem of establishing the special environmental regulation system. The International Commission for Radiological Protection proposes the option of selecting especially sensitive ecosystem species, and their response could serve as a basis for a judgment as to exceeding or non-exceeding of the permissible ecosystems biota contamination levels.

From our point of view, development of the environmental norms system for permissible discharges and releases of pollutants to ecosystems biota requires special approach and creation of special models. Relatively simple approaches and models of permissible air, water and foodstuffs contamination levels assessment are used under the existing hygienic regulation system. Their control arrangement would be enough to ensure compliance with hygienic norms. The task of establishing environmental norms for permissible biota contamination levels is far more complex.

Limitation of the dose of effect on biota within an ecosystem structure requires dynamics and mechanisms of pollutants distribution and redistribution between components of a particular ecosystems be determined for a critical biota link be found, where depositing of the most considerable amount of pollutants, as well as the highest does of it, should be expected, and where the most negative impacts on biota may occur. But it will not necessarily be the selected in advance most sensitive organism species. At initial stages of an accident, some individual very sensitive species may certainly respond to relatively high radiation doses, but these specific species will not necessarily be responsible for fate of the whole ecosystem biota. Eventually any ecosystem biota survival is driven by its capability of saving biomass, sufficient for the ecosystem procreation and maintenance of the property of conditioning inhabitation viable for the biota. Consequently, our opinion is that for biota of the ecosystems characterised by real processes of distribution and redistribution of captured radionuclides the third option for critical biota components determination must be applied under the environmental regulation system, and those shall be used for radiation factor regulation.

By using site data and results of calculations based on the developed by us models of radio capacitance of virtually any ecosystem, specific values of (in particular) ^{137}Cs radioactivity could be determined in each component of ecosystem biota under study. Using data on ^{137}Cs Fa (accumulation factor), radio capacitance model of any components of the subject ecosystem, and results of studied ecosystem compartment model running may allow of obtaining data on ^{137}Cs radionuclide distribution and redistribution dynamics according to the system of differential equations representing the compartment model.

For practical application of the proposed approach the calculation was done for a slope ecosystem. It is tolerable that the initial level of ^{137}Cs radionuclides ingress into the upper level of the forest ecosystem (prototype of the slope on Uzh river bank) makes up 1 MBq. Using site data and compartment model of the ecosystem under study, and radio capacitance models, it is suggested to calculate the part of radionuclides and biota irradiation dose, and ^{137}Cs radionuclides concentration that will form in different inhabitation locations (Table 2.4).

Table 2.4.

Dose rate (Gy) calculation for the lake ecosystem and permissible annual radionuclide discharge depending upon Fa values for benthos biota (at rising value of ^{137}Cs supply to forest)

Doses from lake ecosystem components impacting biota	**Benthos biota Fa**					
	1	**10**	**100**	**1000**	**10000**	**100000**
From water	5.4^{-9}	5.4^{-9}	5.4^{-9}	5.4^{-9}	5.4^{-9}	5.4^{-9}
From benthal deposits	3.2^{-8}	3.2^{-8}	3.2^{-8}	3.2^{-8}	3.2^{-8}	3.2^{-8}
From lake biomass	1.4^{-8}	1.4^{-7}	1.4^{-6}	1.4^{-5}	1.4^{-4}	1.4^{-3}
Internal dose	3.3^{-8}	3.3^{-7}	3.3^{-6}	3.3^{-5}	3.3^{-4}	3.3^{-3}
Overall biota dose	5.2^{-8}	4.8^{-7}	4.7^{-6}	4.7^{-5}	4.7^{-4}	4.7^{-3}
Permissible ^{137}Cs discharge to forest given that benthos biota dose does not exceed 4 Gy/h	7.7^{+13} Bq	8.4^{+12} Bq	8.4^{+11} Bq	8.5^{+10} Bq	8.5^{+9} Bq	8.5^{+8} Bq
	2100 Ci	220 Ci	22 Ci	2.3 Ci	0.23 Ci	0.023 Ci

By setting differing biota contamination levels in different compartments according to the B.Amiro model, one may assess biota dose loads based on the general level of ^{137}Cs radionuclides supply equal 1 MBq. It is clear that these doses will be low as against the proposed here critical bounding dose of 4 Gy/h for biota. Then in determination of the ratio, limits of ^{137}Cs radionuclides supply to the compartment – forest were set, given that dose rate does not exceed the value of 4 Gy/h. It is therewith demonstrated that the greatest dose loads are expected in the lake benthos biota. As follows from Table 1, depending on Fa – benthos biota, permissible radionuclide contamination levels (environmental norms for ^{137}Cs radionuclides discharge) in forest change appreciably in the range of hundred of Ci to very few. It means that: 1) critical benthos biota may limit abruptly the environmental norm value; 2) not only the upper area of the slope ecosystem may be subject to radionuclide contamination, but also other slope ecosystem compartments located below. While strictness of the environmental norm as to permissible levels of radionuclides discharge grows appreciably in case, when ^{137}Cs radionuclide contamination affects lower levels of the slope ecosystem – grassland, terrace. The lower contamination gets down the slope, the lower is a permissible level of radionuclides supply to the slope ecosystem under study.

In review of calculation results presented in Table 1, it should be emphasized that the two bottom lines contain listing of permissible levels of ^{137}Cs radionuclides discharge to the lake using the above presented ratios. Accordingly, the environmental norm for a permissible level of ^{137}Cs ingress during the first year after an accident at an actual high Fa value of benthos biota equal 1000 must not exceed an overall value of 2.3 Ci in the event of a single discharge.

In case of additional discharges of radionuclides into the forest during the years following the accident, this requirement criterion shall be evaluated as a still smaller value. The point is that, high Ac values for the bottom biota, which is critical for the slope ecosystem, indicate very limited levels of environmental standards for permissible levels of radionuclides discharges and releases, even in the top slope. In case of radionuclide fallouts to the lower slope sections, a permissible level of environmental standard for their contamination by ^{137}Cs radionuclides shall be still noticeably lower. Furthermore, it is easy to calculate that hygienic standards for the lake water, as drinkable one, (2 Bq/L) have never been exceeded subject to these ecological standards.

The same may be demonstrated by the fact that in case of ^{137}Cs radionuclides penetration into the forest at a level of 2.3 Ci or 0.23 Ci, contamination levels of the terrace meadow grass and forage grasses shall never result in an excess of the hygienic standard (DU-2006) for milk contamination amounting to 100 Bq/L, in case of contamination resulting from obtainment of milk from cows grazing on the meadow and from cows feeding on the terrace forage grasses. The same refers to contamination levels of vegetables, in case lake water is used for their irrigation, this will also not result in an excess of the hygienic standard for vegetables contamination by ^{137}Cs radionuclides amounting to 100 Bq/kg. Consequently, in this actual situation involving contamination of the slope ecosystem by ^{137}Cs radionuclide, the proposed environmental standards for permissible levels of radionuclides discharge and release are noticeably lower than the hygienic standards in effect in the given slope ecosystem.

It is known that modern active ecological paradigm is that if ecological situation in a specific ecosystem is favourable for people, then the ecological situation for wild biota shall be even more so favourable. This specific analysis that was performed for a near-real slope ecosystem based on calculation of an environmental standard for permissible ^{137}Cs radionuclide contamination levels indicates that the above paradigm is not always true. It is possible to presume that environmental standards for permissible levels of actual ecosystems' contamination by pollutants may be stricter than hygienic standards for people. The hygienic standards are relatively easy to develop, because they refer to the only biota species, i.e. people. Furthermore, individual components of a habitat are subject to standardization, i.e. contamination levels for air in breathing zone, drinkable water, and food. Thereby, these standards are developed and calculated only once, and then are very rarely adjusted.

Development of the environmental standards for critical permissible levels of pollutants discharge and release into various types of ecosystems, and hence assurance of environmental safety, require special knowledge and models. Complexity of the problem is that even for one and the same ecosystem (for example, a slope ecosystem), an environmental standard shall vary depending on Fa values, i.e. biota, bottom sediments depending on pollutants distribution in ecosystem's components, etc. The task complexity shall increase in case of analyzing and calculating environmental standards for various types of ecosystems, especially those aggregated into complex landscape ecosystems. This may implicate that environmental standardization, in case it is subject to development, shall require significant theoretical and experimental effort.

Analysis of pollutants' behaviour in ecosystems of slopes, which form the basis of practically all terrestrial landscapes, indicated a possibility to describe distribution and redistribution of radionuclides by the methods of radio receptivity theory, using compartment models. Researches demonstrate that a rate of radionuclides migration in a landscape is generally determined by several characteristics: degree of slope on a slope (P1), type of coverage (P2), landscape fissure (P3), vertical (P4) and horizontal migration (P5). Each of the factors shall be evaluated from 0>1. Due to independence of landscape values, the overall evaluation of radionuclides migration probability in landscape elements shall be evaluated as the convolute probability and calculated by formula $P = P1 \times P2 \times P3 \times P4 \times P5$. Real landscapes are extremely problematic, when estimations of radio receptivity parameters are applied to vast territories, where factor systems of radionuclides impacting redistribution in biotic and abiotic components of the ecosystems apply. It is known from field research of the processes for radionuclide migration in slope systems and for soil erosion under an impact of surface flow, that flow intensity rises sharply as a slope degree increases.

Using technical potential of ESRI ARCGIS software, we have developed a simulation and analytical GIS (geographical information system) enabling analysis and predictive modelling of contaminating agents' migration in ecosystems. The mathematical model of contaminating agents' migration in ecosystems, which we have developed, forms the GIS mathematical framework. Physical and chemical, biochemical characteristics of contaminating agents as well as conditions of natural and anthropogenic environment are the model's basic informational components. The input data analysis enables to end up with key blocks of the model, i.e. factors of pollutants import and export in ecosystems. The method enables reconstruction of an area contamination process, as well as extrapolation of contamination factors to an entire research region based on point-by-point field measurements, as well as environmental standards for landscapes.

2.2. Formation of radiation conditions and economic activities in the areas contaminated as a result of the ChNPP accident

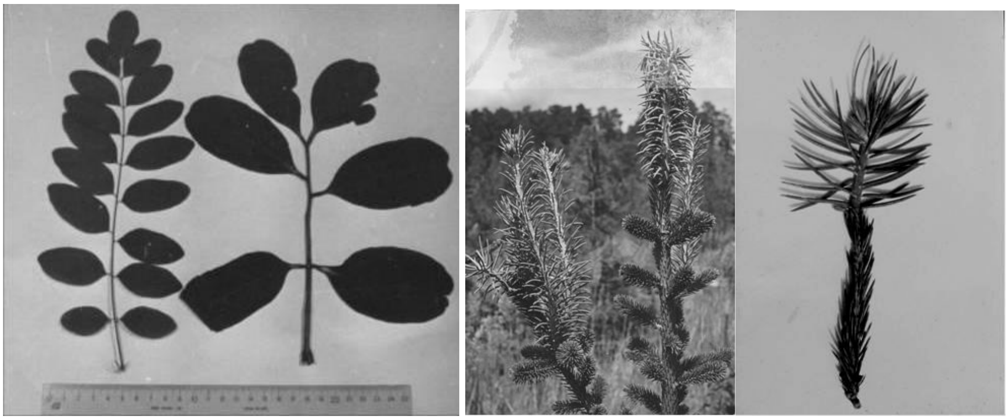
2.2.1. Radiobiological effects of ionizing radiation impact on biota

The biota objects within the 30-km ChNPP Exclusion Zone, including plants, mushrooms, all groups of animals, microorganisms, and viruses, are subject to chronic ionizing radiation effects. This is precisely why a special attention is given recently to the radiation risks assessment with regard not only to mankind, but also to other organisms. An issue of radioecology basic paradigm is based on the statement ‘Once mankind is protected, another biological objects are protected too’ (ICRP 91, 103) is being raised. This is indicated by ample discussion about establishing the levels for radiation standards, search for the ways to develop dosimetry models for biota, as well as establishment of a corresponding working group by the IAEA in 2004 (EMRAS BWG) and launching of the 5th ICRP committee devoted to environmental protection in 2005. The goal of activities carried out during an early period of the ChNPP accident was first of all to protect the public and personnel from exposure. At the same time, biota in the Chernobyl zone was subjected to acute exposure producing radiobiological effects at various structural levels of the biological system, starting with a cell or an organism and ending with an ecosystem. Particularly, such effects, inclusive of lethal outcomes, were registered for coniferous forests in vast areas within the Exclusion Zone [45].

The rates of exposure doses and doses absorbed by organisms vary in a wide range between lethal ones for more radiosensitive organisms and the levels that are close to a natural background of radioactivity. The biota was subjected to the most acute exposure during early months after the accident, during the fallout of radioactive agents onto surfaces of leaves, soil, and water. In due course, the exposure dose rates declined due to radioactive decay of radionuclides and deepening of the latter into the soil. Nevertheless, there are some natural plant-filled sites within the 10-km zone, where even now the exposure dose rates amount to dozens of mR per hour.

The biota objects are exposed to both external sources of γ-radiation and inner sources related to biological uptake and tissue accumulation of radionuclides emitting β-, γ-, and for some even α-radiation. In early months after the accident, the high radiation dose absorbed by the biota objects was due to the hot particles adsorbed by organisms’ surfaces. Uptake of radionuclides through plant root systems was gaining significance in the following years. Currently, cycles of ^{137}Cs and ^{90}Sr, and sometimes of Pu and Am isotopes, became established; and as a result definite differential regimes of irradiation of all living components in biocenoses are being maintained. Various radiobiological effects in all biota components have developed under these irradiation regimes, i.e. when external exposure joins the internal one [46, 47]. An extreme manifestation of the radiobiological response presented itself as a collapse of pine trees and spruces in the area afterwards called the ‘Red Forest’. The two sites, significant in their area, were distinguished in the ‘Red Forest’; the first one is situated along the Western Trace about 5 km away from the ruined reactor, and the second one is located along the Northern Trace on the left bank of the Pripyat River. Dead trees, and not only needle ones but also some broad-leaved species, including for instance birches and black alders, indicate extremely high initial radiation doses in the area. The average values of doses absorbed by the trees exceeded 170 Gy. Various species of both plants and animals have died there.

The Scotch Pine (*Pinus sylvestris* L.) is among the most radiosensitive plants. At the same time, it is a basic forest-forming species in the Exclusion Zone. Thus, studying biota exposure has a direct practical meaning. In 2007, the fifth committee recommended a pine tree to be a reference plant for assessing the radioactive effects on biota [48]. On several sites within the Exclusion Zone (first of all, the RAWTSS 'Red Forest' site and other plantations of pine trees within the ChNPP 10-km zone), the species plant populations indicate suppressed development and mass morphological variations in some trees (Fig. 2.22).



a *b*

Fig. 2.22. *Gigantism of locust (Robinia) leaves (a) (the city of Pripyat) and abnormal limbs and very big needles of common spruce (b) (Novo-Shepelychi forest nursery).*

A precise dependency between the frequency of morphological changes (removal of apical dominance) and exposure dose rate was estimated (Fig. 2.23) making it possible to unambiguously identify that exactly the radiation factor is the reason of the above changes [49, 50].

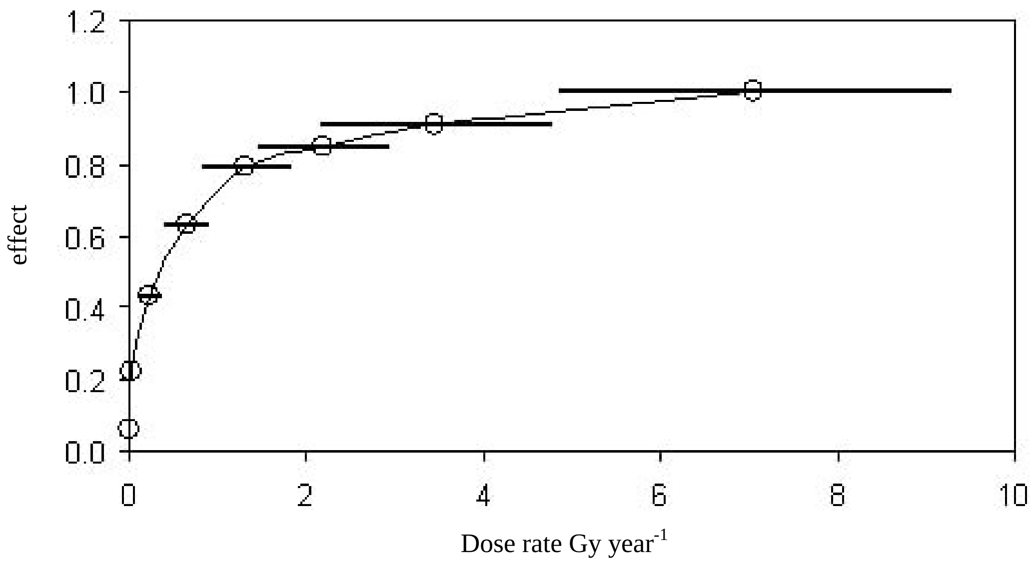


Fig. 2.23. *'Dose rate – effect (frequency of morphological changes)' dependency for the Scotch Pine.*

Also, the dependencies between a cellular-level radiobiological effect (chromosome aberration, DNA damage) and an exposure dose rate were estimated for the Scotch Pine. And high sensitivity of this species to radiation was thus confirmed. The «dose-effect» dependencies obtained for the Scotch Pine are of still broader significance. In case a reference level of terrestrial ecosystems dose rate amounts to 10 μGy hour^{-1} [51], a rather high frequency of effects was observed in the Scotch Pine, which can cause suppression of the population or even dropout of the species out of the ecosystem.

Further effort should be focused on studying radiobiological effects of irradiation on other reference species of the Exclusion Zone's biota. First and foremost, this applies to plant species that are currently not defined within the framework of the above mentioned approaches [48, 51]. The Chernobyl zone provides the corresponding favourable conditions, due to its marked irregularity of radioactive contamination, proximity of soil and climate conditions, and absence of other significant sources for man-caused impacts onto the biota.

Changes in the cenoses within the Chernobyl-affected area demonstrate not only radiation effects, but also a wide range of secondary processes directly related to radioactive contamination of the environment. The extremely significant effects onto biota were caused by stopped economic activity, particularly agricultural one, and resettlement of people from the settlements located within the contaminated area. A sharp withdrawal of anthropogenic pressure on the excluded areas facilitated natural mechanisms of demutation self-recovery and revival of the forest and marsh biogeocenoses typical for Kyiv Polissya.

A recovery of natural vegetation by way of changes in corresponding types of biocenoses, which is gradually resulting in recovery of the forest systems typical of this area, has started on former agricultural lands. In line with the above changes in vegetation types, a food reserve for herbivores and for the first order consumers is being recovered, thus forming a new composition of wildlife species. Certainly, the animal species, which accompany people, have disappeared. However, the biological diversity is expanding due to an increase in a number of the species, which normal development has been suppressed by human activities, particularly hunting. The Exclusion Zone with its actual reservation conditions is a unique area as far as fauna is concerned. There one can run across bird and mammal species registered in the Red Book of Ukraine [52]. Worth noting is successful introduction of such red-listed species as European bison and Przewalski's horse into the Chernobyl Exclusion Zone in 1998.

A gradual recovery of vegetation is going on at the locations, where biocenoses were subjected to drastic changes caused by the initial intensive exposure effects, particularly in the Red Forest. Needle-leaved trees found now their favourable conditions under the crown cover of broad-leaved ones.

All dead pine trees have fallen within the zone of lethal damage, where no decontamination activities were carried out in 1986. The broaleafed trees species have fully recovered their state. Typical deafforestation groups involving agrestals meadow species, moss, lichens, have formed on dead stand sites. Dense patterns of self-seeding birch, aspen, and buckthorn have appeared.

20–85 % of pine trees planted within the sublethal damage zone are well preserved. Populations of self-seeding broad-leaved species started to form there. The survived rare pine specimens have a broad head, which is not typical for the plantations of trees. The gramineous and ruderal cenoses prevail in the ground cover. However, the typical components of pine forests were preserved; and a moss layer is now at the same old place. In recent years, non-uniform self-sown pine trees have appeared among the nurse-wood at the Red Forest border.

Studies of the Exclusion Zone vegetation followed the Chernobyl accident revealed a sufficient number of species in phytocenoses. Along with successful development of populations of vascular plants, registered in the Red Book of Ukraine (2009), their approximate 10% extension is observed. The Institute of Botany of M.G. Kholodnyi of the NAS of Ukraine registered over 40 species, mostly adventive and ruderal, that are new in the area [53]. Over 40 red-listed plant species were found in the zone of absolute resettlement in Zhytomyr Oblast (province). These included the region-largest populations of perennial plants, new lichen species, lichenphyllic fungi [54], macromycetes, bryoflora taxons [55].

The increase in ecotopic diversity has logically resulted in the extended diversity of species with regard to both flora and fauna of the Exclusion Zone. *In 25 year after the Chernobyl NPP accident, no strong hazards at the present state in flora and fauna were detected even in highly contaminated areas, exclusive of some sites within the Exclusion Zone, i.e. under the former Red Forest and some other significantly smaller sites* [56].

Mycobiota. *Generally, mycobiota, particularly the soil one, was subject to melanization, i.e. mass outbreak of melan-comprising radioresistant species.* In radioactively contaminated area, the melanin enriched fungal strains have formed in the fungal complexes in some myxomycete populations. Exposure effects and earlier stages of the accident are reflected in melanization of microflora. The ability to actively destroy 'hot particles' is inherent to the mycobiota.

Biota of water bodies. Biota in the worst contaminated water basins is characterized by a high level of radioactive contamination. Fish tissues accumulate not only ^{137}Cs but also ^{90}Sr, as well as Pu and Am isotopes, thus causing a damage of reproductive tissues accompanied by a decreased quantity of some species, particularly spike and bream. The highest values of specific activity in fish were registered for predatory fish. A nearly ten fold increase of cells with chromosome aberrations, if compared to 'clean' ones, is observed in the above water basins. Quantity of aberrant cells was increasing in mantle medium of the molluscan shellfish [57].

Suppressed development of the club rush (*Scirpus*) is observed; it is due to a severe deterioration caused by parasitic fungi and haloforming ticks. However, seed production is subjected to drastic decrease missing out the plant species out of the flood plain cenoses. The high exposure doses certainly reduce plant resistance to the above affections and parasites.

The biota auto-rehabilitation processes occurring in the landlocked waterbasins of the Exclusion Zone are extremely slow.

Amphibian and rodents. Increase in cytogenetic abnormalities, i.e. metaphases with Robertson interchromosomal fusion, as well as aneuploids are discovered in bone marrow cells of myomorphic rodents subject to reproduction in biocenoses characterised by elevated radioactivity levels. The myomorphic rodents demonstrated that a share of radioresistant animals is gradually increasing in natural population of the Red Forest. Therewith, the higher radioactive contamination level is the higher is the radioresitance survival.

Radionuclides are depositing in bone tissue of amphibian and rodents living within the Exclusion Zone thus involving defective processes of differentiation and specific functioning of their osteogenetic cells. This causes development of dystrophic aberrations of epiphyses and metaphyses in spongy bones as well as separation of bone plates. The adaptive, compensatory, and pathological changes of this kind progress as an animal age increases.

Cattle. The following are observed in the HL generations that have absorbed doses of about 0.8 $Gy \cdot year^{-1}$ (from ^{137}Cs) during the first year after the accident: a) decline in the birth rate and excessive mortality of new-born calves; b) disorders in equiprobable inheritance of specific alleles, i.e. elimination of some alleles and predominant inheritance of the others; c) a genetic pattern of parental generation, which is typical for the dairy stock, declines towards less specific forms in subsequent generations; d) under the conditions of low-dose exposure, changes in a generation's genetic pattern coincide with reactions of the population to extreme impacts produced by factors of another, non-radiation, nature. Therefore, *the major response of an animal body to chronic effects of ionizing radiation corresponds to a selection of new gene combinations in subsequent generations* [51].

Viruses. As per observations, the frequency of PVX, TMV, PVY viruses detection is higher in the radionuclide contaminated area of the Chernobyl zone. A significantly higher detection rate for plant viruses was registered for vegetation in the 30-km zone. Apparently, vegetation of this zone can act as reservoirs (or hosts) for viral pathogens. It is noteworthy that this study supports the hypothesis that *radionuclide contaminated ecosystems can act as 'hotbeds' of viral infections and sources of epidemics of plant viral diseases*. The main reason for such hypothesis may be a 'narrowing' in the diversity of the plant species able to grow in contaminated soil. Another reason may be the less efficient mechanisms of plant natural resistance to viral infections, as demonstrated for maize and cereal crops that have been experimentally grown within the 30-km Exclusion zone. Whatever the reasons are, they may produce a more efficient spread of viral infections, since plants of a contaminated environment are potential 'hotbeds' of infection.

Soil bacteria. Currently, composition of microflora in biocenoses started to recover gradually. During the first post-accident decade, significant changes in microorganism species structure were observed in various habitats. Particularly, pseudomonades, actinobacter, cellulose-fermenting, nitrifying, and sulfate-reducing bacteria suffered losses [58]. The decrease in biomass of these bacteria in soil caused reduced transformation intensity in organic substances. Also, the bacteria distribution along soil profile has changed, i.e. a particularly sharp decrease in both, number of species and total biomass of the bacteria was observed in the uppermost layer of soil. Only at a depth of 20 cm, the bacterial composition closely approximated the reference values. It was demonstrated that under the conditions ensuring high levels of a substrate radioactive contamination, a rate of bacteria mutant formations increased thus indicating a possibility of more radioresistant configurations emergence.

Consequently, *the Exclusion zone's high-level radioactive contamination has resulted in some extent on biological diversity of species and biocenosis but with time processes of recovery of flora and fauna have begun and self-purification of ecosystems in the excluded area for radioactive contamination are continued being accompanied by biodiversity alterations.*

Radiation effects, being traditionally regarded as a negative ecological factor, have produced a significantly less impact than an almost complete elimination of anthropogenic pressure.

However, obvious are manifestations of the reactions indicating the signs of radiation injury to some plant and animal species. The cytogenetic and genetic effects resulting from genomic stability disturbances are of particular significance; they are the reason of mutations, stratification of populations, reducing in reproductive capacity, and loss of some species.

This fact is not inconsistent, as cumulative radiobiological processes are going on over many generations thus allowing to assume that the present realization of long-term effects may be incomplete. Moreover, negative effects of irradiation are opposed by a strong system of recovery processes, security system of some organisms and biocenoses on the whole potentially ensuring security of the biocenoses autochthonous composition.

In particular, the radionuclide contamination of ecosystems produced intensification of microevolution changes in populations of some species, probably due to a change in the norm of reaction to environmental conditions. Thereby, the two directions of this process take place in biota of the Exclusion zone: adaptation of species to new conditions and stabilizing selection. The first one consist of an augmentation of the rate of variability by means of epigenetic (and consequently, genetic) processes that manifests itself as advanced capabilities of adaptation to unfavourable living conditions with further shift of the reaction norm subject to the conditions, confirm a selection of specimens, and finally populations of species, the most adapted for radiation pressure (i.e. radiation adaptation). The second direction is related to the phenomenon of somatic radioadaptation. This effect is verified by a reaction of small rodent populations that declares itself as a relatively low level of variability with a preservation of corresponding sustained quantity allowing a population to retain its features.

2.2.2. Addressing water supply problems in population centres

Radionuclide-free water supply to the residents of Kyiv and other cities located on the banks of the Dnipro River is among the most important tasks that have emerged after the ChNPP accident. Intense radionuclide fallout at the Dnipro River water intake caused a sharp increase in radioactive contamination level of the river. In May 1986, the average decade values for ^{90}Sr concentrations in the water to the north of Kyiv (the village of Nedanchychi) amounted to ≈ 100·10–10 $Ci{\cdot}l^{-1}$, and for ^{137}Cs they were still higher [59]. Erection of coastal systems to protect rivers from storm and spring radionuclide wash-offs as well as construction of entrapment dams, bottom separators, and barriers in the beds of the Pripyat River and Dnipro River turned out to be ineffective. Under those conditions, provision of drinking water supply using the contamination proof groundwater was the most reliable means to protect people [60, 61].

Just then, according to the proposals set forward by the Ukraine’s NAS commission, the government made a decision to urgently drill wells with the objective to ensure emergency water supply to the people of Kyiv and other population centres. Later on this initiative has developed into construction of well-rooms proved to be the most important source of high-quality drinking water for the people of Kyiv. While addressing the problem of the cities water supply, the role of groundwater well-rooms became particularly evident in 1991, when ice gorges tuned up near Yaniv Bridge over the Pripyat River in Chernobyl during ice motion. Notwithstanding a significance of the problem, the municipality of the city of Kyiv closed the most of well-rooms in 2008.

While analyzing the Chernobyl accident aftermath in terms of water supply to cities, as early in 1987 scientists insisted on acceptance of some conceptual principles to ensure a reliable water supply to cities with due regard for various potential emergencies:

drinking water supply consisting of mostly groundwater, and particularly establishment of an echelon water supply system having various sources in the cities, where groundwater resources are scare in terms of the cities’ existing and prospective needs. Supply of groundwater in such systems should take the maximum possible priority in overall water supply;

exploration and development of emergency groundwater supply sources used in case of surface water intakes cut-off are essential for the cities, where water supply is completely or partially based on surface water;

during construction of new residential districts, a preference should be given to self-contained groundwater supply sources.

Over the last 15–17 years, absolute and fractional (if compared to surface water) decrease in groundwater uses for the public water supply is observed. However, a large untapped reserve of the groundwater discharge is available. Undoubtedly, such actions will not be to the benefit of reducing a public hazard and are unacceptable.

Certainly, specific assessments of groundwater intakes performance potential under various running conditions, under emergency conditions of various types and durability, under complete or partial cut-off of the groundwater supply, should have been accomplished in the cities having mixed water supply a long time ago. Special hydrogeological studies of useful groundwater storage should be carried out, and emergency groundwater intakes for public water supply should be constructed in the cities having only surface water supply. A special nominal operation mode for such water intakes should be developed and implemented [61].

Thereby, *there is an urgent necessity to carry out a specific assessment of groundwater supply under various emergency conditions*. The outcomes of such assessment should underlie development of the activities targeted at establishment of a reliable emergency water supply system. Only then will the Chernobyl lesson concerning water supply to the cities be learned.

2.2.3. Farming in radioactively contaminated areas

The International Conference entitled «15 Years after the Chernobyl Accident. Lessons Learned» recognized the ChNPP accident to be a «communal rural accident» that has stricken out customary way and mode of life of the affected rural population and changed people’s links with the environment. In Ukraine only, over 8 million hectares of land in 74 rayons (districts) of 12 region (provinces), where lived over 3.2 million people including 600 thousand children, were contaminated with radionuclides as a result of the Chernobyl disaster.

Consequences of the accident turned out to be extremely severe for Polissia population, i.e. northern areas of Volyn, Zhytomyr, Kyiv, Rivne, and Chernihiv oblasts. This area was subject to the worst radioactive contamination resulting from the ChNPP accident. In these areas, agriculture was the major sector of regional economy. Natural landscapes with meadows, pastures, and forests yielded a significant portion in the product. And the public exposure dose was mainly formed due to the consumption of locally produced food. In recent years, these statements are still true and even more complicated against the background of the nation-wide economic collapse that followed the accident. In 25 years after the accident, a percentage of private farms in a total volume of gross agricultural product are exceeding 75 % for the above areas. However, approximately 60 % of meat and 75 % of milk are produced on private farms. Eating these products stipulates formation of up to 90 % of the public internal exposure dose.

The products are used by the producers and enter Ukraine's consumer market. There is no doubt that a need in countermeasures for the individual farms in critical population centres must be completely satisfied. In fact, in recent years, only about 0,3 % of the annual funding envisaged for the Chernobyl disaster elimination in Ukraine was actually spent every year on the agricultural countermeasures that allow to get «clean» products and prevention of public exposure above the established limits. Furthermore, financing priorities are not followed. The disequilibrium in financing of agricultural countermeasures existing in Ukraine inhibits the elimination of the purely accidental origin consequences (production and intake of products that do not meet state normative requirements, increase of public exposure dose), and contributes to maintenance of social and psychological tension in regions affected by the ChNPP.

According to Ukrainian Constitution Clause16 «...elimination of Chernobyl catastrophe consequences, the global catastrophe, genetic conservation of Ukrainian nation is the duty of the State…» the state must provide compensation of people for production being not in line with requirements of PL-2006. *Cost of the protective measures that will allow today of this problem, but also significantly reduce of exposure dose at present is almost 20 times less than the cost of contaminated products*.

Internal passport average annual effective dose (AAED) in Ukraine used in decision making and optimization of protective measures process is calculated by «Methodology–96» [62] based on measurements of ^{137}Cs average specific activity in milk and potatoes. Over 15 years from the date of this methodology approval, structure and volume of agricultural production and consumption of major foods have changed significantly. Moreover, as a result the lack of work in the region, milk became practically the major marketable product for the population, which resulted in reduced consumption of it by the producer. The above caused considerable differences, up to 45 times in some settlements, in internal AAED estimates made by the «Methodology–96» and measurements based on WBC data [63].

The distribution of land areas by radioactive contamination. In June 1986 the Method of cultivated land radioecological monitoring was developed with assistance of Agronomical and Agrochemical Departments of the USSR State Agricultural and sanitary – epidemiological service. The monitoring was performed by taking an average representative sample for each of 445 administrative regions of Ukraine. The essence of it was in taking individual soil samples following the method of an envelope: 5 samples in each corner and at the intersection of envelope diagonals that covered five fields in each of the 25–28 farms of a region. Samples were accumulated and averaged in a damp lorry body, then an aliquot was taken for measurements. Specific ^{137}Cs and ^{90}Sr activity was measured in soil by 11 scientific – research institutes and 29 regional zonal agrochemical laboratories under centralised metrological support. By this means rather accurate map of cultivated lands average contamination levels by long-lived radionuclides was obtained in 10 days reflected almost all the spots with increased density of fallout. This provided an opportunity to initiate protective measures.

As a result of such monitoring, it was found that the area of agricultural land contaminated by the Chernobyl accident with contamination level of 37 to 185 $kBq \cdot m^{-2}$ (1–5 $Ki \cdot km^{-2}$) was 865 hectares, about·30 % of which are hayfields and pastures. Area of lands with contamination density from 185 to 555 $kBq \cdot m^{-2}$ (5–15 $Ki \cdot km^{-2}$) equals 90 thousand hectares, 50 % of which are meadow – pasture lands. Approximately 15 % of the total area of contaminated agricultural lands and almost half of hayfields and pasture in the Rivne and Volyn oblasts are on acid organic peat soils that are characterised by intense ^{137}Cs migration within the «soil – plant» system. Moreover, mineral soddy – podzolic soils that are even the most common for the Polissia are insufficiently provided with nutrients and soils with pH < 5 make up about 10 % of contaminated lands and about 20 % with potassium content lower than 8 mg per 100 g of soil. On such soils radiocaesium transfer factors in the chain «soil – plant» in 10–100 times exceed corresponding values of clean mineral soils.

The system of products radiation monitoring. Since 1991 the UIAR developed and provided for production application the complex of normative documents on sampling and methods of radionuclides content measurement in raw materials, food and environment. First of all among the above the interagency methodical instructive regulations «System of food and agricultural products quality control in the event of a large radiation accident» which became the basic procedure methodical paper for this issue [64]. Over the last 5 years the amount of agricultural product samples with ^{137}Cs and ^{90}Sr radionuclides content above allowable levels of less than 2 % and annually decreases. As of today, 53 % of products exceeding PL-2006 present the share of forest products, 40 % – milk, 3–4 % – vegetables and meat.

Dynamics of radionuclides inclusion in food chains and prediction of radiation situation in the contaminated territories

Levels of agricultural products contamination by radionuclides were determined not only by soil contamination density, but also their type and agrochemical properties. A significant influence of environmental conditions (landscape and soil type) on rates of caesium intake by population is reflected the data of the nationwide passportisation of Ukrainian settlements [65]. In the the first year after fallouts, when aerial contamination of vegetation was prevailing, shares of external and internal exposure in the total dose of population exposure were equal in two Ukrainian region with equal contamination level of soil, but differing soil properties. For the second year, when the major way of radionuclides intake in plants was soil, the contribution of internal exposure dose on organic peat soil was 10 times higher than on mineral chernozem. Moreover, the value of total annual effective dose of population exposure in the year of fallouts was almost the same on the both types of soil, but for 25 post-accident years is almost 10 times higher on peat soil, than on chernozem. These data are evidence of the significant role of ecological factors in formation of population exposure dose after the accident at the ChNPP.

A large-scale production radioecological monitoring of agricultural lands was started from 1987 in 33 farms of 4 of the most contaminated regions of Ukraine with aim at clarify radiation situation and prediction of agricultural products contamination and countermeasures planning. The monitoring scheme covered wide spectrum of soil and climatic conditions of agricultural production typical for the zone contaminated by Chernobyl emissions varying in soil contamination density up to 100 times for ^{137}Cs and 10 times for ^{90}Sr. 16 crops forming the basis of food ration of animals and people, which contribute to intake of the major part of radionuclides by an organism, were studied during the monitoring. The monitoring takes place up to date, though the volume of it has been reduced.

One of the basic mistakes made in the course of Chernobyl accident consequences elimination was acceptance of limit contamination density (LCD) of soil as the radiation hazard criterion, but the exposure dose of man. The value of 555 $kBq{\cdot}m^{-2}$ was chosen as the ^{137}Cs LCD. The above and insufficient number of in-process dose measurements resulted in wronge estimates. This was most display on the territory of Polissya. Population exposure dose was higher in settlements at the distance of 300 km from the ChNPP with contamination levels up to185 $kBq{\cdot}m^{-2}$, than near of accident epicentre with contamination density exceeding 555 $kBq{\cdot}m^{-2}$ [66–68]. Such actions of the government led to that milk and meat contamination standards were exceeded even on officially «prosperous» territories by soil contamination levels.

Only in 1988 according to the data from the Ukrainian Academy of Agricultural Science regarding rather high of radionuclides transfer factors from soil to milk the Verkhovna Rada of Ukraine included

Rivne and Volyn regions in the number of affected regions and in these territories began to carry agricultural countermeasures. Unfortunately, the countermeasures were not carried out over the first two most critical years though recommendations on their implementation had already existed [69, 70]. Therefore the *major parameter for hazard assessment and taking decision on countermeasures implementation must be total population exposure dose*, and information about soil contamination density is only one of its component along with ecological, demographic, and other characteristics of the territory.

Absence of the «Chernobyl» phenomenon concerning high radiation hazard of «cleaner» areas as against contaminated areas, and increase of radiation dose with time while soil contamination density decreases, was supported by the based on monitoring data linear dependence between radionuclide specific activity of vegetation SA and particular soil type contamination density D. The linear dependence between SA and D was determined back in 1967 based on data from the East – Ural Radioactive Trace [71]. Unfortunately, many of radioecologists diverged from this postulate after the accident at the Chernobyl NPP. The main reason for mistakes made by many of researches was first of all noncompliance with the condition of soil identity with different values of D. Differences in soil properties within the territory contaminated as a result of accident at the ChNPP were so large that different types of soil were placed into the same group (sample) of soils with differing D values based on the criterion of «name on large – scale maps». The proved linear dependence between SA and D confirmed that *values of radionuclide transfer factors do not depend up on soil contamination density for all species of crops on all types of soil*, and products contamination level, as well as population exposure dose is not only the function of soil contamination density, but also ecological specifics of the territory. Results of such work enabled determination of new values of soil radionuclide LCD for particular species of crops and even sorts based on particular soil types.

Data array of many thousands with equal distribution of data among crop and soil types enabled tracing of radiation situation dynamics in contaminated agricultural lands and developing models for predicting radionuclides accumulation by agricultural products. It was determined that values of RN transfer factor TF from soil to agricultural products decrease with time. Moreover, value of ^{137}Cs TF from soil to crops changed very quickly during first 3–5 years, and slowly during the following years, ^{90}Sr – steadily during the whole period after fallout. Determination of radionuclide TF value in the year of fallouts was not possible, since vegetation was contaminated not only through soil, but also airely. Radionuclide TF in the year of the accident were obtained by means of dynamic curves extrapolation (Table 2.5).

Table 2.5.

Values of radionuclide transfer factors TF(t=0) extrapolated at the fallouts, $kg^{-1}\cdot m^2$ ($\delta \leq 25$ %)

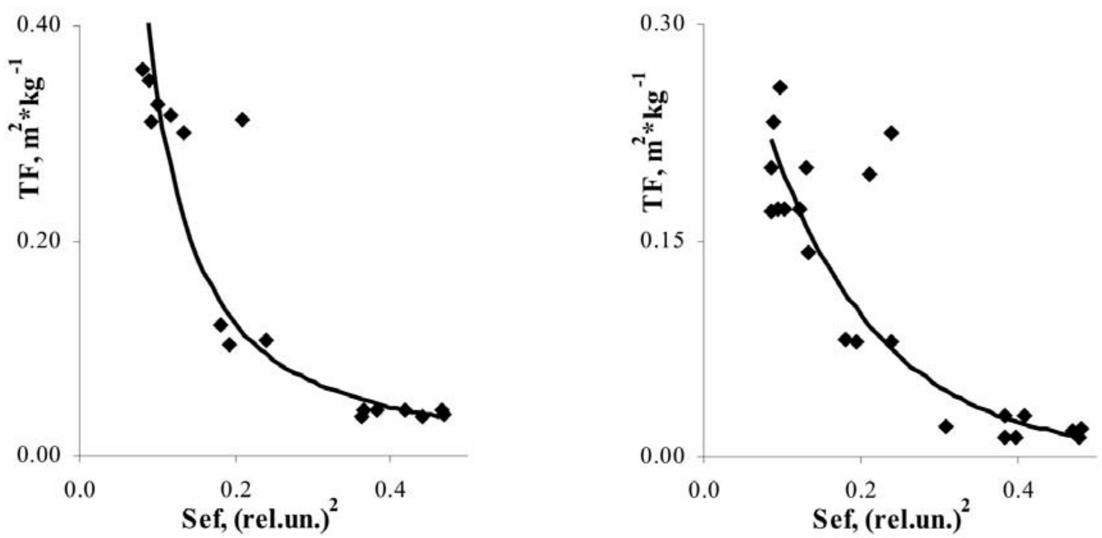
Crop group	**Peat bog**	**Soddy-podzolic**		**Grey forest**		**Chernozem**	
	^{137}Cs	**^{137}Cs**	**^{90}Sr**	**^{137}Cs**	**^{90}Sr**	**^{137}Cs**	**^{90}Sr**
Hay of natural grasses	223	29		10		–	
Hay of sown grasses	95	5.8		4.9		3.3	
Green forage *maize, lucerne, clover*	39	3.8		1.9		1.6	
Vegetables *cabbage, tomatoes, cucumbers*	–	2.9	0.52	2.0	0.14	1.2	0.033
Tubers, roots *onion, beet, potatoes*	10	1.6	0.79	0.63	0.23	0.60	0.10
Cereal grain *winter wheat, barley, rye*	7.3	0.89	3.5	0.66	0.72	0.36	0.32

Over the whole post-accidental period ^{137}Cs was for the most part accumulated by natural grasses, less by sown and forage grasses, vegetables, tubers and roots, and the least ^{137}Cs was accumulated by cereal grain. Differences in caesium TF values between grasses and grains are as follows: for organic soils 50–100 times, for mineral 5–30 times. ^{90}Sr was accumulated the most by grain crops, 3–4 times less by tubers and roots and up to 10 times less by vegetable crops. Knowledge of differences in values of radionuclide TF from various types of soil (several soil types can occur within one agricultural farm) to agricultural crops *enables control of crop contamination levels via organizational countermeasures, i.e. crops selection and determination of their place in crop rotation, especially forage crops.*

Cereals, tubers, roots and vegetables have very low values of TF RN from soil. Besides, these crops are traditionally grown on the most fertile soil types and most often with the use of fertilizers. Therefore, in the remote period after the accident the content of radiocaesium in all crop productions did not exceed allowable levels within almost the entire territory. However, using the population to grow crops, mainly potatoes, organic or soddy – podzol sandy and sandy soils, the specific activity of ^{137}Cs in products may reach the level of PL-2006 and sometimes exceed it. The above can be typified by cases, registered over the recent years, of exceeded allowable content of ^{137}Cs in vegetables and potatoes grown on peat soils of Gnoine area in villages of Rokytnivskyi and Dubrovytskyi rayon of Rivne oblast. With soil contamination density about 100 kBq·m^{-2} specific activity of radiocaesium in vegetables and potatoes exceeds PL-06. Therefore, *for countermeasures be carried out necessary information on soil properties and density of radionuclide contamination of soil for optimal placement of particular crops and and use of predict date of contamination agricultural products in order to apply countermeasures.*

The values of ^{137}Cs and ^{90}Sr transfer factor to all agricultural crops differed much for various types of soils both during the year of fallouts and following years. For all crop species on peat – bog soil ^{137}Cs TF are 7–15 times higher than on soddy – podzolic, 10–20 times – on grey forest, 15–30 times – on chernozem. The highest ^{90}Sr TF values are on soddy – podzolic soil and almost 5 times lower on grey forest soil and 10 times – on chernozem.

Such significant differences demonstrate sensitivity of ^{137}Cs and ^{90}Sr TF value to plant grow type of soil that, in its turn, has certain agrochemical properties. Usage of monitoring data on radionuclide TF and agrochemical properties of soil enabled development of the method complete estimation of soil properties Sef. The CESP is based on assuming soil as a three-phase system with the following main characteristics: pH of soil solution reaction (liquid phase), organic matter content (OM) and sum of absorbed bases (SUB) or content of exchange potassium (K_2O). The CESP is graphically defined as a sectional area of three-dimensional space Sef – a triangle, corners of which lie on pH, OM, SUB axes [73, 74]. This assessment allowed of defining the TF relation with soil agrochemical properties that directly affect radionuclide accumulation by agricultural crops (Figure 2.24).



a *b*

Fig. 2.24. *Dependence of ^{137}Cs TF in crops from the complete estimation of soil properties Sef based on the OM – pH – SAB triad (1991):* a *– cabbage;* b *– potatoes.*

The defined dependence between radionuclide TF in crops from Sef is of exceptional importance, since it enables accurate calculation of soil fertilising doses aimed at obtaining product with predicted lower RN content than for the reclamation activities.

Over the post-accident period values of radionuclide TF to crops has decreased up to 100 times on organic soils, by 10–30 times on mineral soils for ^{137}Cs, and up to 3 times on mineral soils for ^{90}Sr. An important factor that significantly changes the radiation conditions in contaminated areas is immobilisation of radionuclides via a soil absorption complex. Furthermore, due to this process, periods of half-reduction of plant radionuclides transfer factors are considerably shorter for ^{137}Cs and ^{90}Sr, than periods of radionuclides half-decay.

Analysis of the numerous monitoring data array on levels of agricultural crops radionuclide contamination and main agrochemical properties of soil allowed to build a kinetic model in order to predict radionuclides accumulation by agricultural crops and further plan implementation of scientifically substantiated countermeasures [74–76]:

$$^{137}\mathrm{Cs}: \quad TF_{Sef,j} = TF_{0,j}(0) \cdot e^{-\lambda_j \cdot Sef} \begin{Bmatrix} (1 + 0.031 \cdot \ln(Sef)) \cdot e^{-0.31 \cdot (1+Sef) \cdot t} + \\ + (-0.031 \cdot \ln(Sef)) \cdot e^{-0.055 \cdot (1-Sef) \cdot t} \end{Bmatrix} \tag{2.1}$$

$$^{90}\mathrm{Sr}: \quad TF_{Sef,j} = TF_{0,j}(0) \cdot e^{-\lambda_j \cdot Sef} \cdot e^{-0.096 \cdot (1-Sef) \cdot t} \tag{2.2}$$

Parameter values of the kinetic model of radionuclide transfer from different types of soil to agricultural crops, obtained by means of using Sef, are presented in papers [74, 76].

The model was verified based on data from the French – German Initiative Database FGI 3a, containing over 6 thousand «soil – plant» pairs obtained as a result of agricultural sector monitoring in the territories of Byelorussia, Russia and Ukraine contaminated as a result of the Chernobyl catastrophe. An accuracy of radionuclide TF model calculations for FGI data was about 30 % even in cases of countermeasures implementation and changed agrochemical properties of soil. Therefore, in the case of radioactive fallouts, for accurate predict of agricultural products contamination, it is recommended to use model of radionuclide behaviour in the «soil – plant» system considering the complete estimation of soil properties.

Since early 90-s products contaminated above the state hygienic standards has not been produced in the public sector of Ukraine [77]. This was enabled by thorough radioecological monitoring, radiation control of agricultural products and implementation of the countermeasures system on collective farms; the measures were conducted under the section «Agricultural Radioecology» of the «Program of Minimization of ChNPP Accident Consequences» over the first 10 years after the Chernobyl catastrophe.

In last years, due to economical difficulties in the country and especially in radioactively contaminated regions there were cases of PL-06 exceeded on radionuclide content in agricultural products produced in the public sector. For instance, in 2009 double permissible content of ^{90}Sr was registered in food grain produced on poor soddy – podzolic sandy soil of Ivankiv rayon of the Kyiv oblast in the area of voluntary guaranteed resettlement (zone III) adjacent to the ChNPP Exclusion Zone. There are the two following reasons for this fact. Firstly, in the initial ^{90}Sr radioactive fallout on this territory was in the matrix of particles of irradiated nuclear fuel and was not available for plants. Fuel particles (FP) dissolved with time and ^{90}Sr transferred into soil solution and its inclusion in the migration processes. Secondly, last liming of acid soils in the Ivankiv rayon financed by the Chernobyl foundation took place in 2006 on the area of 300 hectares and, as required, more than 7 thousand hectares. Since 2008 soil on farms of the rayon was not contribute to soil the organic fertilisers, and mineral fertilizers was conducted at only for 63% of areas. Furthermore, dosage of mineral fertilisers was not met, namely: given that 150 $kg \cdot ha^{-1}$ is the required dose, actual dose was only 25 $kg \cdot ha^{-1}$.

It should be pointed out that ^{90}Sr specific activity in milk, vegetables, and fruits is currently with PL-2006 requirements and does not cause concern practically on the entire territory of Ukraine outside the Exclusion Zone.

In late 90-s years the worst agricultural scenario was implemented on radioactively contaminated areas: collective and state farms were liquidated, agricultural lands were shared. In the process of land sharing in late 90-s population received lands for grazing and haying located in the areas being the most critical in terms of radionuclides accumulation. While Item 3.22 of the «Concept of agricultural production on contaminated territories and their comprehensive rehabilitation for the period of 2000–2010» states that «...safe use of such areas may be guaranteed only if they are owned by a collective farm or are in government reserve» [78]. Consequently, bulk of hayfields and pastures are located on hydromorphic organogenic and soddy-podzolic sandy and sandy-loam soils, most often located in wet depression and floodplain rivers with high groundwater level. Since of ^{137}Cs transfer factors from such types of soil to vegetation are rather high, forage of the population is characterised by significant level of radioactive contamination. Consequently, large number of private households (PHH) still produce milk and meat products with radionuclide content far exceeding the established state standards.

In 25 years after the accident there are less than 20 settlements in Ukraine, where ^{137}Cs specific activity in milk and meat is constantly 3–10 times higher than PL-2006, and less than 100 settlements, where the level of radioactive contamination of milk may exceed PL-2006 in approximately one third of PHH.

According to prediction of agricultural products contamination, as a result of significant slowdown of autorehabilitation processes, levels of their radioactive contamination and, consequently, internal population exposure doses of «critical» settlements will reduce very slowly with the period of half-reduction about 20–30 years without countermeasures (Fig. 2.25).

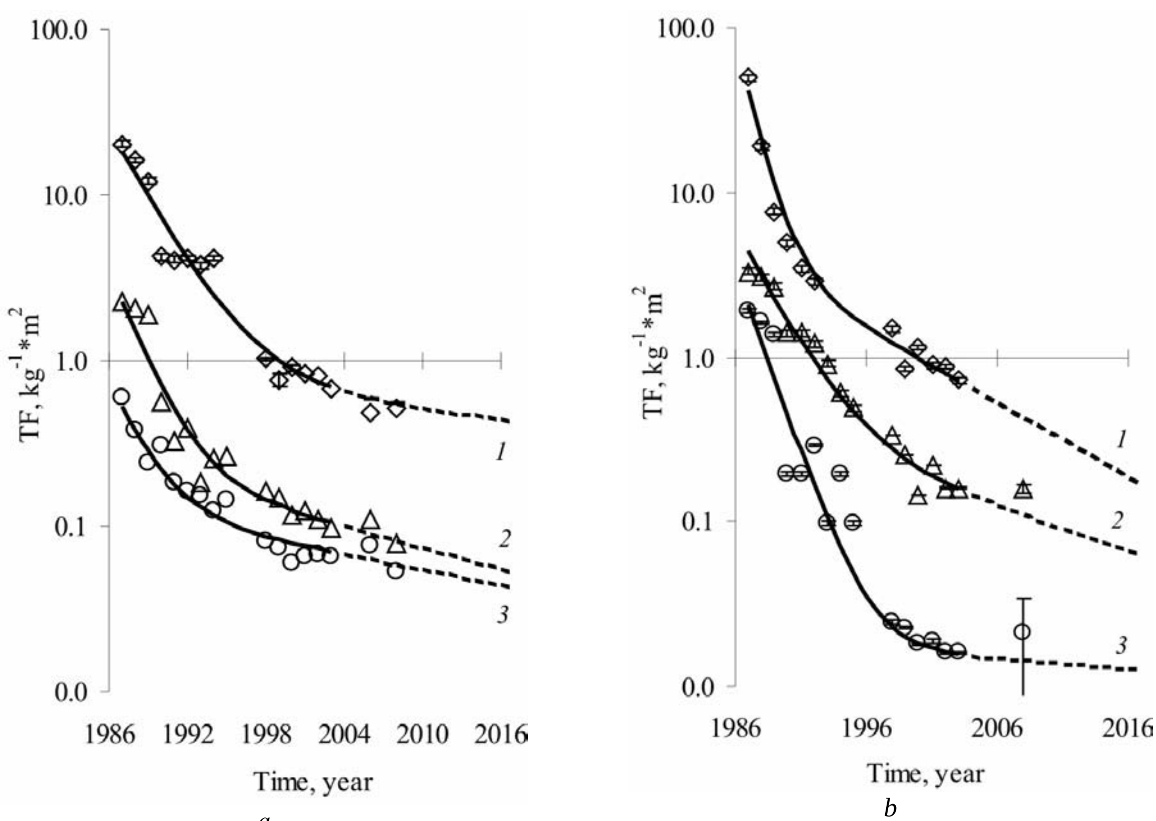


Figure 2.25. *TF ^{137}Cs dynamics: a – on soddy – podzolic soil for: 1 –hay of natural grasses, 2 – cabbage, 3 – barley; b – hay sown grasses on: 1 – peat – bog soil, 2 – soddy -podzolic, 3 – chernozem (TF predict values are in dotted lines).*

Accordingly, countermeasures are the basic methods for further rehabilitation of territories affected by the Chernobyl catastrophe.

Agricultural countermeasures

Countermeasures implemented during the initial period after an accident are of higher dose efficiency, since allow to prevent formation of a greater collective dose comparing to a later period. It is due to that radionuclide concentration in products significantly reduces over time due to processes of radionuclides immobilisation in soil. *Radiological efficiency of countermeasures does not change over time and enables reduces the radionuclide concentration in products in the same number of times in any period after the accident.* Countermeasures cost is also equal during various periods after an accident. Therefore, economic efficiency of one and the same countermeasure, as well as dose efficiency, reduces with time after radioactive fallouts. Accordingly, adherence to priorities is of critical importance, first of all, direction of financial resources for agricultural production, consumption of which to contribute the intake of major part radionuclide by human organism.

Failure to meet priorities of countermeasures is the major drawback of the elimination of consequences of accident at the ChNPP. Works were often carried out simultaneously in many directions in spite of the lack of funds. This resulted in an incomplete implementation of required measures and considerable decrease of investments efficiency. The project «Setting Priorities within the Accident Consequences Minimization Program» was implemented under EU support aimed at resolving the task of foreground performance. Project results were praised, but were scarcely implemented during the first year and completely forgotten later. Absence of a prioritization and progress control system became the reason for many deficiencies in the implementation of the Accident Consequences Minimization Program (CMP). A perfect *example of failure to adhere to priorities in the course of protective measures is presence of almost 50 critical settlements with milk contamination levels exceeding PL-2006 even in 25 years after the accident*.

Plant cultivation

Plough-land. Together with scientists from research institutions and other UAAS industry institutions, including UIAR was developed recommendations and regulations – guidelines for agriculture in conditions of radioactive contamination for different levels of government: national, regional (5 regions), regional and level of private sector [67]. These recommendations were reprinted in various periods after the accident as radiation environment was changing on contaminated agricultural lands.

Since soil represents the basic source of radionuclides inclusion in the food chain, protective measures were aimed at decreasing their availability for plants via changing soil properties. The countermeasures known before the Chernobyl accident [70] were verified during the post-accidental period and adapted to the ecological conditions of contaminated areas (Table 2.6).

Table 2.6.

Decrease of radioactive contamination of plant cultivation products with countermeasures, times [66, 67]

Countermeasure	Mineral		Organic
	^{137}Cs	^{90}Sr	^{137}Cs
Liming, 4 – 6 t·ha^{-1}	1.5–3.0	1.5–2.6	1.5–2.0
Treatment with NPK	1.5–2.0	0.8–1.2	1.5–3.0
Manure, 50 t·ha^{-1}	1.5–3.0	1.2–1.5	–
Liming + NPK	1.8–2.7	–	2.5–4.0
Zeolites	1.5–2.5	1.5–1.8	–
Ploughing, 35 – 40 cm	8.0–12	2.0–3.0	10–16

Liming of acid soils and additional mineral fertilising were among immediate measures within the zone affected by accident at the ChNPP. It was determined that mineral fertilising per the recommended optimal ratio of N:P:K 1:1.5:2 is an effective method of increasing yield and decreasing ^{137}Cs contamination of agricultural crops by 1.5–3 times. Fertilising dosage depends on crop species and soil properties. For instance, mineral fertilising rate for potatoes is twice lower as against other vegetable crops.

Countermeasures implemented during 1986–1993 resulted in above 1.5 million ha of contaminated soil reclaimed in Ukraine. Liming on contaminated territory along with fertilisers allowed of 2.5–5 times decrease of radionuclides content in products. Due to economical difficulties in 1994–1996 volumes of these works were greatly reduced, which resulted in negative balance of nitrogen, phosphorus and potassium in soils, which lead to increased radioactive contamination of crop production.

During 1996–1999 there was an attempt to use locally produced mineral sorbents in order to save money on meliorants transportation. 723 thousand tons of sapropel and peat compost were used in units of the Rivne oblast. These measures were not effective enough, as radionuclides immobilisation processes slowed down considerably at that stage as against the first years after the accident.

Despite of numerous reductions of the value of permissible levels of radionuclides content in food and raw materials for them, the completed protective measures allowed of many times decrease of volume production exceeding PL compared to the first post-accidental period and on the average two times lower of population dose. The IAEA and Global Community was officially acknowledged that *all the countermeasures completed till 1994 had been intensive, effective, and had not been to disadvantage of the country* [79–81].

It is of importance that *amounts of Chernobyl Program financing could be considerably less, if should prevailed the modern technologies, balanced ahrofony and rations in the agricultural industry of Ukraine* that provide high yield crops and livestock productivity.

Today, countermeasures on arable lands funded from the State Budget are practically not carried out.

Meadows and pastures. Measures – surface and amelioration improvements – were carried out on natural pastures and meadows during the post-accidental period that, on the one hand, grass improvement, and, on the other hand, decreased radionuclide penetration to it. These measures included: treatment of soil, acid soil liming and mineral fertilising (Table 2.7).

Table 2.7.

Countermeasures efficiency on meadow – pasture lands

Countermeasures	Factor of ^{137}Cs accumulation decrease in grass, times	
	Mineral soils (sandy, loam)	Organic soils (peat)
Drainage	–	2–4
Disking or rotary cultivation	1.2–1.5	1.8–3.5
Common ploughing	1.8–2.5	2.0–3.2
Deep ploughing with clod overturn and deepening to 35 – 40 cm	8–12	10–16
Liming	1.3–1.8	1.5–2.0
Application of nitrogen fertilisers and increase of phosphoric and potassium fertilisers dosage	1.2–3.0	1.5–3.0
Surface improvement	1.6–2.9	1.8–14
Amelioration	3.0–12	4.0–16

Scientists recommended optimal liming and mineral fertiliser doses while improving hayland and pastures, mixed grass crops for cultivating cultural hayland, optimal terms of grass mow in order to produce various types of forage, the ten years pasture changing scheme. According to the recommendations [70] a differential system of forage conservation for cattle was proposed: hay made on meadows differing in contamination density shall be stored separately and used for different animal groups. Forage for milk cattle and meat cattle final fattening must be conserved on cultivated or ameliorated meadows. This measure was neither taken in the first years after the accident nor is used today.

Countermeasures on private pastures in fact not conducted throughout the post-accident period. On the base of the UIAR were developed 46 technology projects concerning development of differential countermeasures on forage lands of settlements, where ^{137}Cs PL is exceeded. Unfortunately, almost none of them were used in implementation of the «Rehabilitation Program....». In 2004–2008 radiation environment in critical settlements within the RN contaminated areas of Ukraine was surveyed with identification of practically all the smallholdings cattle pastures [82]. *But the data obtained by scientists are actually not used in financing of protective measures.*

Liming and repeated liming of meadows and pastures is currently practically suspended on the territory of Ukraine contaminated as a result of the Chernobyl catastrophe.

Irrigation agriculture. In 1993 water from the Dnipro river was used to irrigate about 1.6 million ha of 2.6 million ha, which is the total area of irrigated lands in Ukraine, and about 4700 million m^3 of Dnipro water was spent annually for this purpose. Approximately 80 % of irrigated lands were located in five south oblasts of Ukraine. Irrigated areas reduced in the following years and in 2007 only about 520 thousand ha were watered. Positive dynamics regarding irrigated lands was registered over the two recent years. Owing to radionuclide migration in aquatic ecosystems ^{90}Sr and ^{137}Cs were delivered to soil of flooding checks with irrigation water. Over the 10 years post-accident evolution, content of these radionuclides in soil of rice checks increased by factor 1.7 and 2.7 respectively.

Waterway of radionuclides delivery to agricultural crops in irrigated agrocenosis depends on many factors, the basic of those are as follows: physical and chemical properties of radionuclides and specific water radioactivity; forms of radionuclides presence in water; quality of irrigation water (hydrochemical grade and saltiness); irrigation procedure (irrigation rate and number); irrigation methods; biological plant properties and their development phases. Direct proportion was determined between radionuclide water concentration and value of their transfer to plants. This allowed of conclusion that given radioactive contamination of irrigated crops is forecasted, it would be proper to use factors linking specific radionuclide water and standing crop concentration, considering procedures of particular crop irrigation with water of particular hydrochemical grade.

^{137}Cs content in irrigated crops was from 2 to hundreds of times higher, depending on their species, than ^{90}Sr content. Delivery of ^{137}Cs to agricultural crops did not change in a substantial way over the 10 post-accident years, and in 1996 was practically on the level of 1988, and delivery of ^{90}Sr increased almost by factor 20 due to radionuclide particle that penetrated through root. But absolute contamination of irrigated crops with overhead irrigation of sown areas with water containing ^{137}Cs and ^{90}Sr made up from tenths of becquerel to several becquerels.

Basic factors affecting crop contamination with lands irrigation were identified over the post-accident years: number of irrigations with radionuclide contaminated water, watering rate, irrigation method.

It was determined that in 20 years after commencement of irrigation with water contaminated by ^{90}Sr its delivery to vegetable and some other crops will result from soil way, while delivery of ^{137}Cs over a very long period of time (up to 200 years) will result from water contamination.

Rehabilitation of set-aside lands. Issues of ChNPP Exclusion Zone territory practical use recovery are not considered so far. The territory of the 2-nd Zone of Absolute (Mandatory) Resettlement in the Zhytomyr oblast is already partially used in economic operations, for instance, for industrial crops production, cattle pasturing, as hayland and vegetable gardens, fish breeding lakes and so on. Above 6 thousand ha of the previously set-aside lands were recovered in Ukraine in 2008.

The following circumstances hamper recovery of set-aside lands for economic operations in Ukraine:

upon resettlement of people from these territories infrastructure (buildings, electricity, roads, reclamation systems, etc.) was completely eliminated or deteriorated;

set-aside agricultural lands get reforested, become waterlogged again, their fertility degrades, etc;

upon rearrangement of agricultural production over the recent 20 years owing to transition to market economy large scale utilisation of set-aside lands is not required from either economical or social standpoint (except attractive areas, such as bottom of the Prypiat river);

as a result of prejudice and lack of professionalism reflected in the information on Chernobyl issues presented in mass media, public is currently concerned about the attempts to utilise areas of the 2-nd zone for producing any consumption products;

there is no simple legal mechanism in Ukraine for legislative rezoning of radioactively contaminated territories.

Animal production arrangement and maintenance, fodder production

From the first hours of the accident and to date cow milk has been the critical food link, consumption of which results in formation of the greater part of population exposure dose. Milk is the most essential foodstuff one cannot do without, especially at that time (1986) when it was irreplaceable, and its removal from child’s diet would mean putting his health at hazard. Therefore, child’s health prevailed more often, because «radiation is invisible, and a hungry child is apparent to the naked eye». From the first hours of accident at the ChNPP milk generated iodine hazard for population, as it was the milk that became the route for transfer of this hazardous and at the same time biologically active radioactive isotope. It is an essential foodstuff and is currently performing the same function, but for a different radioactive isotope, i.e. caesium.

Hazard and scale of the accident *suppressed by governing bodies* deprived completely the possibility of affecting iodine hazard. The intensive operations commenced after 9 May were vain, consequently, it is the radioactive iodine that generated the iodine pathology. Mass injury of population, especially children, by radioactive iodine, though not completely, but could be avoided. Even at failure to provide considerable costs, population must have been warned, and recommendations that were available at that time developed by civil defence researchers (1973) must have been fulfilled [70]. First and foremost, the following must have been *prohibited immediately: pasturing of milk cattle on open territory, consumption of milk of grazer cows, and usage of fodder conserved after radioactive cloud passed, before further details*. Constraint and prohibitive measures are the most effective during first days upon any radiation. But they were not carried in full. As a result of that milk cattle products became the major source of thyroid gland irradiation and human organism as a whole, firstly, owing to radioactive iodine, and later radioactive caesium isotopes.

Livestock evacuation. First days after accident at the ChNPP became the most dramatic for animal industry of Ukraine. Active elimination of radiation accident consequences started only on 2 May. Decision of the Government Committee on resettlement of 30-km zone population over 3 days from 2 to 5 May enabled arrangement and implementation of livestock evacuation from the 30-km zone: 50 thousand head of cattle, 13 thousand pigs, 3.5 thousand sheep, 1 thousand horses [83].

Along with transportation, areas of temporary relocation in fly camps of Borodianka and Makarov rayons were arranged. When accepted livestock was subject to partial veterinary examination, treatment with washing agents, radiological control, feeding, and was sent to place of further allocation to Kyiv oblast units that existed at that time. The above efforts related to animals that actually presented ionizing radiation sources were managed by the Veterinary Medicine Department. All of them were treated by animal industry specialists.

In order to preclude any violations in the epizootologic situation, despite of absence of any hard information on actual radiation situation, and also well-defined policy of further actions the Veterinary Department carried out veterinary and sanitary cleaning and two-phase disinfection of all the free of animals facilities, farm territories and divisions within the 30-kn zone, shooting and disposal of more than 23 thousand stray animals. *Even today it is hard to imagine the scope of work done, and most important is that bulk of the efforts was useless.*

Radiological monitoring of livestock products. On 9 May 1986 the Veterinary Department was the first agency of the State Committee for Agricultural Sector that approved recommendations on procedure for radiological monitoring and animal production on the contaminated territory, developed by specialists of the Main Administration for Veterinary Science of Ukraine and experts of the All-Union Research Institute for Agricultural Radiology. The Department was short of equipment and human resources to support full-scale radiological monitoring in the animal industry and of animal products from 74 rayons of 12 contaminated oblasts, and almost immediately after the accident contaminated livestock was supplied to meat-processing factories. For instance, during May-July 1986 118 thousand livestock heads, including 95 thousand head of cattle and 23 thousand pigs were slaughtered at Zhytomyrskyi, Novograd-Volynskyi and Korostenskyi meat-processing factories without any prior radiological monitoring. Exceeding of permissible radionuclide content in the meat stored in cooling rooms was registered during laboratory analysis. Meat was stored in cooling rooms of meat-processing factories over a long period of time. Since meet was contaminated by isotopes of $^{134,137}Cs$ with half-decay periods of 2.4 and 30 years contamination level did not decrease with time. Cooling rooms at meat-processing factories were packed to capacity and the decision was taken to send radioactively contaminated meat to Russia, countries of Central Asia and Caucasus, but radiation control posts had been already arranged there. All that meet, that is about 10 thousand tons, was returned to Ukraine and in almost 10 years after accident at the ChNPP was disposed in the Exclusion Zone. That was not just a loss of essential foodstuff, but disposal of hundreds of millions of hrivnas. Though the «Recommendations...» [70] existed at that time and stated: «*Meat cattle shall not be slaughtered without prior radiological monitoring and, as necessary, fed by clean fodder till bulk of radionuclides is removed from an organism*».

Management and prohibitive countermeasures. Thanks to the initial recommendations milk from the most contaminated rayons of the Kyiv and Zhytomyr oblasts was sent for churning. In early May it was **prohibited** to send milk to Kyiv from production units of northern rayons, procedure of differentiated collection of milk for milk processing factories based on its contamination levels was established in the city. The most contaminated milk was sent for churning and making cheese, i.e. products that allow of their long-term storage till decay of short-lived radionuclides, and having up to 10 times lower content of long-lived radionuclides ^{137}Cs and ^{90}Sr as compared to milk. 'Clean' milk was sent for baby food production. This allowed of 10 times reduction of dose loading on 4 million Kyiv citizens.

Lack of both management specialists, as well as radiometric survey equipment and specialists, and suppression at the critical phase of the accident, and further lack of understanding of the accident scale by country executives; failure to use and comply with the Recommendations and so on developed before and after the accident led to mass delivery of radionuclide contaminated products to processing factories.

In April 1987 the *Methodology of intravital assessment of animal organisms contamination with radioactive caesium*, developed by the Institute of Agricultural Radiology, was agreed and introduced, as well as later the one for agricultural production within the radionuclide contaminated territory. With the assistance of veterinary medicine specialists radiological monitoring points were arranged at meat-processing factories and later at production units when sending cattle to meat-processing factories. In early 90-s, cattle (meat) contaminated above the state health standards practically was not delivered to meat-processing factories.

Scientists of the UIAR studied mechanisms of radionuclide metabolism in farm animal organism that enabled short term development and introduction of a set of recommendations, instructions on disposal of feedingstuffs, productive animal rations and in fact enabled scientific control of processes of radionuclides delivery form soil to vegetation and through animal ration to their organism, and with animal products to human organism. Thanks to the mentioned developments and their introduction in maximum short terms the reliable barrier on the way of radionuclides delivery to human body was arranged in early 90-s. All of the stated above was made possible thanks to joint efforts of the government, ministers, departments, laboratories, local authorities, and, undoubtedly, agricultural radiological science, recommendations of which were implicitly fulfilled with its prevailing opinion.

Zootechnical countermeasures. Till 1990, scientists, in particular of the UIAR, directed their major efforts on minimisation of agricultural products radioactive contamination to creating conditions for obtaining clean crop products as the basis for animal forage resources, based on fundamental knowledge of mechanisms of radionuclide behaviour in the ‘soil-plant-animal products’ link. Analysis of radiation conditions on cultivated lands has shown that with inhomogeneous radioactive contamination and differing ecological specifics of the territory even within one production unit forage resources could be arranged for animals of various productivity: the most contaminated forage shall go to meat cattle, the cleanest – to milk cattle. During first years after the accident the *three stage process of meat cattle feeding* was proposed [84, 85]. According to the process forage of any level of radionuclide contamination can be used at stage I (from 6 months to 12–16 months). During stage II that lasts 1–2 months depending on the level of sales of animal contaminated muscular tissues, forage with contamination level up to 40 $kBq \cdot kg^{-1}$ can be used. Feeding stage III, depending up on the level of animal contamination, may last 30–60 days, when forage by an order of magnitude ‘cleaner’ than at stage II is used, it allows of practically 5–8 times reduction of ^{137}Cs level in an animal organism as a result of its export. As for ruminant animals, depending on their age and productivity, the period of ^{137}Cs half-removal lasts 20–40 days. Furthermore, intravital ^{137}Cs content in muscular tissue can be easily determined by the Methodology of intravital assessment of animal organisms’ contamination with radioactive caesium.

Veterinary countermeasures. In early 90-s it became born in that land treatment and reclamation measures are not enough to finally cease production of animal products, in particular, milk, exceeding permissible levels, especially in private sector. Private sector utilises natural forage lands that may not always and fully be subject to land treatment. Major scientific centres of Ukraine, Russia, and Belarus turner their research works to development of preparations that selectively absorb radionuclides. Dozens of natural and synthetic substances precluding radionuclides delivery from ration to milk and meat has been tested. Special attention from economical standpoint should be paid to the approaches of *using ration admixtures* that, once forage gets to gastrointestinal tract (GIT), block radionuclide absorption into blood via competitive interaction with them, adsorption and chemical binding.

Ferrocene, otherwise known as ferric ferrocyanide, is a high-performance compound for limiting caesium isotopes absorption into GIT of animals, as well as its derivatives, namely: iron, ammonium, cobalt, nickel, copper ferrocyanide and some metals. Ferrocine forms insoluble compounds with caesium that do not penetrate through GIT walls into blood and further in tissues, and are extracted from organism with metabolic products. When a cow is fed 3–6 g of ferrocine daily, 8–10-fold decrease of ^{137}Cs is registered in milk [86–88]. Preparations containing ferrocine have passed comprehensive experimental and production tests after the Chernobyl catastrophe at contaminated production units of Ukraine, Russia, and Belarus.

Efficiency of ferrocines utilisation in decreasing levels of animal products contamination with ^{137}Cs was studied on all farm animal species for thousand heads of cattle. Ferrocines have been proven to be safe for health status, productive and reproductive abilities of farm animals and consumption of products from animals that received ration with ferrocene containing preparations, as well as different amounts, over a lengthy period of time [86].

It was Ukraine where forrocene preparations testing started and that hosted all-union and international commission tests of forrocene preparations in various used forms: powder, salt brickets, boluses, ferrocene on cellulose carriers. Unfortunately, tests were the last activity related to the mentioned developments. This technology did not develop into an industrial scale one in Ukraine. Along with pure ferrocine a ferrocine containing preparation was developed in Ukraine based on wine industry waste, which is almost as effective as ferrocine, but is cheaper. Natural zeolites have been used as sorbents over many years in Ukraine, but their efficiency in reducing ^{137}Cs content in milk is 1.5–2 times less.

Private sector. Up to 1989 in became born in [65] that success in practical resolution of radioecological issues in public sector of animal industry cannot be automatically shifted to the private sector of animal production. Unavailability of proper forage base for private sector livestock, deregulation of this production market, and above all, absence of mechanisms for this sector management by state led to animal production private sector criticality in terms of radiation hazard for population. It is the sector that to date provides animal products (basically cattle meat and milk) with exceeding of the existing state standards. In spite of destructive processes in the economy of the country in 90-s, it was possible to reduce the number of critical populated localities from 600 in early 90-s to 100 in late 90-s, though even several dozens of such settlements still remain (Fig. 2.26). Radiation environment in the mentioned populated localities will remain as is over a rather long period of time, since natural processes of lowering of radionuclide transfer from soil into vegetation have significantly retarded, and physical decay will ensure double decrease of the content in products every 30 years.

The amount involved in the issue of exceeding radionuclide content in milk as of today is about UAH 20 million a year. For instance, current annual collective dose on the territory of the Exclusion Zone is about 200 man·Sv. The same dose may be formed due to probability of an emergency event (1 time in 100 years) for instance, Shelter collapse. Millions of hrivnas are spent annually on this. Approximately 600 man·Sv is the annual collective dose currently formed outside the Exclusion Zone, and only UAH 2- 5 million are allocated for elimination of the issue.

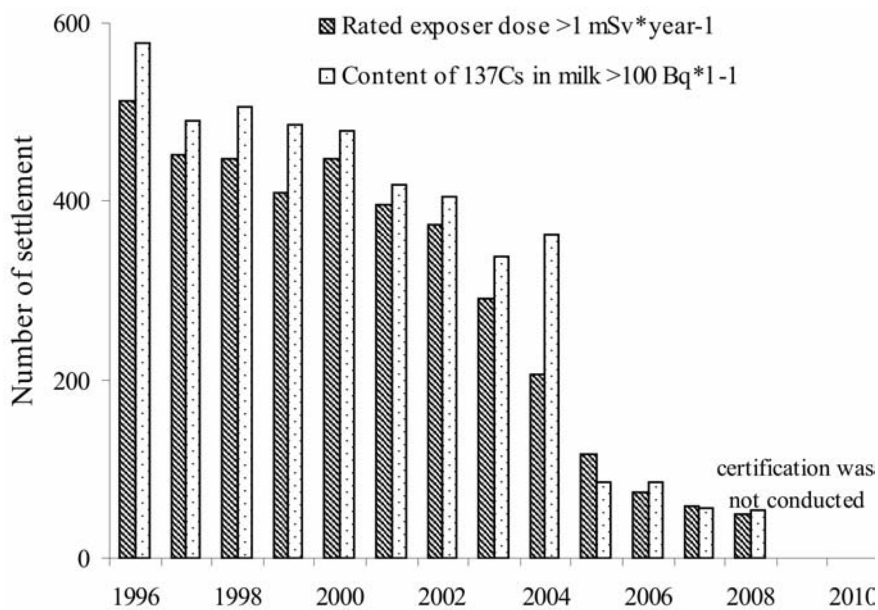


Fig. 2.26. *Distribution of settlements Populated localities dose rating based on overall dosimetric certification.*

Child food problem

One of the priority tasks for the state on contaminated areas is providing radiologically safe food for infants and schoolchildren. Milk is the major source of ^{137}Cs delivery to organism of all age groups of children. Contribution of dairy products to internal exposure dose reduces from 90 % for babies of 0–3 years up to 75 % for infants and 65 % for schoolchildren. Families having cows use their own dairy products. Infant food production on radioactively contaminated territories requires a set of countermeasures be carried out. «clean» pastures shall be allocated for cows producing milk for infant food. Should it be impossible, then reclamation of grasslands and pastures is mandatory, or new grasslands shall be arranged on ploughed fields. Ration of these cows shall contain sorbents or Cs-binding preparations.

The child food issue is especially pressing in critical populated localities in contaminated Polissya, as this is the area where families having many children are common, i.e. up to 10 and more children in a family (Rokytnivskyi, Dubrivytskyi, Sarnenskyi rayons of the Rivne oblast). From their birth children consume with milk «Chernobyl becquerels» prohibited by Ukrainian Laws. Today, this issue is not dealt with at all and is not singled out in planning and in the course of protective measures. Though the state should first of all care about health of the younger generation and not keep away from the issue of radioactive contamination of child ration.

2.2.4. Solving of radioecological problems of forestry

The Chernobyl catastrophe resulted in radioactive contamination of forests in 17 oblasts on the country. Density of ^{137}Cs ground deposition within 1.23 million ha of forests exceeded 37 kBq·m^{-2} as of the time of survey (1991–1992) [89]. Part of forests, where the mentioned contamination density value was exceeded, in Zhytomyr, Rivne, Kyiv oblasts made up respectively 60 %, 56 %, 52 % of the total area of their forest reserves, and approximately 20 % in Volyn, Chernihiv, Cherkasy, Vinnytsia and Sumy oblasts. Common feature of forests radioactive contamination is its mosaic, spot, high-gradient form [90].

As is well known, as a result of radioisotopes physical decay radiation conditions in contaminated forests gradually change. As per estimated data, the area of forests with density of ^{137}Cs ground deposition exceeding 37 kBq·m^{-2} reduced by 400 thousand ha in 2010 as against 1992 and it can be used for any forest management activities without restrictions. But there are no legal grounds for that, since radiation survey was not iterated. Therefore, the State Committee of Forestry of Ukraine developed the Concept and Program of Contaminated Forests Rehabilitation. Survey of forest lands with density exceeding 370 kBq·m^{-2} is planned during 2010–2020, it will enable recommencement of economic activities at about 600 thousand ha.

Dynamics of radionuclide concentration in wood, wild-growing mushrooms and berries and their role in population exposure dose formation

Forest ecosystems have a complex vertical structure and considerable area of aboveground phytomass. Consequently, forests, especially coniferous, have considerable radiological capacity. Immediately after radionuclide fallout on forests their vertical migration started from the upper level of the phytocenoses to soil cover, one of the elements of which, forest litter, became a peculiar kind of depot for radionuclides [91]. Research work in forest ranges within the ChNPP 30-km zone (Lelev forestry) allowed of observation that over the period from 20.05.1986 through 15.06.1986 radioactivity of forest litter of 35–year pine stands increased by factor 2.5 [92]. 90–95 % of the total content of radioactive substances migrated on ground surface in two or three months after their fallout on forests [93].

Velocity of radionuclide migration in forest ecosystems is governed by composition, age, and degree of density, and depends on intensity of forest litter mineralisation. Forest litter mineralisation process is slower in coniferous forest ranges as against deciduous, while forest litter mass is large per an area unit. Consequently, organic substance is conserved in coniferous forest stands, and release of mineral substances, including radionuclides is slowed down. Accordingly, it can be stated that forest litter plays the role of geochemical barrier in forest ecosystems and precludes radionuclide carry-over beyond the ecosystem.

In order to facilitate systematic research aimed at obtaining reliable data on ^{137}Cs and ^{90}Sr migration in components of Ukrainian forest ecosystems in 1991–1993 stationare network (above 100 experimental plots) was established in Polissya and Forest-Steppe zones on forest typological base.

Research of contemporary distribution of ^{90}Sr and ^{137}Cs radionuclide content within forest biocenosis of pine stands in fresh subor, demonstrates that bulk of overall ^{137}Cs and ^{90}Sr content (76–83 %) is contained in soil, 6–13 % are accumulated by forest litter, 6–10 % are held over by tree canopy, the rest (1–5 %) is contained in moss cover.

Soil presents a starting point for many trophic chains in forest ecosystems that directly or indirectly lead to humans. Many years research demonstrated that in 1986 maximal specific activity of ^{137}Cs was registered in the upper forest litter; in 1991 – in the layer of half-decomposed forest litter, and in 2009 – in the most of forest ecosystems – layer of decomposed forest litter. Difference in distribution of total radionuclide activity in forest soil is obvious in the same period. In particular, in 1991 60–70 % of total ^{137}Cs activity of forest soil were kept by thick full-profile coniferous forest litters, the rest migrated to mineral soil; in 2006–2009 distribution of total radionuclide activity in subors and sudubravas turned out to be contrary, but in the pine forests it didn't change essentially. Soil enrichment and moisture play significant role in vertical migration of radionuclides [91].

Analysis of ^{137}Cs vertical distribution in Ukrainian Polissia trophotopic catena soils: bors – subors – sudubravas, under wet growing conditions, 60-year pine stands (Fig. 2.27) allows of stating that with increasing of soil richness the part of ^{137}Cs activity kept by forest litter reduces considerably, and the part of the above mentioned radionuclide that had migrated to mineral layer of soil increases accordingly.

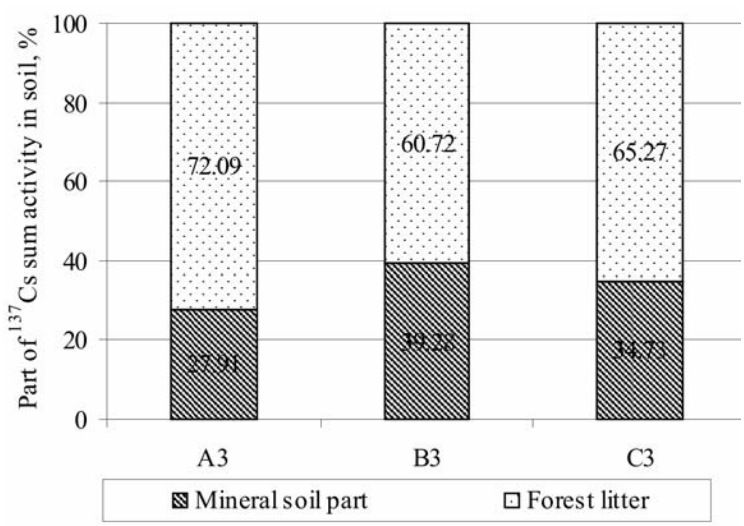


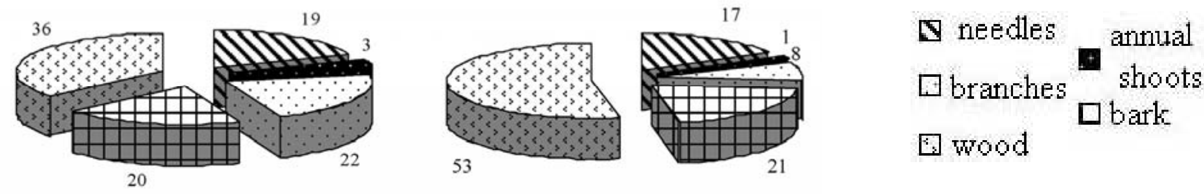
Fig. 2.27. *Ratio between total ^{137}Cs activity in the forest litter and mineral soil part of Ukrainian Polissya trophotopic soils catena*

The above summarised data evidence that under bor conditions the main ^{137}Cs total stock in the soil is contained in the forest litter (72 % of the total stock ^{137}Cs in the soil), abrupt reduction of this index occurs with transfer to subors (39%) and sudubravas (34 %). Such considerable differences in total ^{137}Cs activity distribution between forest litter and mineral soil layer in soils of studied trophotops are associated with a complex of factors, including different contents of forest litter per an area unit and differing velocity of its mineralisation, which in its turn is closely related to fraction composition and mineralisation intensity, and mostly biological one, where major role is played by soil micromycets.

Radioactive elements transfer from the forest litter to the mineral part of soil, on the one hand, increases their migration ability due to presence of a considerable number of fine roots of many plants in the top layer of soil, and, on the other hand, their fixation in clay minerals.

The ratio between migration ability and radionuclides fixation in soil needs to be studied further.

Wood. Researches carried out during the five recent years demonstrated that tree trunks present the major depot of the total radionuclides stock in aboveground part of forest stands. While specific activity of both ^{137}Cs and ^{90}Sr in wood is the minimum due to its mass which exceeds mass of the rest of components radionuclide stock of it is the maximum (Fig. 2.28).



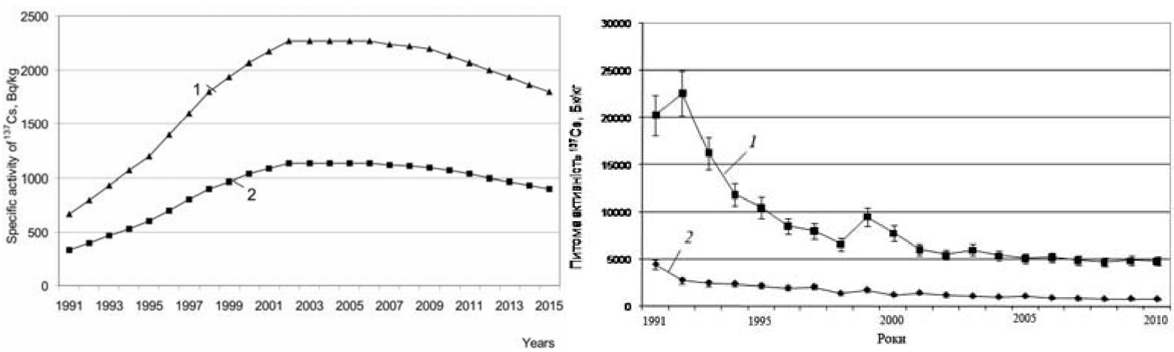
a *b*

Fig. 2.28. *Distribution of* ^{137}*Cs* (a) *and* ^{90}*Sr (*b*) sum activity in phytomass of pine stands in Polissya*

It was found that regardless of tree species in response to a type of forest vegetation conditions ^{137}Cs specific activity according long-term studies increases in the majority of tree components: annual shoots, needles (leaves), bark internal, wood tissue, and just in respect of bark external post-accidental trend of the mentioned above index was contrary. ^{137}Cs content increased in Scotch pine wood during 1991–2002 (Fig. 2.29*a*) in 60-year pine stands of moist subor.

Mushrooms and berries. 20–30 % decreasing of ^{137}Cs content was observed during the last five years (2005–2010) in the majority of edible mushrooms, mycelium of which is located in forest litter (Xerocomus badius, Cantharellus cibarius, Clitocybe nebularis).

As to species with mycelium in deeper soil layers (Boletus edulis, Russula virescens) specific activity of ^{137}Cs in fruitbodies grew at the same period because of radionuclide migration into deeper soil layers. The mentioned above trend will be observed during the following 5–7 years.



a *b*

Fig. 2.29. *Long-term dynamics of* ^{137}*Cs specific activity and its predict:* a *– in Scotch pine wood in moist subor (B_3) with differing density of soil radioactive contamination (1 – 370 kBq/m*^{2}*; 2 – 185 kBq/m*^{2}*), air-dry shoots (1) and fresh berries (2) of bilberry (density of* ^{137}*Cs ground deposition in 1991– 250 kBq·m*$^{-2}$*)*

From 1991 through 2010 considerable reduction of ^{137}Cs specific activity was typical for main forest berry species (Fig. 2.2.8*b*). For instance, fresh cranberry berries ^{137}Cs content lowered by factor 3–4, bilberry – by factor 5. Duration of the ecological effictive period of ^{137}Cs half-decreasing makes up: for bilberry and cowberry in wet subor conditions (B_3) – 7.5 years; for cranberry in damp subor (B_4) – 7.7 years, in moist pine bor (A_5) – 5.5 years. Predictive duration of the following half-removal period for the listed species is approximately twice longer.

Surveys at radiological stations resulted in the observation of *linear dependency between radionuclide content and density of radioactive contamination of soil in particular edatope in respect of all economically valuable species.* This allowed to calculate ground deposition density for obtaining forest products with radionuclide content below permissible lewels. It also allowed to make a grouping of forest managements according with possibility of particular forest raw materials usage.

Corresponding recommendations for forest management in contaminated environment were developed on this methodological basis [94–96].

Hygienists' researches proved that internal exposure dose of rural population of highly forested areas of the Ukrainian Polissya as a result of forest mushrooms and berries consumption currently makes up on average 20% of the total dose. Internal exposure dose of men from the same village may differ widely. It may be caused by differing ration of population. Whole elimination of forest products from a diet decreases population exposure dose more than 10 times.

Radiation environment in forests has stabilised and improved over the post-accidental period due to radionuclide decay and their involvement in biological cycle. This trend will continue in the following years. Changes in radiation environment in forests will be associated with radionuclide fixation in soils and physical decay.

Forest management on radioactively contaminated territories

Before accident at the ChNPP there was no experience of forest management under large-scale radioactive contamination in the international practice that put Ukrainian forestry in predicament. In order to ensure radiation safety and uninterrupted operation of industrial facilities, investigation of radiation environment in forests, development of normative documents that would govern forest management, forest harvesting operations, and non-wood forest resources utilization were required in a relatively short time. Therefore, priority task of foresters was urgent forests inspection for radioactive contamination, as well as development of scientifically grounded recommendations on forest management for radioactively contaminated areas. With this object in view the former Ministry of Forestry of Ukraine conducted a number of management and physical measures.

Firstly, organization structure of the Ministry of Forestry of Ukraine was subject to changing, the most radioactively contaminated forests (Chernobyl and Novoshepelivka forestlands of the Kyiv oblast, i.e. about 110 thousand ha) were transferred to the Exclusion Zone. Any forest management activities were prohibited within the area of about 50 thousand ha, due to high levels of radioactive contamination. Forest management restrictions were applied on wide areas of the state forest fund. For instance, forest harvesting of non-wood production was prohibited within the area of above 1.1 million ha, wood cuttings within approximately 1.1 thousand ha were subject to regulation [96].

Today in conditions of radioactive contamination, 55 forestry enterprises with 36 thousand of employers (third part of employees in the forestry) are operating. Annual medical examination and individual dose measurement are carried out in order to maintain medical condition of employees operating in the contaminated zone.

Radiation control of forestry production. After accident at the ChNPP Radiation Monitoring Department was established within the structure of the State Committee of Forestry to ensure: obtaining of in-process information about radiation conditions in forest stands, production and dwelling premises status, dose measurement within areas of forest management activities, sampling and measurement of radionuclides content in forest products, radiation databank maintenance, reporting to enterprise management and local executive bodies, as well as local public communities on forests radiation status within territory under their authority and radionuclides content in forest products [97].

The Radiological Department is provided with the precise dosimetry and radiometry equipment, as well as professional staff. During 1986–1992 the Radiological Department ensured radiation survey of a forest area of 4.5 million ha and facilitated radiation monitoring of various species of forest products.

Moreover, scope of radiation monitoring of forest products within the sector gradually decreased. Budget financing of the Radiological Department of the State Committee of Forestry was stopped (from the side of MNS) in the current year. This will undoubtedly reflect on radiation monitoring efficiency, especially of forest food production.

Countermeasures in forest sector of economy. Restrictive measures were the priority countermeasures at forest sector enterprises during the critical post-accidental period, including: reduction of daily working hours number, stopping of economic operations on particular areas with high radioactive contamination levels, evacuation of enterprises and their employees to safe area, prohibition of particular types of forest enterprises production operations (preparation and selling of wild-grown berries, mushrooms, medical herb raw materials, wood etc.).

In order to ensure operation of contaminated area forestry enterprises, scientifically grounded recommendations on forest management in radioactive contamination environment were developed and served as a basis for the below provided grouping of all the enterprises depending on soil radioactive contamination density under the growing stock and products radioactive contamination level: *I* – σ (Cs^{137}) < 37 $kBq{\cdot}m^{-2}$; *II* –enterprises of Ukrainian forest-steppe having on their territory forest areas with σ (Cs^{137}) > 37 $kBq{\cdot}m^{-2}$ with spots (100–300 ha in area) with σ (Cs^{137}) < 370 $kBq{\cdot}m^{-2}$ on fertile clay and loam soil; *III* – enterprises of Ukrainian Polissia with σ (Cs^{137}) < 185 $kBq{\cdot}m^{-2}$; *IV* – enterprises of Ukrainian Polissia with σ (Cs^{137}) > 185 $kBq{\cdot}m^{-2}$ with plantations on poor soil with intensive radionuclide migration to vegetation.

Economic activities of enterprises belonging to group *I* were based on standard methods. Preparation of wild-grown berries and mushrooms is regulated at enterprises of group *II* and *III*, their radiation monitoring is arranged, and the following is prohibited at group *IV* enterprises: preparation of foodstuff forest resources, medical herb raw materials, game animals shooting, and firewood stocking is regulated.

Countermeasures taken during the critical and further post-accidental periods at different levels of state regulation in the forestry allowed to precluse staff overexposure, maintaining their medical condition, and facilitated stability in enterprises operation and production growth.

Starting from 1989 all the measures on Chernobyl ChNPP accident consequences elimination related to the forestry were implemented and funded under the state Programs of accident consequences mitigation that enabled huge effort be implemented, preclude overexposure of forest sector employees and reduce collective exposure doses of population in general. Since 1992 financing of the Programs of minimization of ChNPP accident consequences in the forestry was reduced by 50 %, and completely stopped from 2009.

Status of radioactively contaminated forests rehabilitation. According to estimates, above 100 thousand ha of forest ranges could be currently rehabilitated and economic activities is recommended. Rehabilitation of forests shall be based on detailed cartograms of their radioactive contamination. This requires additional survey of forests by areas since substantial mosaic is typical for radioactive contamination levels of areas.

The State Committee of Forestry of Ukraine developed and approved «Program of radiation survey and rehabilitation of radioactively contaminated forests for 2010–2015» that envisages gradual forest survey and, if possible, economic activities recommencement or utilisation of particular forest resources. Rehabilitation of forest products utilisation can be illustrated by recommenced preparation of wild-grown berries, medical herbs, and mushrooms by state enterprises of the Volyn, Rivne, and Chernihiv oblasts. All the prepared products were subject to radiation monitoring and are in line with radiation safety norms. The listed enterprises will increase preparation of forest foodstuff resources in the following years. Similar measures should be planned on a part of forestlands in the Vinnitsa, Cherkasy, Sumy and Chernihiv oblasts.

Iterated survey of a part of forests is carried out for rehabilitation of forest ranges of the Zhytomyr oblast, since forest management and logging operations are prohibited there. Area survey of forest ranges for their radioactive contamination allows of the following: determine current radiation conditions, plan (if possible) forest management activities on stands improvement within areas surveyed 20 years ago, stock timber with radionuclide content below the set standards. Since 2005 8.7 thousand ha of forest ranges previously regarded to the mandatory resettlement zone were surveyed and rehabilitated at enterprises SE «Narodytske SLG», SE «Ovrutske SLG», SE «Ovrutske LG». In 2010

1.7 thousand ha of forests were surveyed at the SE «Narodytske SLG» with soil radioactive contamination levels exceeding 555 $kBq \cdot m^{-2}$, among which forest management activities were recommenced on 1.6 thousand ha. First of all, the forest enterprise started sanitation felling of forest stands, requiring this effort be taken, which, on the one hand, allowed brining them in satisfactory conditions, on the other hand, certain revenue was derived.

Efficient forest management in the radioactive contamination environment is substantially impeded by some issues unsettled on the legislative level. In particular, completely prohibited forest management in forests with ^{137}Cs soil contamination density exceeding 555 $kBq \cdot m^{-2}$, set forth in the Law on status of territories that suffered from the Chernobyl catastrophe, interferes with implementation of vital (for instance, young growth felling; sanitation felling) and economical arrangement of the contaminated area (reconstruction of roads and bridges, firewater ponds, ride between compartments, carrying out cutting under high voltage lines etc). Consequently, amending of the mentioned Law accordingly is critical now.

2.3. Main tasks and expected future development of agriculture on radioactively contaminated territories

In an effort to solve issues of suffered territories rehabilitation and recovery the State Long-Term Program of Agribusiness Development on the Territories Contaminated as a Result of Accident at the ChNPP and their Comprehensive Rehabilitation should be implemented in the following years. According to the «Concept of Agricultural Production on Contaminated Territories and their Comprehensive Rehabilitation for 1998–2010» [78] the program should ensure resolution of priority radiological issues, notably comprehensive improvement of radiation environment in critical populated localities, stopping of agricultural output with radionuclide content exceeding state standards, resolution of the priority task of child food, obtaining guaranteed clean, competitive agricultural products. It also should ensure economical development of the regions and social benefits for population.

In an effort to solve issues of suffered territories rehabilitation and recovery the State Long-Term Program of Agribusiness Development on the Territories Contaminated as a Result of Accident at the ChNPP and their Comprehensive Rehabilitation should be implemented in the following years. According to the «Concept of Agricultural Production on Contaminated Territories and their Comprehensive Rehabilitation for 1998–2010» [78] the program should ensure resolution of priority radiological issues, notably comprehensive improvement of radiation environment in critical populated localities, stopping of agricultural output with radionuclide content exceeding state standards, resolution of the priority task of child food, obtaining guaranteed clean, competitive agricultural products. It also should ensure economical development of the regions and social benefits for population.

Pursuant to decision 62 of the UN General Assembly as of 12.11.2007 the third decade after the Chernobyl catastrophe (2006–2016) proclaimed as: «...The decade of rehabilitation and stable development of the suffered regions that must be focused on achievement of the objective of restoring normal living of the suffered population, if possible, in the same period». Current value of the products that do not meet health physics standards of PL-2006 makes up about UAH 200 mn, which is dozens-fold above the cost of the protective measures directed at this issue resolution.

Ceasing of milk output with radionuclide content below the PL-2006, first of all, requires ferrocene be used with the cost of approximately UAH 10 million in year. Moreover, countermeasures shall be directed to the most critical villages, rather than dispersed all over the territory that suffered from the accident. It is important to remember that ferrocine must be used regularly and upon its discontinuation the effect of lowering milk contamination level decreases dramatically. In view of the complexities associated with the procurement under the State Budget (duration of tendering exercises, irregular funding, difficulties of foreign supplies and so on) actual efficiency of ferrocene consumption in Ukraine may turn out to be lower than expected. Therefore, forage lands amelioration should also take place being a very effective and lengthy countermeasure on peaty soils of the Rivne oblast.

For the purpose of agriculture development on radioactively contaminated territories a set of major tasks must be fulfilled.

Prioritise measures in populated localities of continuing consumption of milk and some other products with exceed of ^{137}Cs content standard. The state is obliged to eliminate the issue of non-contaminated milk supply to children over 25 years. The issue requires funding in the amount of several dozens of million UAH, while overall cost of the Chernobyl Program is UAH 3.5 milliard!

Animal and human rations must be balanced via additives and application of complex fertilisers containing micronutrients, as lengthy ferrocene consumption aggravates micronutrient malnutrition typical for the Polissia zone.

Perform scientifically grounded demand calculations and ensure implementation of a countermeasures set in regions, where ^{137}Cs content in cattle milk, meat or crop products is above 80 % of the standard or exceeds it. As this takes place, after-effect of countermeasures in crop cultivation should be taken into consideration, since it exhibits over several years and enables soils amelioration and crop production increase.

Establish minor target programs and thoroughly supervise their progress. In order to accomplish this, a listing of urgent and mandatory points should be developed and validated.

Urgently develop a procedure of programs scientific and technical expert review in order to streamline and minimise the scope to a possible extent under the acute shortage of investments.

Develop a works scientific support program for the next period and ensure its financing.

Revise involving scientists the radiation monitoring program for products quality with the major focus on the most critical regions. *Take necessary steps in order to keep professional* radiologists and maintain working efficiency of veterinary and agronomical radiological departments over the entire area of the zone of radioactive contamination.

Facilitate centralised maintenance of databases on radiation conditions in various production sectors, obtained by various departments over the entire post-accidental period.

Establish and implement a State Social and Economic Development Program for contaminated territories. All the development and construction restrictions applicable to the regions that suffered shall be eliminated for attracting investments, except set-aside territories.

Increase management responsibility for programs implementation and set results accomplishment.

Reconvene review of the «Social and Economic Development Program for Contaminated Territories» developed by the group of people’s deputies of Ukraine conjointly with the Ministry of Agricultural Policy, and NAAS of Ukraine passed in a first reading by the Verkhovna Rada of Ukraine, but vetoed by the President of Ukraine, V.A.Yushchenko.

Intensive crops cultivation and animal production with adherence to methods may ensure products contamination lowering at the current stage of contaminated territories rehabilitation. Accordingly, the major way to rehabilitation of the territories contaminated as a result of accident at the ChNPP is social and economic development of the region, and basic line of agricultural management is its intensive development and rise in profitability.

3. RADIOLOGICAL AND HEALTH CONSEQUENCES OF CHERNOBYL DISASTER

3.1. Irradiation doses

Chernobyl radioactive release started April 26th, 1986 and according to some estimates, lasted 10-15 days. Short-lived radionuclides (radioisotopes such as niobium, zirconium, iodine, etc..) played a role of dose factors in the early phase of the accident. With the distance from the start of the accident, the increasing role in shaping the dose was played by radioisotopes of cesium (^{137}Cs, ^{134}Cs) and much less – strontium (^{90}Sr). Radioisotopes of transuranic elements (^{238,239,240,241} Pu, ^{241}Am), though were present in radioactive emissions, but the physical and chemical properties of the inactive carriers in which they were fixed, stipulated that the role of the transuranic dose was small.

During the emergency radioactive release the weather conditions constantly changed, causing significant heterogeneity of radioactive fallout in Ukraine: ^{137}Cs fallout density varied from units to several hundred kBq · m^{-2}. ^{90}Sr contamination levels were approximately 10 times lower. In the area of population residence levels of fallout ^{239}Pu varied from 0.004 to 0.9 kBq m^{-2} (at the average level of global fallout ^{239,240} Pu for Ukraine – 0.037 kBq · m^{-2}).

While in the area of radiation influence of the Chernobyl accident virtually all the residents of Ukraine were somehow involved, but four critical forces that are most experienced accidental exposure are highlighted:

1) clean-up workers of ChernobylNPP accident known as «liquidators» those who were directly involved in work on the industrial site or in the Chernobyl 30-km zone;

2) evacuated residents of Pripyat and Chernobyl, as well as settlements of 30-km zone;

3) children and adolescents (age – at the time of the accident), whose thyroid gland has undergone irradiation by radioactive isotopes of iodine, which came into the body with food or inhaled in May-June 1986;

4) rural residents living on contaminated territories.

The population of the contaminated areas *is the largest in number among the four contingents outlined above and makes millions of people in Ukraine*.

Dose load were formed by two basic ways of irradiation for population of contaminated areas:

1) *external* whole body *gamma irradiation* from the complex of gamma-emitting radionuclides in the fall-out on the soil;

2) *internal irradiation* of thyroid gland from *radiocesium* (in 1986) and whole body irradiation from *radiocesium* (and much less from other radionuclides) due to consumption of contaminated foodstuffs produced (grown) at the radioactively contaminated territories.

3.1.1. Radiation doses of clean-up workers of the accident. Retrospective dose reconstruction of clean-up workers of the accident

Clean-up workers of the Chernobyl NPP accident (also known as «liquidators») compose one of the largest and probably the most exposed cohort affected by the Chernobyl accident. Despite the importance of this population – both in terms of medical and social aspects and position of studying the consequences of accidental exposure – exposure picture of the situation with the liquidators for a long time remained uncertain. Thus, among the clean-up workers years of 1986–1990 included in the State

Register of Ukraine (SRU) of persons affected by the Chernobyl accident only about a half have records of individual doses. Remained unclear both the quality of available dosimetric data, and the overall success or failure of radiation protection during clean-up works.

Traditional were ideas of almost total falsification of data on radiation doses and the mass excess of fixed dose limits. It was also uncertain situation with radiation dose of crystalline lens, one of the most radiosensitive organs, especially beta radiation from the Chernobyl radionuclide mixture. Therefore a large range of activities was planned and largely implemented for the past ten years aimed at bringing clarity to the real exposure of clean-up workers and retrospective evaluation of dosimetric monitoring results during clean-up works.

A special place in the complex problems of exposure assessment dosimetry of clean-up workers took the need of dosimetric support of post-Chernobyl epidemiological studies. These studies require information on subjects'individual doses, and solving the problem of dosimetric support needs the implementation of integrated approaches. The main practices of individual retrospective dosimetry, which was developed in recent years and successfully used to reconstruct individual doses of clean-up workers is RADRUE (Realistic Analytical Dose Reconstruction and Uncertainty Analysis) – analytical calculation method jointly developed by Russia (Institute of Biophysics), Ukraine (Research Centre for Rradiation Medicine, Chernobyl NPP), USA (National Cancer Institute) and France (International Agency for Research on Cancer).

An important feature of this method based on an inquiry of clean-up workers, the reliability analysis of responses by expert monitoring team and the use of expansive databases of radiation situation in the places of clean-up works, is that it can be universally applied to any clean-up worker, including the deceased (through the inquiry of colleagues and relatives).

RADRUE method was widely used to reconstruct individual doses for whole body and bone marrow of subjects (cases and controls) of Ukraine-US research of leukemia among liquidators. Altogether 1,010 doses were reconstructed for clean-up workers using RADRUE method, in particular 79 subjects who died (through questioning colleagues and relatives of the deceased clean-up workers).

Taking into account that the cohort studied included clean-up workers of 1986–1990, which have official status and registered liquidators in the SRU, the dose range was from zero to about 3.2 Gy, arithmetic mean dose (expectation) – 90 mGy, geometric mean – 12 mGy. Such a huge range of doses suggests extreme heterogeneity of cohort of clean-up workers composed at the same time with the people who received large doses in the first days after the accident, and household sector employees or persons who visited the 30-km zone during a short business trip.

Doses of certain occupational categories among the clean-up workers differ (Table 3.1.13). Thus, the employees of the Ministry of Internal Affairs (MIA) for which there were fewer opportunities to effectively influence on the levels of exposure, and nuclear power professionals (NPP employees, workers of Construction Administration-605) received relatively higher doses. It should be noted that the last group (nuclear power professionals) also includes so-called early liquidators, i.e. people from Chernobyl NPP personnel exposed to radiation at the initial crash, when there were no established effective system of radiation protection and radiation control.

Obviously, the highest doses received participants of clean-up works for which no effective system of radiation protection and exposure management was used, first of all, early liquidators (those who participated in the clean-up works during April-May, 1986) and certain categories of workers who carried out works on individual tasks, mostly outside the scope of attention of radiation monitoring services. Dynamics of military liquidators exposure by years (Tabl.3.1) adequately reflects the evolution of the radiation situation in the 30 km zone and a gradual reduction of the dose limits within 1987–1988. It should be noted that the average dose of military liquidators were significantly lower than officially registered and established in the public consciousness value. This finding agrees well with the independent analysis of official dose records and qualitative considerations concerning radiation monitoring features of the troops during the clean-up works. l

Table 3.1.

Results of reconstruction of individual doses by RADRUE for some categories of occupational accident (data of SI «RCRM of AMS of Ukraine»)

Category	Number	Average dose (mGy)	Median dose (mGy)	Geometric standard deviation
Military (total)	218	76	54	2,1
Separately by year of participation in the clean-up works				
1986	99	105	82	1,89
1987	52	78	46	2,32
1988	44	29	17	2,41
1989	20	31	17	2,22
1990	3	60	24	2,89
Professional atomist	35	381	277	1,78
Staff of MIA	27	203	173	1,86
Sent in official journey	340	70	48	1,95
Drivers	213	64	41	1,99

It should be noted that the cohort of subjects of Ukraine-US study of leukemia among liquidators is quite representative, because data on levels of doses, type of work and distribution of professional groups (categories) of clean-up works (Table 3.2) are very informative and can characterize the total set of Ukrainian clean-up workers.

A separate scientific and practical problem is to determine the lens exposure in clean-up workers, including assessment of individual doses of beta-radiation. The essence of the problem is that during the clean-up works beta-irradiation doses were not controlled (becausse of shortage of existing logistical and methodological basis) while in the Chernobyl mixture of radionuclides were amply represented hard beta emitters (^{144}Ce/Pr, ^{106}Ru / Rh, ^{90}Sr / Y), which could form a substantial remote dose beta-irradiation. Under certain conditions, beta doses on lens of clean-up workers may exceed an order of the appropriate dose of gamma-radiation.

A large study on reconstruction of individual doses of lens beta-irradiation of 8,607 participants of Ukraine-US ocular Chernobyl research (UACOS) RCRM specialists conducted jointly with the Institute of Occupational Health, AMS of Ukraine (the main contractor of the project UACOS). Developed dosimetric model took into account the time elapsed after the accident (and, accordingly, changes in the composition of the Chernobyl nuclide mixture), peculiarities of exposure (which were determined through questioning of liquidators) – character of work, workplace characteristics, using of protective eyewear. To assess an adequate exposure model was used (phantom, taking into account the anatomical location of the lens, exposure from horizontal and vertical surfaces with different textures) and the method of calculating the distance doses of beta radiation by the Monte Carlo method.

Although the ultimate goal was to assess the total doses to the lens, a correlation between doses of gamma and beta radiation is also of interest (Fig. 3.1). It was found that approximately 32 % of subjects for study beta-irradiation doses were higher than the corresponding gamma doses (i.e., the total radiation dose in the lens was more than two times higher than the assessment only gamma dose), while for about 53 % of subjects of beta irradiation did not exceed a half of the corresponding dose of gamma radiation.

Parameters of total doses (beta + gamma) of lens irradiation in certain groups of clean-up workers – the study subjects are listed in the table. 3.3. The table shows that the largest radiation dose received so-called early liquidators, i.e. staff persons from the Chernobyl NPP and other units that were involved in the clean-up worksin at the first days and weeks after the accident. It should be noted that in view of the nature of exposure (dose gamma irradiation + beta; see. Fig. 3.1) and characteristics of the cohort (clean-up workers of 1986–1987) doses of the largest group of studied subjects – military liquidators – are in a good agreement with the dose reconstruction by RADRUE (Table 3.1).

Table 3.2.

The structure of clean-up workers, who were the subjects of Ukraine-US study of leukemia

Category	All cohort study		Kyiv and Kyiv region		Other regions		Estimate for all Ukrainian clean-up workers
	number (%)	duration of work - median (minimum, maximum)	number (%)	duration of work - median (minimum, maximum)	number (%)	duration of work - median (minimum, maximum)	
Witnesses of the accident	3 (0.5)	7 (1. 11)	2 (0.7)	6 (1. 11)	1 (0.4)	7 (7. 7)	<1
Directly affected	2 (0.3)	2 (1. 2)	2 (0.7)	2 (1. 2)	0 (0.0)	- (-. -)	<1
Early liquidators	66 (11.5)	7 (1. 185)	50 (17.1)	7 (1. 185)	16 (5.7)	7 (3. 16)	~10
Staff of Chernobyl NPP	9 (1.6)	317 (36. 1420)	8 (2.7)	379 (36. 1420)	1 (0.4)	225 (225. 225)	~1
Temporary submitted NPP staff	1 (0.2)	31 (31. 31)	1 (0.3)	31 (31. 31)	0 (0.0)	- (-. -)	<1
Staff of CA-605	5 (0.9)	31 (19. 63)	1 (0.3)	24 (24. 24)	4 (1.4)	46 (19. 63)	~1
Staff of the Institute of Atomic Energy, named by I. Kurchatov	2 (0.3)	157 (138. 175)	0 (0.0)	- (-. -)	2 (0.7)	157 (138. 175)	<1
Military clean-up workers	220 (38.5)	67 (6. 833)	33 (11.3)	65 (7. 366)	187 (66.8)	69 (6. 833)	48
Civil liquidators sent to the 30-km zone	181 (31.6)	19 (1. 1710)	121 (41.4)	18 (1. 1710)	60 (21.5)	21 (2. 103)	28
Staff of Industrial Association "Combinat"	4 (0.7)	458 (164. 1450)	4 (1.4)	458 (164. 1450)	0 (0.0)	- (-. -)	<1
Mixed type	79 (13.8)	250 (4. 1710)	70 (24.0)	258 (4. 1710)	9 (3.2)	111 (9. 1710)	10
Total	**572**		**292**		**280**		

Another original feature of ocular dosimetry project was the sharing of various methods of dosimetry that were relatively uniform across a single calibration standard («gold standard»). Thus, to assess individual doses of gamma irradiation the high-quality data of personal dosimetry monitoring (staff of Construction Administration № 605 – CA-605), the results of calculation and analytical dose reconstruction (ADR), the official dose records (ODR) of military liquidators were used.

Dose estimates from independent sources were calibrated against EPR dosimetry on tooth enamel as the most accurate and valid method for retrospective dosimetry. This caused the introduction of calibration correction in the primary dose assessment. Thus, it appears that ODR of military liquidators approximately twice overstate the actual levels of exposure in this category of clean-up workers.

To correct the primary ODR and take into account of doses uncertainty it was to multiply the initial ODR by an adjustment of logarithmically normal distribution type with the following parameters: geometric mean – 0.5, geometric standard deviation – 2.2. These options of the corrective distribution reflect large systematic shift of registered doses, as well as a considerable uncertainty of radiation monitoring data of military liquidators. Unique data on individual doses of liquidators' lens irradiation enabled to succeed ocular research and to analyze the risks of cataract under the influence of ionizing radiation.

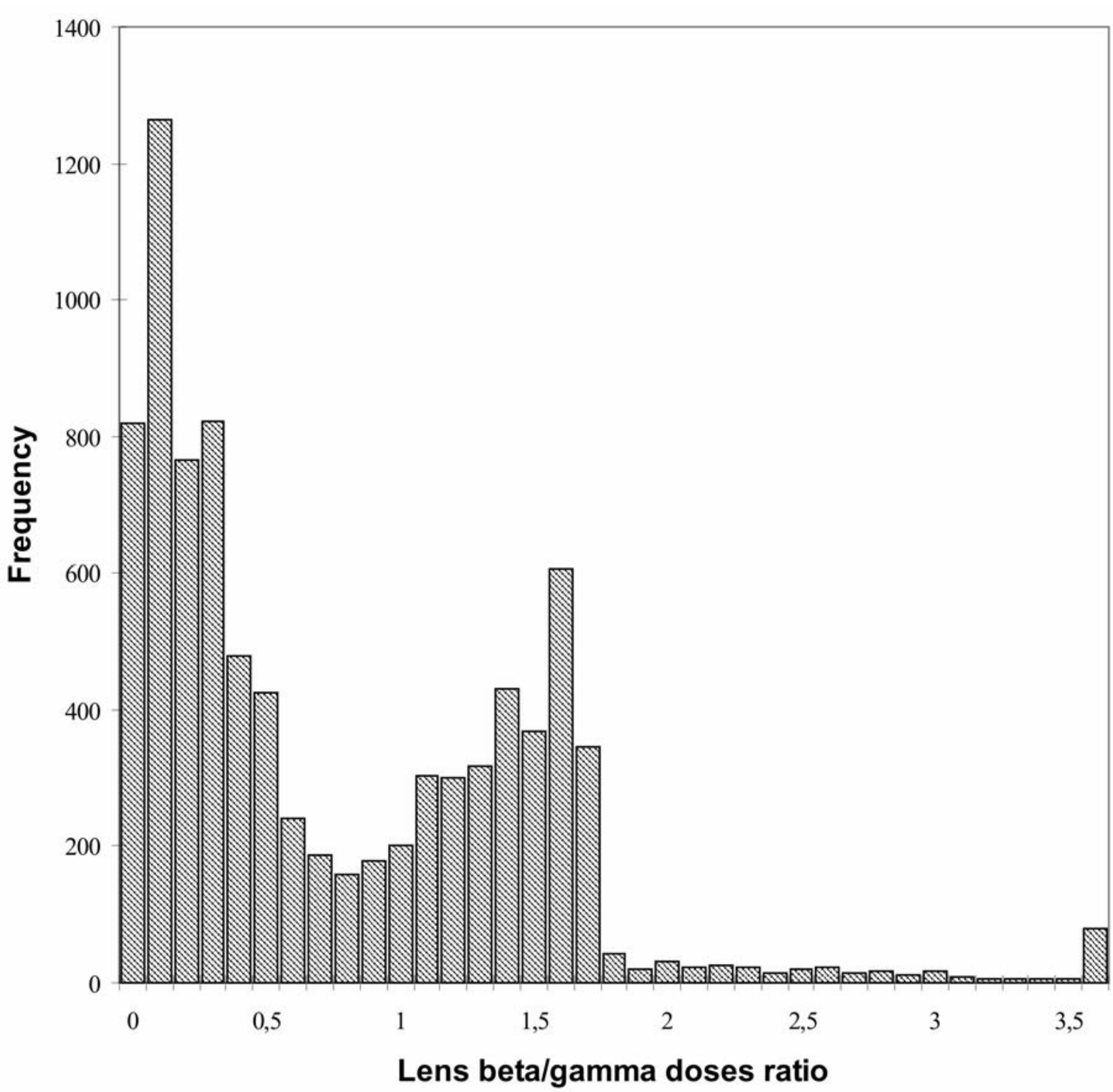


Fig. 3.1. *The distribution ratio of beta-irradiation to doses of gamma radiation for the 8,607 subjects of Ukraine-American Chernobyl ocular research (UACOS).*

Table 3.3.

Characteristics of lens exposure of certain groups of clean-up workers-participants of Ukraine-American ocular Chernobyl research (UACOS)

Group of clean-up workers / dosimetry method	Number in the tested cohort	Dose distribution parameters of lens (beta + gamma) mGy: Median (5 % and 95 % percentile)
Employees of CA-605 / individual monitoring by TLD dosimeters	410	16 (2, 235)
Representatives of various groups / EPR dosimetry in tooth enamel	104	94 (19, 426)
Early liquidators / analytical dose reconstruction (ADR)	712	502 (142, 1143)
Sent to the 30-km zone / ADR	126	16 (1, 242)
Military liquidators / Official dose records (ODR), received by the group and group-calculating method	7,255	121 (30, 287)
Total	8,607	123 (15, 480)

Serious attention was paid to assessing the quality and reliability of existing dose records of radiation levels of clean-up workers. These attempts were made on several areas:

Collection and unification of all existing databases on individual doses and the corresponding paper archives.

Studying the practice of radiation protection and radiation control of various contingents of clean-up workers, including institutional and regulatory aspects.

Study of dosimetric registration accuracy by statistical methods.

Retrospective evaluation of dosimetric uncertainty of SRU data by comparing the official results with the results of dose reference EPR dosimetry.

In the direction of the collection of available dosimetric information with funding from the National Cancer Institute (USA) all the electronic databases of radiation control during the clean-up work were acquired. Unfortunately, this information gathered by the efforts of Russian colleagues from the Institute of Biophysics (Moscow) was not useful for practical use due to lack of reliable identifiers for linking records in dosimetric databases with the data in SRU.

Noteworthy achievement was the transfer of dosimetric data archives of the Ministry of Defence of Ukraine in an electronic database. Results of this work, carried out jointly by specialists of Military Archive, Military Medical Academy and the RCRM was the database containing more than 45 thousand entries of Ukrainian troops (reguular and reserve), those that include the terms of participation in the clean-up works, the number of units and individual dose during the clean-up works. Comparison of data from the archive of Ministry of Defence (MOD) with ODR of the State Register of Ukraine proved to be very instructive. It appeared that the dose of military liquidators who are registered on the SRU practically coincide with the data contained in the military archive. Moreover, the degree of overlapping data sets and SRU and Military Archive was quite high – almost all of the records contained in the Military Archive is reflected in the SRU. This conclusion confirms the high importance of SRU data as a source of dosimetric information for military liquidators, who are about 90 % of people with registered dose in the SRU.

Study of regulations and practices of radiation protection and radiation monitoring during the clean-up works that has been done in the framework of Franco-German Initiative «Chernobyl», allowed to better assess the quality, reliability and completeness of dosimetric data on clean-up workers. It was found that in terms of quality and level of contingent coverage by dose control, five periods cann be singled out (Table 3.4).

If at the preaccidental period the dosimetry and radiation safety service satisfactorily fulfilled its tasks, sudden accident revealed a complete failure of the existing dosimetry to effectively determine individual dose of workers and provide the necessary level of personnel radiation safety in emergency conditions. It should be noted that the period of confusion was quickly overcome and since the second decade of May, 1986 dosimetry system in support of emergency workers began to be made gradually and in early June (about a month after the accident) the foundations of effective radiation protection and radiation control of the main forces involved to overcome the disaster were laid.

Table 3.4.

Periods of dosimetric maintenance of clean-up works

Period	Time Interval	Description
Preaccidental	1978-26.04.1986	Normal functioning of Chernobyl NPP dosimetry service in accordance with Radiation Standards-76
Initial	26.04.1986 – about 10.05.1986	Inability of Chernobyl NPP dosimetry service, the use of the war-time approaches to dose control of forces
Interim	about 10.05.1986 – 01.06.1986	Parallel operation of dosimetry services Chernobyl NPP and the army, introducing a single exposure limit (250 mGy), CA-605 organization with its own dosimetric service
Main	June-October, 1986	Operation of dosimetry services of Chernobyl NPP, CA-605 and MOD units based on different approaches
Rutine	after November, 1986	Parallel operation of dosimetry services of Chernobyl NPP, CA-605, IA «Combinat» and MOD departments. Gradual return to normal operation, reduction of dose limits (1987-1988)

It was found that the quality of dosimetry data (a radiation monitoring) essentially depends on which service or agency conducted radiation protection of liquidators and dosimetry control. During the clean-up works (1986–1990) in the 30-km zone four large independent dosimetry services (Table 3.5) and several smaller independent service providers (USSR Academy of Sciences, USSR Academy of Medical Sciences, Integrated Expedition of Institute of Atomic Energy, etc.) were in function. These dosimetric services began at different times after the accident, covering various contingents and, most importantly, practiced radically different approaches to the assessment of individual doses of clean-up workers. Therefore the completeness, quality and reliability of their dosimetric data differ significantly (Table 3.5).

Table 3.5.

Basic dosimetric services that performed dosimetric control of clean-up workers

	Service	Відомча належність	Period of function	Coverage of clean-up workers	Data quality
1.	Chernobyl NPP Radiation Monitoring Service	Ministry of Energy and Electrification of the USSR, from July 1986 – USSR Ministry of Atomic Energy	May, 1986 – to present	NPP personnel and temporarily attached to the Chernobyl NPP personnel	satisfactory-high (depending on the period after the accident)
2.	Departments of Ministry of Defence	USSR Ministry of Defence	May, 1986 – end of 1990	military liquidators	low
3.	Division of Radiation Control CA-605	Medium Machine Building Ministry of the USSR	June 1986 – 1987	civil and military constructors of CA-605	igh
4.	Office of Radiation Control of IA «Combinat» and its successors	USSR Ministry of Atomic Energy	November, 1986 – to present	civilian personnel who worked in the 30-km zone outside the building site of Chernobyl NPP	satisfactory

Dosimetry control of CA-605 staff of the Ministry of Medium Machine Building (MMMB) of the USSR, a specialized construction organization created to build a sarcophagus («Shelter» Confinement) was the best organized. The result of this exemplary work was 100 % coverage of quality TLD individual control more than 20 thousand employees of CA-605, mostly business travelers from MMMB enterprises, based in Russia.

Dose control, performed by Chernobyl NPP Radiation Safety Service is characterized by failure in the first weeks after the accident (when the regular dosimetric means have proved inadequate for measuring high levels of doses) and the gradual restoration of high-quality dose monitoring, which ended only in June–July, 1986. Negative consequence of such failure of the regular radiation control of Chernobyl NPP was that doseS of early liquidators – probably the highest among clean-up workers – remained unknown. Consequently, the completeness of dosimetry data of Chernobyl NPP personnel was insufficient (including – in the sense of covering by dosimetric data for each liquidator during the entire period of clean-up works) that determined the need for reconstruction of individual doses. Throughout the years 1986–1996 in total 1,600 individual doses of Chernobyl NPP workers and those temporarily assigned to the station were evaluated ADR calculation method. Since July, 1986 dosimetry monitoring and recording of individual doses were carried out at the Chernobyl NPP properly and that dosimetric information is characterized by high quality and completeness.

Dose control of civilian personnel (permanent and temporarily assigned), working in 30-km zone, due to organizational problems practically was not carried out during 1986 and part of 1987, while this function gradually took over the Office of Dose Control of IA «Combinat» / RIA ‘Pripyat’. Thus, doses of this contingent, especially in 1986–1987, are characterized by a lack of completeness and not always high quality.

The largest contingent of clean-up works were military liquidators – professional soldiers, soldiers (initially) and, the most, persons temporarily called to the army from reserve. The importance of this category is greater, as about 95 % of ODR in SRU belong just to military liquidators (Fig. 3.2).

Such a situation with ODR of military liquidators is the result of a 100 % coverage of this contingent by dose control and peculiarities of input dosimetric information to SRU – through the dose certificate (in case of military personnel – a supplementary sheet to military ticket) which were on hand in all military but in very few civilian clean-up workers. However, concurrently with the exemplary coverage the dosimetry of military liquidators differed by the lowest precision of individual doses because of rude and inaccurate methods of dose assessment. For military liquidators generally used group (one dosimeter per group) and group-calculated (when the dose of all group members was calculated in advance on the basis of dosimetric situation and the planned work) dosimetry methods.

It was found during the retrospective assessment of accuracy and bias of the dose estimates of military liquidators that the average doses estimated by these methods exceeded twice the actual level of exposure, and geometric standard deviation (uncertainty) was very high and comprised about 2.2. It is significant also that widespread interpretation of abnormal distribution of individual doses of the military liquidators (Fig. 3.3) as the evidence of fraud dosimetry information to bring the reporting of exposure levels of military personnel in accordance with the applicable dose limits (250, 100 or 50 mSv) not was confirmed.

Statistical methods showed that the possible contribution of false (falsified) results of the dose does not exceed 10 % of the total, and the atypical form of distribution (left depleted and a sharp precipice at doses above the limit) corresponds to fairly unusual practice of doses management when the person who received allowance dose exempted from the armed forces and their replaced by a new reservist.

In general, dosimetry control, which was carried out for different groups of liquidators and the system of radiation protection of contingents involved in clean-up works overcoming the Chernobyl accident consequences, allowed to comply with current norms and exposure limits. Mass overirradiation of cllean-up workers was characteristic only for the initial phase of the accident and concerned rather limited group of so-called early liquidators.

In the future (from late May, 1986) contingents of many thousands was provided with adequate radiation protection forces, and cases of exceeding the established dose limits (250 mSv in 1986 and graduated limits of 100 and 50 mSv in subsequent years) were rare and usually occured in cases prescribed by current at that time Radiation Standard-76.

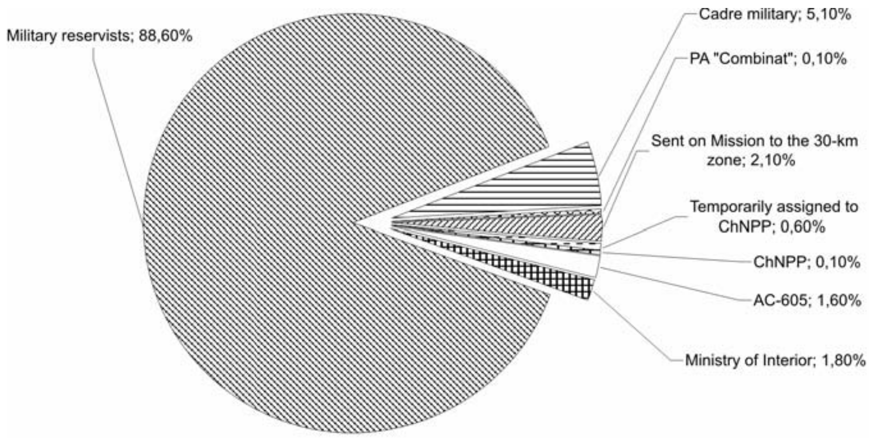


Fig. 3.2. *Distribution of clean-up workerst included in SRU according to departmental affiliation (per survey).*

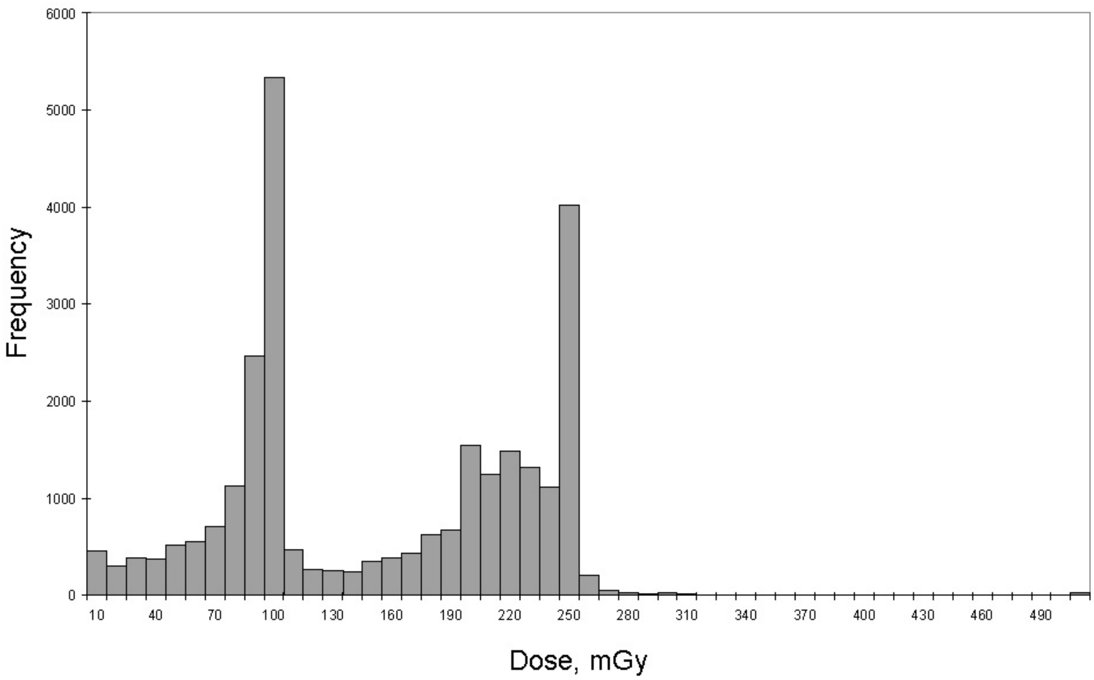


Fig. 3.3. *The distribution of individual doses of military reservists (so called «partisans») of 1986-1987.*

Conclusions:

1. The largest individual doses received so-called early liquidators – people who participated in the clean-up works in April–May, 1986, under conditions of poorly explored radiation situation and lack of adequate facilities for radiation control.

2. Doses of clean-up workers of later periods (since June, 1986) are largely in accordance with established at the time dose limits. Radiation protection system, introduced during the clean-up works, mostly fulfilled its function and provided non-exceeding of permissible exposure.

3. The quality and completeness of dosimetry information significantly differ for different groups of clean-up workers, causing the need for a critical approach to the use of existing dose records, retrospective assessment of individual doses and revision and correction of available dosimetric data.

4. Doses of military liquidators are not characterized by strong falsification, but are displaced (in the direction of overstating actual exposure) and not accurate (with large uncertainty).

5. Studying health consequences of Chernobyl NPP accident among clean-up workers cohort requires broad application of retrospective dosimetry to determine individual doses of subjects research.

6. Developed in recent years retrospective dosimetry methods, in particular instrumental EPR dosimetry on tooth enamel and analytical calculation method RADRUE allow to effectively support the post-Chernobyl epidemiological studies.

7. Beta-radiation gave a significant contribution to the lens doses of clean-up workers. Consideration of this factor is needed in assessing risk of cataract in clean-up workers.

3.1.2. Dosimetry of evacuees

Individual effective dose of irradiation for 12,632 inhabitants of Pripyat (group A, about 25 % of the city evacuated population) and 14,084 residents of other villages of 30 km area (group B) were recovered and analyzed by the method of imitation and stochastic simulation based on direct measurements of dose rate and inquiry of evacuees. Overall evacuees represent 104 village of 30-km zone, including the cities of Pripyat and Chernobyl; 223 residents who lived in 40 settlements of the Belarusian part of the 30-km zone were also interviewed and included in the total number of investigated.

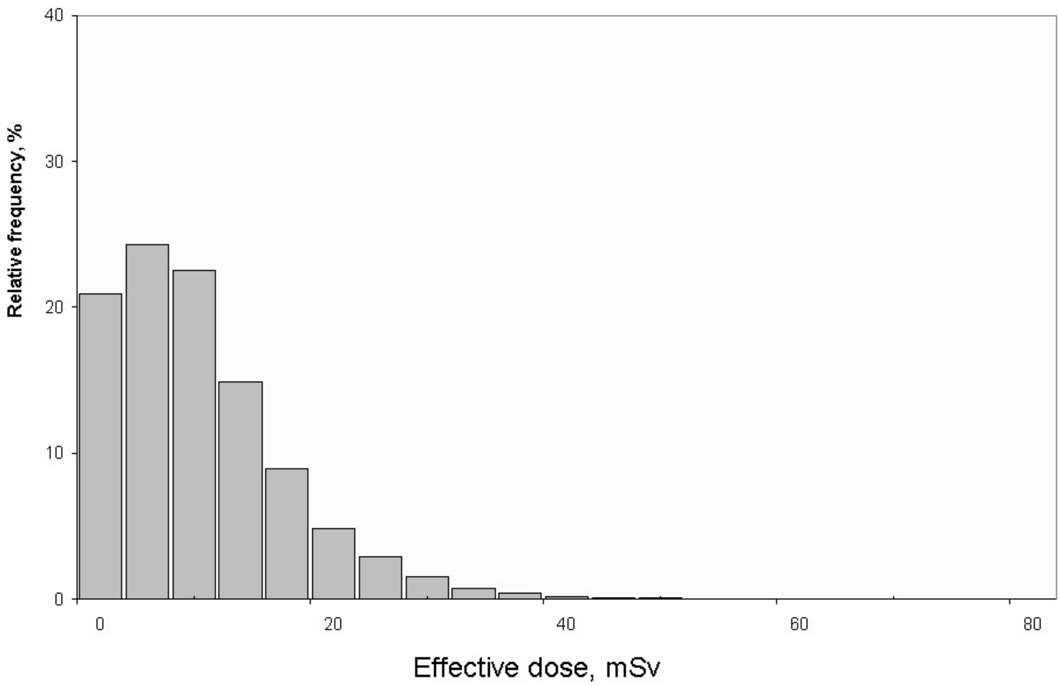


Fig. 3.4. *The distribution of individual doses of irradiation for 12,632 persons evacuated from Pripyat Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)*

Table 3.6.

Parameters of external exposure individual doses distribution for individuals evacuated from Pripyat. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)

Number of persons in the group	12,632
The average portion of time outdoors	0.21
Distribution of effective doses of external gamma radiation exposure (mSv)	
The arithmetic mean	10.1
Median	8.93
Geometric mean	6.79
Geometric standard deviation	3.1
75 percentile	14
95 percentile	24
The coefficient of variation (%)	74

Table 3.7.

The dependence of the distribution of individual external exposure from the age of persons who were evacuated from Pripyat. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)

Birth years	**1983-1986**	**1979 – 1982**	**1974 – 1978**	**1970 – 1973**	**1961 - 1969**	**1931 - 1968**	**до 1931**
Age group (years)	**0-3**	**3-7**	**7-12**	**12-16**	**16-25**	**25-55**	**>55**
Number of persons in the group	1597	2104	2133	601	1159	4456	582
The average portion of time outdoors	0.14	0.17	0.18	0.21	0.25	0.25	0.21
Distribution of effective doses of external gamma radiation exposure (mSv)							
The arithmetic mean	8.32	9.09	9.0	10.5	10.8	11.5	10.2
Error in mean	0.15	0.15	0.14	0.31	0.24	0.12	0.32
Median	7.35	7.89	7.63	9.35	9.63	10.5	8.56
Geometric mean	5.50	6.15	6.32	7.16	6.77	7.85	7.07
Geometric standard deviation	3.18	3.04	2.79	3.02	3.6	3.13	2.74
75 percentile	11.2	12.2	12.2	15.1	15.3	15.6	14.2
95 percentile	20.0	21.2	21.3	24.8	25.9	25.8	23.9
The coefficient of variation (%)	74	75	73	72	75	70	75

Table 3.8.

The dependence of the distributions of individual doses of irradiation from a professional affiliation of persons who were evacuated from Pripyat. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)

Professional group	**Preschoolers**	**Schoolboys**	**Teachers**	**Medical workers**	**Consumers services**	**Workers**	**Engeneers**	**Municipal economy workers**	**Chernobyl NPP staff memberrs**	**Housewives**	**Pensioners**
Number of persons in the group	3494	2945	376	202	799	2629	670	210	452	156	375
The average portion of time outdoors	0.16	0.19	0.22	0.23	0.23	0.26	0.24	0.27	0.28	0.20	0.20
Distribution of effective doses of external gamma radiation exposure (mSv)											
The arithmetic mean	8.81	9.4	10.2	11.5	10.9	11.5	10.8	12.6	13.0	8.94	9.51
Error in mean	0.11	0.13	0.36	0.59	0.28	0.16	0.30	0.73	0.40	0.54	0.35
Median	7.72	7.99	9.66	10.8	9.6	10.5	9.66	10.8	12.4	8.54	8.11
Geometric mean	5.92	6.51	7.35	7.57	7.66	7.7	7.11	8.27	8.39	5.74	6.92
Geometric standard deviation	3.11	2.88	2.72	3.16	2.86	3.21	3.46	3.09	3.84	3.25	2.53
75 percentile	11.89	12.8	13.7	16.5	14.5	15.9	14.9	16.7	18.0	12.8	13.4
95 percentile	20.64	22.6	22.4	27.4	25.1	26.2	24.7	29.7	28.2	20.1	20.4
The coefficient of variation (%)	74	74	68	73	72	71	72	84	66	75	70

The average effective dose of group A contingent that was accumulated prior to evacuation, was 10.1 mSv. Doses of 534 persons from this group exceeded the level of 25 mSv and only 18 people received doses of 50 mSv. Maximum value of effective doses among this group of inhabitants of Pripyat was 75 mSv.

Frequency distribution of individual effective doses is shown in Fig. 3.4. Parameters of this dose distribution are shown in Table. 3.6.

The calculation of external exposure of people evacuated from villages of 30 km zone

Dosimetric models for the rural population were used to calculate individual doses of 14,084 persons evacuated from the settlements of the 30-km zone. The calculation covered the period from the beginning of the accident and till the moment of evacuation beyond the 30-km zone. The average effective dose among this group (about 25 % of the evacuated population) was 15.9 mSv. Among this group the dose of 1,260 persons exceeded 50 mSv for 120 effective doses were higher than 100 mSv and only one person with a dose of 214 mSv dose exceeded 200 mSv. Calculated in the course of revision the average dose of 15.9 mSv was slightly (14 %) lower than the one that was identified in preceding study – 18.2 mSv. This difference has several reasons.

Firstly, from this review 3,119 persons were excluded, who lived in remote from Chernobyl NPP villages and whose doses were, respectively, quite small. On the other hand, a critical review of dose rate measurement forced to reject some, perhaps, false values. In addition, a more sophisticated method of spatial interpolation has prevented the development of artificial unreasonably high values of the interpolated dose rates. For these two reasons, number of persons with high doses slightly decreased. So, if according to the preliminary consideration 644 persons had dose more than 100 mSv, the results of the audit assessed the number of 120 with doses of such magnitude. Moreover, just as in the problem of dose assessment of the urban population, use of age-dependent factors of transition to an effective dose also contributed to a certain reduction of effective doses received as a result of the audit.

Table 3.9.

Parameters of individual doses distribution of external exposure of individuals who were evacuated from villages of 30 km zone. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)

Group strenghs	14,084
The average share of time outdoors	0.41
Distribution of effective doses of external gamma radiation exposure (mSv)	
average	15.9
median	7.77
geometric mean	7.13
geometric standard deviation	4.08
75 percentile	16.1
95 percentile	67.7
coefficient of variation (%)	142

Noteworthy is a very large coefficient of variation of individual doses – 142 %. Such a large variation can be explained by significant differences in dose in different villages of the 30-km zone, varying duration of the population in the zone of radioactive contamination (different time of evacuation), and individual differences in proportion of time spent outdoors. The distribution of individual doses (Fig. 3.5) presented evidence of heterogeneity of presentet in the calculation population, comprising the residents of faintly contaminated villages (such were majority) and dwellers of localities with high dose rate.

Quite a wide was distribution of shares of time outdoors. Fig. 3.6 shows that half of the population spent more than 42 % of time on the street and level of 65 % of time outdoors exceeded 5 % evacuees among the rural population. If the urban population was characterized by average share of 21 % time outdoors, (Table 3.7), the rural residents more time spent in the court, that certainly contributed to higher levels of exposure. Another factor that has considerable influence on the resulting dose was the duration of stay of residents in the area of increased radiation.

The parameters of individual doses distributions for the settlements included in the reconstruction of doses are presented in Table. 3.10. For villages with a number of surveyed less than 20, the median and 95 % quantile were not determined. The table shows that for all sectors except Sector B (Fig. 3.7), maximum (95 % quantile) dose for the individual settlement exceeded the level of 50 mSv. On average, the highest doses were received in the villages Usiv – 154 mSv, Mashevo – 79 mSv (both – Sector C) and Chistogalivka – 70 mSv (Sector A). The parameters of the distributions are shown in the Table. 3.11. For comparison, the table contains parameters for the distribution of Chernobyl – much less affected settlement of the most populated settlements among the 30-km zone population.

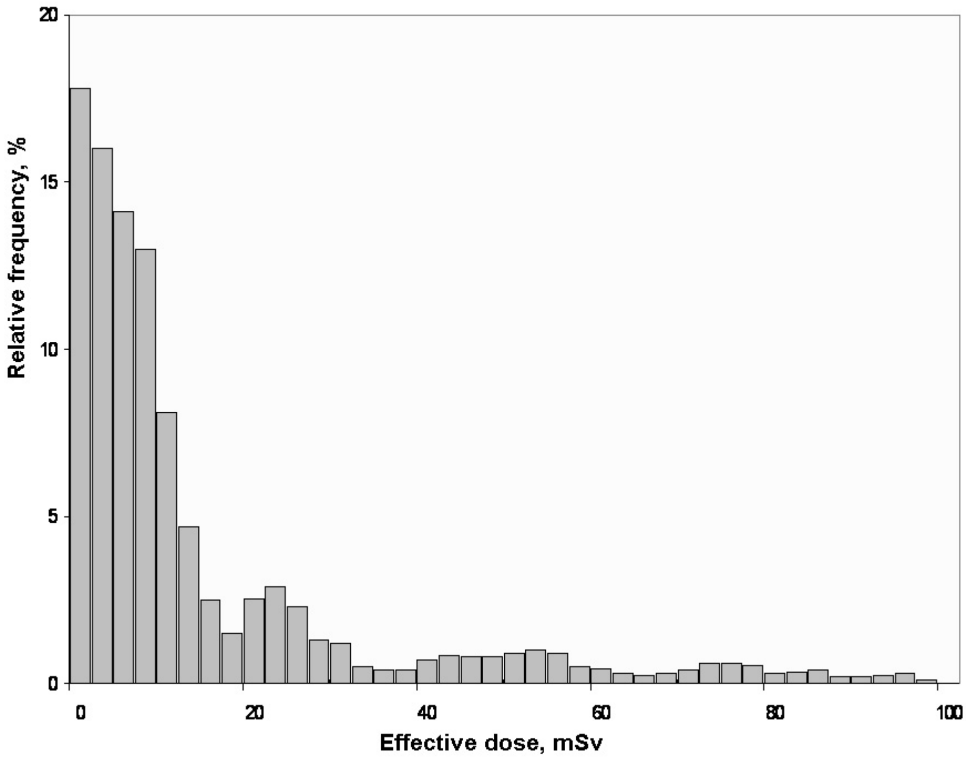


Fig. 3.5. *The distribution of individual doses of irradiation 14,084 persons evacuated from settlements in the 30-km zone. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine).*

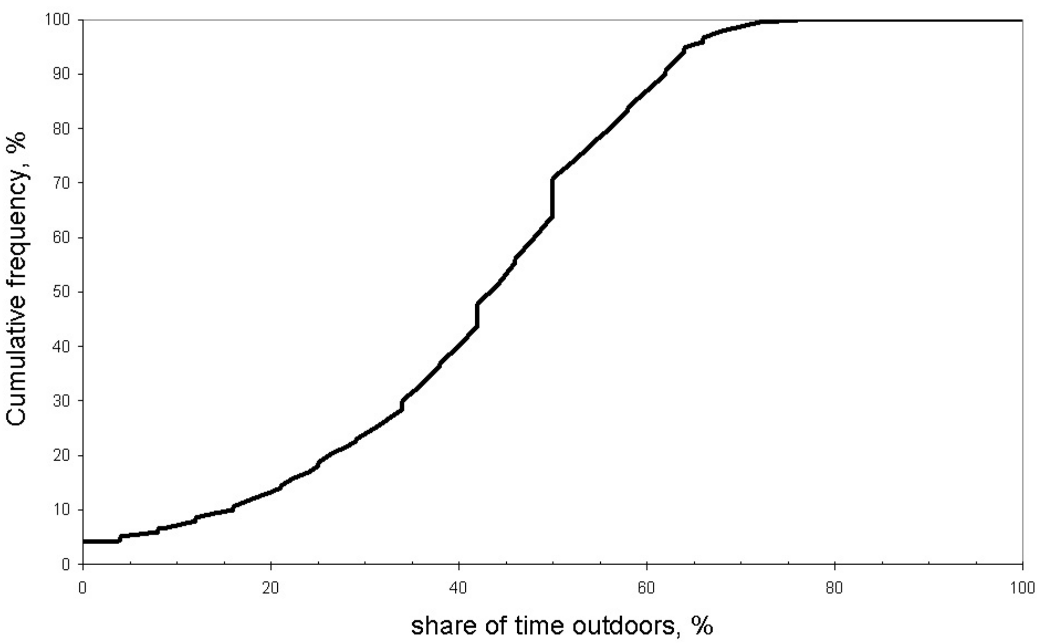


Fig. 3.6. *Cumulative distribution of shares of time outdoors for people who were evacuated from villages of 30 km zone (data of SI «RCRM of AMS of Ukraine).*

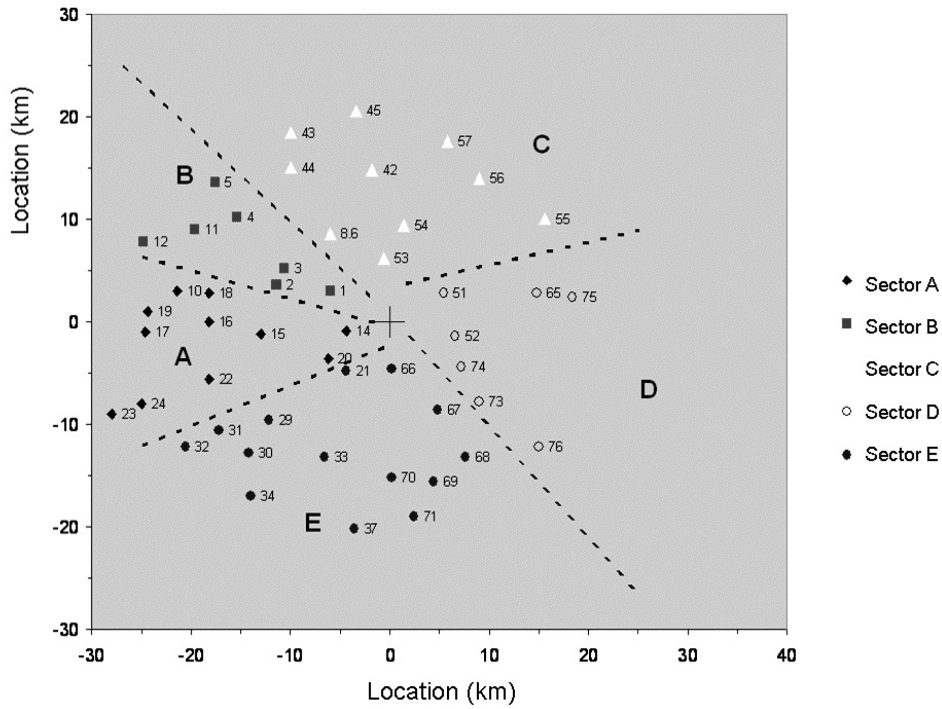


Fig. 3.7. *Location of 30-km zone settlements and distribution per sectors. Line numbers of settlements and their names see in Tables 3.10, 3.11 (data of SI «RCRM of AMS of Ukraine).*

Table 3.10.

Results of deterministic calculation of individual doses for particular settlements of 30-km zone. Location of settlements see Fig. 3.7 (data of SI «RCRM of AMS of Ukraine)

Code	Name of settlements	Quanntity of persons	Day of evaku-ation	Part-time in the open air as, %	Average	Median	95 % percentile
	Sector A						
14	Yaniv	63	3	34	22	9.5	84
20	Chystogalivka	331	7	44	61	70	98
15	Buriakivka	56	8	45	29	24	81
16	Nova Krasnytsia	89	8	48	23	23	29
18	Rechytsia	382	7	50	24	26	33
17	Tovsty Lis	408	8	51	52	60	81
19	Krasne (of Tovstolis rural district)	297	8	49	34	15	97
10	Rud'ky	43	7	32	10	12	19
22	Stara Krasnytsia	20	7	36	9.2	8.4	17
23	Vilshanka	24	10	34	10	11	13
24	Lub'ianka	304	10	46	12	12	16
	Sector B						
1	Novoshepelychi	815	6	37	15	13	31
2	Staroshepelychi	209	7	50	21	22	31
3	Beniovka	101	8	48	18	18	26
4	Bila Sovoka	7	6	41	16	-	-
5	Dovliady	10	5	36	12	10	23
12	Khatky	19	9	44	10	9	12
	Sector C						
54	Mashevo	162	8	54	75	79	96
41	Usiv	89	8	48	150	154	165
43	Molochky	2	7	34	31	-	-
55	Zalissia	2	6	36	12	-	-

Code	Name of settlements	Quanntity of persons	Day of evaku-ation	Part-time in the open air as, %	Average	Median	95 % percentile
56	Kriuky	14	7	44	66	-	-
57	Kulazhyn	2	8	12	28	-	-
	Sector D						
51	Zymovyshche	431	7	37	37	42	56
52	Kryva Gora	146	8	40	47	51	67
74	Starosillia	100	8	40	3	3	4
73	Koshovka	126	8	45	9	8	12
76	Paryshiv	286	8	46	4	4	5
65	Chapaivka	211	8	39	6	7	8
75	Chykalovychy	3	8	50	8	-	-
	Sector E						
66	Copachi	432	8	40	45	53	66
67	Leliov	604	8	42	22	23	30
68	Chernobyl	4558	7	32	6	6	14
69	Zalisssia	1611	8	52	7	8	10
70	Zapillia	69	9	48	6	7	8
71	Cherevach	263	9	47	5	5	8
37	Novosilky	202	9	48	6	6	8
33	Korogod	601	8	52	4	5	6
29	Stechanka	333	8	43	4	4	5
30	Roz’yizzhe	49	8	37	3	3	4
31	Ilintsy	366	8	45	3	3	4
32	Rudnia Illinetska	15	11	36	4	4	5
34	Glinka	227	7	34	2	2	2

Table 3.11.

Parameters of distributions of individual external exposure doses to certain localities of 30 km zone. Results of deterministic calculation (data of SI «RCRM of AMS of Ukraine)

Settlement	**Usiv**	**Mashevo**	**Chystogalivka**	**Chernobyl**
Quantity of group	**89**	**165**	**331**	**4558**
Distribution of effective doses of external gamma radiation exposure (mSv)				
average	150	74.8	60.8	6.38
median	154	78.7	69.7	5.84
geometric mean	146	69.2	44.7	3.4
geometric standard deviation	1,28	1.66	2.77	4.14
95 percentile	165	95.7	98.1	14.4
coefficient of variation (%)	15	27	52	85

It is seen that within the same locality variation of individual doses is rather small. Geometric standard deviation size for small settlements equal to 1.4–2.8 proves for a great homogeneity of the population in terms of exposure, in particular mode of behavior. The exception to this rule are such large settlements like Chernobyl, many population groups of which are characterized by a variety of behavior modes. In addition, the migration of Chernobyl residents out of the city, as well as self-evacuation of some of them resulted in significant expansion of doses absorbed by residents of this settlement. Therefore, geometric standard deviation of the doses distribution of Chernobyl evacuees is very large and complrises 4.14, which is very close to the value of this index calculated for general distribution of doses of 30-km zone evacuees (Table 3.9).

In general, as it is seen from above quite typical examples, the uncertainty of individual dose estimates of the rural population is slightly higher than for the reconstruction of the urban population doses, but even with uncertainty at the level of 60–80 % (coefficient of variation) can be stated that such precision is adequate for the purposes of retrospective assessment of individual doses of population evacuated from the accident.

Doses of evacuation route

The doses received by Pripyat residents during evacuation were estimated as a result of the study. Analysis of routing messages (formal form), completed in 1988–1989 during a large-scale survey of evacuees allowed to identify four main routes by which the people of Pripyat moved in the direction of evacuation points (Table 3.12).

The most significant itinerary was the road to Polisske which passed in the west direction. Prevalent quantity of evacuees took this route. Another, somewhat less important, was the route to Kyiv direction, the path of which went through the «Red Forest», Kopachi, Chernobyl, Cherevach and further to Kyiv. Two less important itineraries were revealed: the railway in the direction of Chernigiv, and self-evacuation on their own transport towards Belarus (the road to the Bila Soroka).

Table 3.12.

Features of evacuation itineraries from Pripyat (per survey)

Current №	Direction of evacuation	Code of route	Number of persons	Percentage of total
1	Polisske	1	6831	42
2	Kyiv	2	4478	27
3	Chernigiv	3	938	6
4	Belorussian	4	612	4
5	The route is not specifically listed	5	2271	14
6	In the villages of 30-km zone	6	1063	7
		Total:	16193	100

These data, in general, are not contradictory to information about the organization and realization of evacuation of Pripyat population.

Analysis of the radiation situation at the evacuation routes showed that the entire itinerary can be divided into two essentially different parts (phases): phase 1, which passed through the 5-km zone of Chernobyl NPP, and the rest of the route (phase 2) from 5-km border zone to the place of destination.

Crucial difference of phase 1 is that the evacuation route crossed several extremely powerful traces of radioactive emissions, the scale (characteristic size) of which sometimes reached only tens or hundreds of meters. The rest of the evacuation (phase 2) went through the less contaminated areas with much lower dose rate overfalls.

As a result, assessment of doses received on these or other routes of evacuation was carried out separately for phases 1 and 2. In the case of phase 1 doses reconstruction was conducted manually using cartograms of radiation environment provided by Chernobyl NPP. In phase 2 dose was estimated by integrating the dose rate profiles along the route.

It appears from the estimation of doses received during each of the routes of movement, that staff evacuation route, anticipated by the plan of civil defense in the Poliske direction was not really less safe than Belarussian direction. On the other hand, a small change of route – leaving the Pripyat through the railway crossing near the plant «Jupiter» instead of travel through the contaminated area near the overpass over the railroad, crossing Pripyat-Chernobyl NPP and cottages south of the station Yaniv – could significantly reduce the dose load of evacuees.

Route to Kyiv was also associated with significant dose load due to travel through a very active spot in the cross NPP-Chernobyl-Pripyat. While the rest of the route to the south laid in less contaminated areas, doses formed at the first site were high enough.

Dose was most intense on the route in the direction of Chernihiv. This route flew about 6 % questioned evacuees. Evacuation in this direction was carried by rail, and electric trains leaved from relatively polluted station Yaniv, than went on the north by the fence of the building site where the dose rates reached a fairly large values. Finally, electric trains made stops provided by schedules at platform Semihody (north-eastern outskirts of Chernobyl NPP), which only led to greater accumulation of doses.

As a result, the doses received by evacuations of rail in the direction of Chernigiv were the largest of all possible routes of evacuation.

Thus, the doses of the majority of Pripyat dwellers, received during the evacuation, were within 11-19 mSv, which can be compared with preevacuation irradiation.

For comparison at the individual level components of the dose before and during the evacuation of each evacuees of those who had the ordinary mode of conduct during the general evacuation and indicated clearly the point of evacuation (in total 6,908 people met these criteria) the dose received at the route of evacuation by individualized estimation was attributed. Then the partial contribution of dose received at the route of evacuation in the total dose of radiation was determined. The distribution of dose partial contributions during evacuation presented in Fig. 3.8, shows that this value varies quite widely, but most likely value is 0.5. The average (52±19) % of dose evacuees received just during evacuation.

Thus, it is obvious that the correct estimation of doses during evacuation significantly change the pattern of irraddiation of evacuated Pripyat population. For comparison, it should be emphasized that in case of evacuation of Pripyat in the direction of the Bila Soroka (Belarus route), the dose due to the evacuation would give the only contribution of 6 % of the total dose.

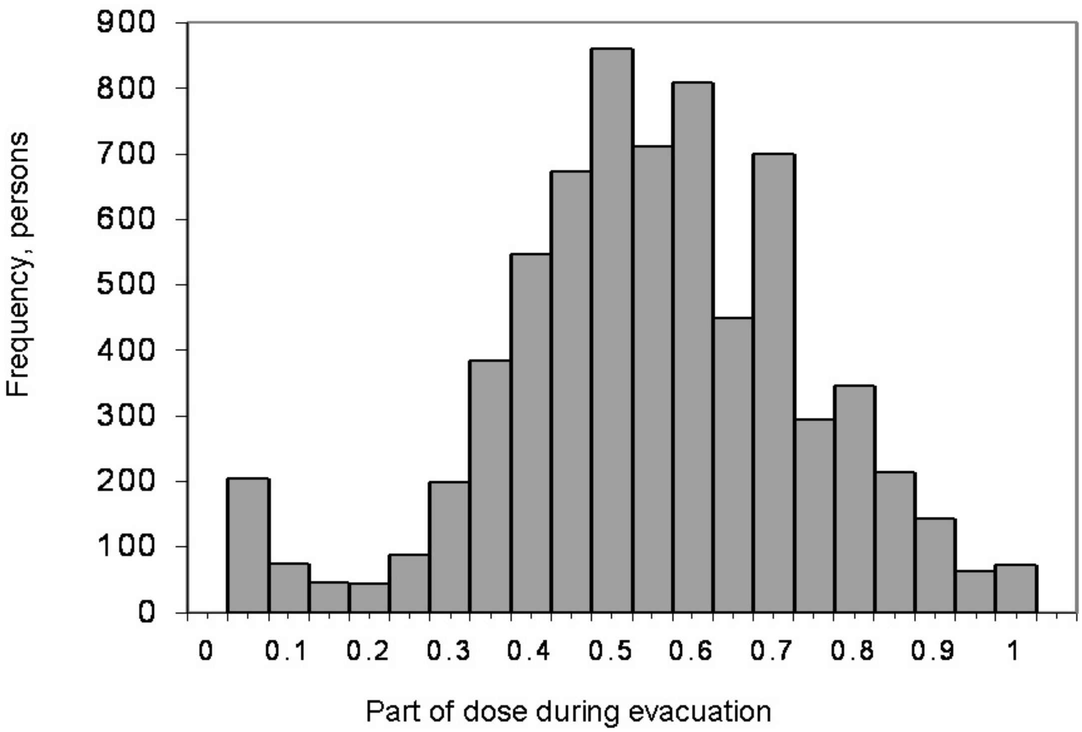


Fig. 3.8. *Fractional contribution of dose received during the evacuation to the total dose of evacuees (data of SI «RCRM of AMS of Ukraine).*

As a result of these efforts, integral dose was estimated separately for each of the four tracks. It appeared that in terms of dose burden during evacuation, manning evacuation route in the Poliske direction, which was the plan of civil defense, was not optimal. Evacuation in the Belarussian direction resulted in the accumulation of an order of magnitude smaller doses than any of the other tracks. On the other hand, driving in the direction of Chernobyl-Kyiv and evacuation by train to Chernigiv gave even higher doses.

Comparison of individualized dose estimates on the evacuation route with individual doses received while staying within the Pripyat during the evacuation, showed that a large number of doses of the evacuation route were comparable or even larger than those that were received prior to evacuation.

In general, the dose of the evacuation route had given the contribution to the total dose of evacuees at around 50 %. Thus, consideration of dose on the evacuation route severely alters the overall picture of evacuees' irradiation.

3.1.3. Population irradiation doses

Radiological monitoring in 1986

In Ukraine in 1986 radiological emergency monitoring was organized so that literally the first hours and days the mass measurement of *gamma-field ratio* in the air from radioactive fallout on the ground, and later – *soil sampling* for gamma-spectrometric studies of radionuclide fallout on the basis of the most radioactively-contaminated areas were carried out.

As for the control of radiation exposure of the population-contaminated areas, the *dosimetry monitoring* was conducted in bulk and enough good quality, as in the earliest (acute) phase of the accident (May-June) when the main source of internal radiation were radioisotopes of iodine, which accumulate in thyroid gland, and at the beginning of the middle phase (August-December, 1986), when the basic role was played by radioisotopes of cesium, which are relatively evenly distributed in the soft tissues.

Total in Ukraine in May–June, 1986 more than 150 thousand direct measurements of radioiodine activity in the thyroid gland of residents of northern districts of Kyiv, Zhytomyr and Chernigiv regions (among them 130 thousand children and teenagers) were made. In addition, since July, 1986 in residents of Kyiv and Zhytomyr regions about 23 thousand measurements of the current content of cesium isotopes in the body (^{137,134}Cs) using whole body counters (WBC) were made.

Doses of irradiation in 1986

Whole body irradiation

Table 3.13 shows values of average doses of internal radiation from cesium residents of districts of Kyiv and Zhytomyr regions, assessed by results of *measurements on whole body counters (WBC)*, conducted in summer and autumn of 1986.

Table 3.13.

Average by districts of Kyiv and Zhytomyr regions individual doses of internal exposure of children and adults from radiocaesium in 1986 (Results of WBC measurements for areas with density of fallout ^{137}Cs in soil >37 kBq·m^{-2} ; data of SI «RCRM of AMS of Ukraine)

District	Children under 10 years			Children over 10 years			Adults		
	number of WBC-measurements	dose, mSv		number of WBC-measurements	dose, mSv		number of WBC-measurements	dose, mSv	
		GM	GSD		GM	GSD		GM	GSD
Zhytomyr region									
Korostens'kyi	-			-			34	0.13	2.9
Lugyns'kyi	-			-			12	0.32	4.8
Narodytskyi	1995	1.8	3.9	1120	1.8	3.9	2753	1.56	4.3
Ovruchskyi	134	1.1	2.8	28	0.43	2.5	18	0.19	3.5
Kyiv region									
Bilotserkivskyi	30	0.44	2.3	26	0.89	1.8	-		
Boguslavskyi	28	0.28	2.4	17	0.30	3.0	-		
Ivankivskyi	208	0.61	3.3	261	0.42	3.0	652	0.29	3.6
Kagarlitskyi	12	0.71	3.2	78	0.39	2.6	-		
Poliskyi	1323	1.2	3.5	1061	0.86	3.3	1872	0.81	3.5
Stavyshchenskyi				31	0.11	3.6	527	0.09	2.8
Chernobylskyi	1195	1.3	5.6	518	0.58	3.3	304	0.61	5.5

Note. GM – geometric mean, GSD – geometric standard deviation

Since WBC monitoring covered the population far from all settlements of radioactively-contaminated areas a *simulation* of the transfer of dose forming radionuclides from Chernobyl release was conducted via the links of trophic chains in the climatic conditions of Ukraine using non-stationary models that are traditionally used for retrospection and prognosis kinetics and levels of radioactive contamination of environmental objects (food in particular) as well as exposure doses of the population consumed these products.

As it was expected, the main source of internal radiation doses in 1986 was the contamination of two components of the diet: leafy green, and milk (and milk products).

Evaluations of effective doses of internal radiation from basic radionuclides of emergency release (per 1 kBq $m^{-2}\cdot{}^{137}Cs$ in soil) obtained according to this model are presented in Table 3.14.

In terms of Western European countries the calculated ratio between doses of first emergency year and doses accumulated over subsequent years, may reach 10 or more in favor of the first year. At the same time a variety of soil characteristics, both in Ukraine and Russia, which makes high (uncharacteristically for European countries) coefficients of radionuclides transfer from soil to vegetation and further into the milk, as well as a retro enough technology of dairy production in the private sector of Ukraine, identified a wide range of internal radiation dose ratios in the first and subsequent years.

Table 3.14.

Effective doses of internal exposure in 1986 from the main radionuclides of Chernobyl release (normalized to 1 kBq·m^{-2} of ^{137}Cs at the soil) in adult rural dwellers of Ukraine, caused by consumption of milk and leafy green (data of SI «RCRM of AMS of Ukraine)

Radionuclide	Relative contributions to total dose of internal radiation dose components					
	«milk»		«leafy green»		total	
	µSv per 1 kBq m^{-2} of ^{137}Cs at the soil	relative contribution to dose (%)	µSv per 1 kBq m^{-2} of ^{137}Cs at the soil	relative contribution to dose (%)	µSv per 1 kBq m^{-2} of ^{137}Cs at the soil	relative contribution to dose (%)
^{89}Sr	0.1	0.16	0.064	1.6	0.16	0.26
^{90}Sr	0.39	0.7	0.094	2.4	0.48	0.8
^{95}Nb	9.8E-07	1.7E-06	0.021	0.5	0.021	0.03
^{95}Zr	4.8E-06	8.2E-06	0.042	1.1	0.042	0.07
^{103}Ru	0.002	0.003	0.11	2.8	0.11	0.18
^{106}Ru	0.015	0.026	0.37	9.5	0.39	0.6
^{125}Sb	0.39	0.7	0.015	0.38	0.41	0.7
^{134}Cs	6.8	12	0.26	6.6	7.1	11
^{137}Cs	10	17	0.36	9.2	10	17
^{136}Cs	0.08	0.1	0.014	0.35	0.10	0.16
^{131}I	41	70	2.3	57	43.3	69
^{141}Ce	1.0E-07	1.7E-07	0.038	1.0	0.038	0.06
^{144}Ce	2.5E-06	4.3E-06	0.21	5.3	0.21	0.34
^{140}Ba	0.001	0.002	0.099	2.5	0.10	0.16
All radionuclides	59	100	4,0	100	63	100

In Ukraine (Table 3.15) the ratio of effective dose of internal radiation of the first year (256 days) to the appropriate dose for the next nearly 20 years (1987–2005) essentially depends on the aggregate value of transfer factor «soil-milk» (TF-92) in a given settlement. In areas where the value TF-92 does not exceed 0.5 Bq·l-1 per kBq·m-2, the ratio of doses of the first and another 19 years is 8-50 in favor of the first year. For areas with TF-92 in the range 0.5-2 Bq·l-1 per kBq·m-2, this ratio is 1-2, but still in favor of the first year. At the same time for the settlements, where the value of TF-92 is 2-20 Bq·l-1 per kBq·m-2 doses in the middle and late phases of the accident exceed the first year, so the first year dose is 13-50 % of the dose for further years. In areas with very high values of TF-92 that exceed 20 Bq·l-1 per kBq·m-2 doses of the first year do not exceed 9 % of the accumulated dose for subsequent years.

Table 3.15.

The ratio of internal radiation doses in 1986 to the appropriate doses for the 1987-2005 depending on interval values of the aggregated transfer factor «soil-milk» (TF-92). Doses were estimated by the Method-97 (total 4270 settlements of Ukraine)

TF-92 * Bq · l^{-1}per kBq·m^{-2}	D-86/D87-05 doses ratio	Number of settlements
<0,05	49	269
0,05-0,1	48	261
0,1-0,2	15	1106
0,2-0,5	8,0	1097
0,5-1	2,6	478
1-2	1,1	354
2-5	0,51	404
5-10	0,25	146
10-20	0,13	115
20-100	0,09	40

* TF-92 value was determined for a fixed time interval 1991-1993 based exclusively on results of monitoring radioactive contamination of soil and milk in every settlement

Thus, in some agro-ecological conditions (peat-swampy acidic soil of pastures) the population can receive significantly larger doses of internal irradiation in postaccidental period compared with doses of emergency first year (for example, a number of settlements Rokytne district, Rivne region, and Kamin-Kashirskyi district, Volyn region). On the other hand, where the black earth were prevailing, internal radiation doses accrued subsequent years may be a small fraction of the first year dose (for example, a number of settlements, Cherkassy region).

Irradiation of the thyroid

The most significant in terms of radiation exposure and expected radioinduced consequences after Chernobyl accident was thyroid irradiation of children by radioiodine that came mainly from contaminated milk, dairy products and leafy green in May-June, 1986. A three-level system of reconstruction of thyroid doses developed and verified on the results of direct measurements allowed to execute the average gender-age settlement-specific doses of the thyroid gland for all settlements of Ukraine (Table 3.16).

Table 3.16.

Average regional thyroid doses (mGy) in different age groups of inhabitants of different regions of Ukraine

Region	The average thyroid dose (mGy) by age groups (years)				
	< 7	7-14	15-18	>18	all
Vinnitsa	37	13	9.8	9.2	12
Volyn	87	33	25	21	31
Lugansk	12	4.0	3.1	3.1	4.1
Dnipropetrovsk	13	4.4	3.4	3.4	4.5
Donetsk	24	8.0	6.0	6.1	8.1
Zhytomyr	231	87	67	60	81
Transcarpathian	7.6	2.8	2.1	1.8	2.7
Zaporizhzhia	26	8.8	6.2	6.5	8.8
Ivano-Frankivsk	19	7.1	5.3	4.6	6.7
Kyiv	202	75	58	53	71
Kirovograd	89	31	23	23	30
AR Crimea	34	12	8.8	8.4	12
Lviv	14	4.9	3.8	3.5	4.8
Mykolaiv	20	7.1	5.4	5.0	7.0
Odessa	15	5.2	3.8	3.7	5.1

Region	The average thyroid dose (mGy) by age groups (years)				
	< 7	7-14	15-18	>18	all
Poltava	54	19	15	13	18
Rivne	177	64	49	42	62
Sumy	71	25	19	19	24
Ternopil	18	6.4	4.8	4.5	6.2
Kharkiv	26	8.7	6.5	6.6	8.6
Kherson	30	11	7.8	7.3	10
Khmelnytsky	39	15	11	10	14
Chercassy	142	52	39	37	49
Chernivtsi	40	14	10	9.3	13
Chernigiv	151	55	43	37	50
Kyiv city	94	30	23	24	32
Sevastopol city	56	18	14	14	19
All Ukraine	55	20	15	14	19

Table 3.17

The relative distribution of child, adolescent and adult population with a mean absorbed doses of thyroid

	Relative (%) distribution of population				
Dose interval, Gy	< 7 years	7-14 years	15-18 years	>18 years	entire population
< 0.05	72	93	95	95	92
0.05–0.1	15	4.4	3.5	3.7	5.0
0.1–0.2	8.2	2.2	1.3	1.1	2.0
0.2–0.5	3.7	0.76	0.40	0.21	0.65
0.5–1.0	0.77	0.08	0.05	0.04	0.12
1.0–2.0	0.15	0.03	0.02	0.01	0.03
2.0–5.0	0.04	0.007	0.005	0.004	0.008
>5.0	0.01	0.0005	–	–	0.001

Dosimetric certification and radiological monitoring at the middle and late phases of disaster

«The Concept of the Annual Total Effective Dose», adopted in 1991, was important for planning and carrying out measures to reduce the impact of radioactive emissions on the population. Regulations of this concept were legalized in the Law of Ukraine № 791a-XII «On legal regime of territories which have undergone radioactive contamination as a result of the Chernobyl disaster» (1991) and in the Law of Ukraine № 796-XII «On the status and social protection of citizens affected by the Chernobyl disaster» (1991).

The basic principle of Concept lay in that for the critical population group (children born in 1986), the value of calculated effective dose of additional radiation associated with the Chernobyl disaster, should not exceed 1.0 mSv (0,1 rem) per year and 70.0 mSv (7.0 rem) for life (over the dose received by the population in pre-accident period in certain natural conditions).

The density of soil contamination with radionuclides was taken as a provisional criterion. These laws set a four territorial zone of radioactive contamination (Table 3.18).

In Appendix 1 of the Decree of Cabinet of Ukraine № 106 from July 23, 1991 a list of 2172 settlements was given, which were formally assigned to one of four zones of radioactive contamination according to the Law of Ukraine № 791a-XII.

Annual dosimetric certification was held in Ukraine since 1991 until 2008. All dose calculations were based on results of annual measurements of radiocaesium contamination of milk and potatoes produced in those settlements, which were determined by the Decree of Cabinet of Ukraine № 106. In addition, for radiation monitoring of affected areas residents a united WBC network of Ukraine was set up during the 1995-1997, providing operational control of the levels of radiocaesium in the body of the inhabitants of affected areas (Fig. 3.9).

Table 3.18.

Areas of contamination according to criteria of the annual dose and density of radionuclides fallout determined by The Law of Ukraine № 791a-XII (1991)

Territorial zone		Zoning criteria			
		fallout density on soil, kBq m^{-2} [(a)]			the annual dose mSv $year^{-1}$
		radiocaesium	radiostrontium радіостронцій	plutonium	
1	Exclusion zone	-	-	-	-
2	Zone of implicit (mandatory) resettlement	>555	>111	>3.7	>5
3	Zone of guarantee voluntary resettlement	185-555	5.5-111	0.37-3.7	>1
4	Zone of enhanced radiation monitoring	37-185	0.74-5.5	0.18-0.37	>0.5

[(a)] – in the text of the Law fallout density is given in units of «Ci·km^{-2}»

Medical organization of 12 most affected regions of Ukraine were provided with 57 units of WBC «Skrynner-3M» both stationary (40 units) and mobile (17 units) samples produced at the Institute of Human Ecology (Kyiv) with the use of program-methodical and metrology software, developed by the Department of Dosimetry Control of SI «RCRM of AMS of Ukraine». From 1995 to 2008 about 800 thousand WBC measurements was held within the network of WBC. The table 3.19 contains the relative distribution of all certified settlements according to established territorial areas as a result of dose certification within 2001-2008.

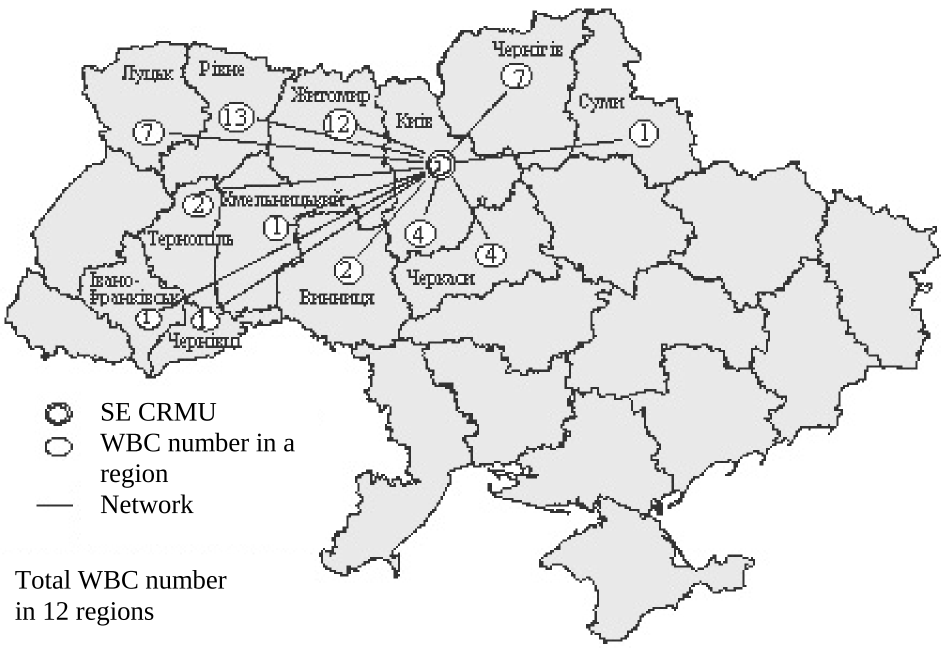


Fig. 3.9. *WBC Unified Network of Ukraine, established under the dosimetric certification.*

The dynamics of change in numbers of settlements in different zones in 2001, 2005 and 2008 for selected regions of Ukraine where the largest number of settlements were dose certified is shown in Table 3.19. As it is seen from the table data, since 2001 ~ 15–19 % of all certified settlements were in the 4th zone of «Enhanced radiation monitoring», and 70–80 % in general were outside the established territorial zones of radioactive contamination.

It should be noted that in the Kiev and Zhytomyr regions in 2001–2008, the number of settlements in 2nd – 4th zones continuously decreased in comparison with the official distribution by the Decree of

Cabinet of Ukraine № 106 (Table 3.20). Most of the settlements in these areas were «shifted» to «safe» zone, where passport annual dose did not exceed 0.5 mSv. In the Rivne region, according to Decree of Cabinet of Ukraine № 106 the majority (~ 76 %) of settlements was attributed to the third zone of «voluntary resettlement» (passport dose should be between 5.1 mSv). But in 2001 already, in this zone remained ~ 30 % of settlements and in 2008 ~ 7 % of the settlements. Most of the settlements «shifted» in the 4th zone (passport dose – 0.5–1 mSv), or «safe» zone (passport dose <0.5 mSv).

Table 3.19.

Change in time (2001-2008) distribution of settlements according to value of passport dose

Year	Quantity of certified settlements	Relative number (%) of certified settlements with the passport dose (mSv per year)			
		< 0.5	0.5-1	1-5	>5
		«safely»	4 zone	3 zone	2 zone
2001	2163	67	15	18	0,23
2002	2163	68	15	17	0,14
2003	2163	71	16	13	0,09
2004	2163	72	19	9	< 0,01
2005	1831	66	14	5	< 0,01
2006	1967	82	14	3,5	0,05
2007	1596	81	15	3,6	< 0,01
2008	1925	86	12	0,02	-

Table 3.20.

A comparative analysis of certification of settlements of Ukraine in 2001, 2005, and 2008

Region	Quantity of inhabited localities with annual doses *(mSv year^{-1})*												
	total	2001				2005				2008			
		≤ 0,5	0,5-1	1-5	>5	≤ 0,5	0,5-1	1-5	>5	≤ 0,5	0,5-1	1-5	>5
Vinnitsa	89	89	-	-	-	88*	-	-	-	87	-	-	-
Volyn	166	-	3	163	-	107	55	3	-	121	40	3	-
Zhytomyr	698	472	135	93	-	524	96	43	-	569	74	14	-
Kyiv	469	441	23	5	-	428	13	3	-	383	9	-	-
Rivne	339	99	109	126	5	151	122	59	-	150	99	25	-
Cherkassy	103	101	2	-	-	100*	2*	-	-	100	2	-	-
Chernigiv	248	205	41	2	-	216	11	-	-	205	11	-	-

Note: *- data for 2006 (in 2005 dose certification was not performed)

In 2008, almost 82 % of the settlements of Kyiv and Zhytomyr regions referred by the Decree of Cabinet of Ukraine № 106 to 2nd – 4th zones actually have a «passport» dose of less than 0.5 mSv/year. That is, the dose criterion of the territory of these settlements have already lost the status of «victims». At Rivnenshchina passport doses below 0.5 mSv per year had 44 % of settlements.

There is an annual reduction of settlements, which according to the dose criteria can be attributed to 3rd zone (1–5 mSv • year-1). For the 2nd zone (dose >5 mSv), since 2000 in Kyiv and Zhytomyr regions there were actually no settlements belonging to that area, and in Rivne region in 2001 in this zone were to be only 5 settlements.

Table 3.21.

Effective dose (mSv) external, internal and total irradiation of different regions of Ukraine depending on the density of fallout ^{137}Cs in soil in 1986

Region	Density of ^{137}Cs fallout. kBq /м^2	% of popula tion	EFFECTIVE DOSE (MSV) according to years of exposure				
			external		internsl		total
			1986	1987-2011	1986	1987-2011	1986-2011
Vinnitsa	<37	94	0.24	0.47	0.51	0.25	1.5
	37-185	6.3	1.7	3.4	3.40	0.31	8.8
Volyn	<37	97	0.19	0.38	0.43	2.4	3.4
	37-185	2.6	1.4	2.9	3.0	13	20.3
Lugansk	<37	99	0.34	0.68	0.48	0.22	1.7
	37-185	0.69	1.0	2.1	1.7	0.33	5.2
Dnipropetrovsk	<37	100	0.1	0.19	0.18	0.19	0.65
	37-185	0.02	1.29	2.6	2.8	0.40	7.1
Donetsk	<37	94	0.2	0.39	0.29	0.21	1.1
	37-185	5.6	1.1	2.2	1.4	0.27	5.0
Zhytomyr	<37	75	0.2	0.4	0.37	0.58	1.5
	37-185	17	2.5	5.1	1.4	5.9	14.9
	185-555	7.2	6.8	14	1.9	3.4	25.8
	555-1440	0.69	20	39	8.2	12	79
	>1440	0.06	52	103	22	32	208
Transcarpathian	<37	100	0.12	0.25	0.24	0.19	0.80
Zaporizhzhia	<37	100	0.07	0.15	0.15	0.16	0.52
Ivano-Frankivsk	<37	95	0.26	0.52	0.55	0.36	1.7
	37-185	4.6	1.7	3.4	3.5	0.5	9.0
Kyiv	<37	76	0.45	0.89	0.5	0.42	2.3
	37-185	22	1.9	3.8	1.5	1.0	8.2
	185-555	1.1	8.2	16	6.5	2.7	34
	555-1440	0.66	26	52	8.2	1.5	88
	>1440	0.08	92	184	41	57	375
Kirovograd	<37	99	0.20	0.40	0.37	0.15	1.1
	37-185	0.68	1.6	3.2	3.5	0.29	8.7
AR Crimea	<37	100	0.12	0.23	0.20	0.17	0.72
Lviv	<37	100	0.09	0.17	0.17	0.16	0.58
	37-185	0.008	1.2	2.4	2.6	1.5	7.7
Mykolaiv	<37	100	0.12	0.24	0.22	0.15	0.73
	37-185	0.06	2.4	4.8	5.3	0.50	13
Odessa	<37	100	0.19	0.38	0.34	0.15	1.1
	37-185	0.19	1.3	2.7	2.9	1.5	8.5
Poltava	<37	100	0.17	0.33	0.31	0.22	1.0
Rivne	<37	78	0.28	0.56	0.45	1.1	2.4
	37-185	21	2.2	4.3	1.9	14	22
	185-555	0.39	7.2	14	5.9	14	42
Sumy	<37	99	0.21	0.42	0.41	0.32	1.4
	37-185	0.98	1.91	3.8	4.1	1.2	11
Ternopil	<37	97	0.15	0.30	0.35	0.37	1.2
	37-185	3.0	1.6	3.1	3.3	0.77	8.7
Kharkiv	<37	100	0.18	0.36	0.32	0.17	1.0
	37-185	0.01	1.12	2.2	2.4	0.54	6.3
Kherson	<37	100	0.07	0.14	0.14	0.13	0.49
Khmelnytsky	<37	98	0.16	0.33	0.35	0.26	1.1
	37-185	1.7	1.6	3.3	3.6	0.29	8.7
	185-555	0.003	6.7	13	15	0.15	35

Region	Density of ^{137}Cs fallout. kBq /м^2	% of population	Effective dose (mSv) according to years of exposure				
			external		internsl		total
			1986	1987-2011	1986	1987-2011	1986-2011
Chercassy	<37	84	0.30	0.59	0.59	0.27	1.7
	37-185	15	1.9	3.7	3.3	0.54	9.5
	185-555	0.37	7.3	15	15.8	0.12	38
Chernivtsi	<37	92	0.36	0.72	0.74	0.35	2.2
	37-185	7.6	1.7	3.4	3.2	0.34	8.6
	185-555	0.31	5.9	12	13	0.25	31
Chernigiv	<37	97	0.23	0.45	0.41	0.50	1.6
	37-185	3.2	1.8	3.6	2.3	2.2	9.8
	185-555	0.08	7.4	15	8.1	4.0	34
	555-1440	0.01	18	35	35	12	100
Kyiv city	<37	100	0.48	0.96	0.28	0.13	1.9
Sevastopol city	<37	100	0.2	0.40	0.34	0.14	1.1

Table 3.22.

Distribution of population-weighted effective doses of total exposure of the inhabitants of Ukraine in general, depending on the density of fallout ^{137}Cs in soil

Fallout density of ^{137}Cs in soil kBq/m^2	% of population	Irradiation, mSv				
		external		internal		total
		1986	1987-2011	1986	1987-2011	1986-2011
<37	96	0.20	0.41	0.33	0.29	1,2
37-185	3.7	1.8	3.7	2.1	3.3	11
185-555	0.29	7.0	14	3.5	3.4	28
555-1440	0.04	23	46	8.4	6.4	84
>1440	0.005	77	154	34	47	313

Table 3.23.

Population-weighted effective doses (mSv) of total whole body irradiation of the inhabitants of different regions of Ukraine

Region	Population-weighted effective doses (mSv) of total whole body irradiation according to time intervals (years)			
	1986	1987-1996	1997-2011	1986-2011
Vinnitsa	1.02	0.61	0.30	1.93
Volyn	0.72	2.34	0.81	3.86
Lugansk	0.84	0.60	0.31	1.75
Dnipropetrovsk	0.27	0.25	0.13	0.65
Donetsk	0.60	0.47	0.25	1.32
Zhytomyr	1.96	2.91	1.32	6.19
Transcarpathian	0.37	0.30	0.13	0.80
Zaporizhzhia	0.22	0.20	0.10	0.52
Ivano-Frankivsk	1.01	0.70	0.31	2.03
Kyiv	1.96	1.86	0.94	4.76
Kirovograd	0.61	0.38	0.19	1.18
AR Crimea	0.32	0.27	0.13	0.72
Lviv	0.25	0.22	0.11	0.58
Mykolaiv	0.35	0.26	0.13	0.74
Odessa	0.54	0.35	0.18	1.07
Poltava	0.48	0.38	0.17	1.04
Rivne	1.48	3.77	1.47	6.72
Sumy	0.67	0.53	0.25	1.45
Ternopil	0.63	0.54	0.23	1.40
Kharkiv	0.50	0.36	0.17	1.03
Kherson	0.22	0.19	0.09	0.49

Region	Population-weighted effective doses (mSv) of total whole body irradiation according to time intervals (years)			
	1986	1987-1996	1997-2011	1986-2011
Khmelnytsky	0.59	0.43	0.20	1.22
Chercassy	1.63	0.95	0.49	3.07
Chernivtsi	1.45	0.88	0.43	2.75
Chernigiv	0.77	0.79	0.34	1.90
Kyiv city	0.76	0.71	0.39	1.86
Sevastopol city	0.54	0.35	0.19	1.08
All Ukraine	0.71	0.69	0.32	1.72

Table 3.24.

Relative (%) distribution of citizens of Ukraine living in rural areas with levels of fallout ^{137}Cs> 37 kBq•m^{-2} (in 1986), according to intervals of effective whole body dose accumulated at various times after the Chernobyl accident

Dose intervals (mSv)	Time intervals (years)			
	1986	1987-1996	1997-2011	1986-2011
	% of the whole population			
<1	-	-	21	-
1-2	6.2	22	34	-
2-5	60	40	31	9.4
5-10	26	19	11	40
10-20	6.9	15	2.7	31
20-50	0.78	4.2	0.21	18
50-100	0.01	0.14	-	1.5
>100	-	-	-	0.08

3.2. The population health and strategy for its conservation in remote post-accident period

Ukraine belongs to countries with priority development of nuclear energy. Since the beginning of 1930 deployed nuclear research, and the late 40's – industrial production and uranium enrichment. Application of nuclear technology was accompanied by an uncontrolled increase in personnel and public exposure with the backlog of medical protection. The most dramatic example of this attitude was the Chernobyl accident.

Those exposed to radiation from artificial radioactive sources in Ukraine belongs to the following groups:

- Personnel and firemen of Chernobyl NPP diagnosed with acute radiation syndrome, militaries-participants of nuclear tests in the former USSR;
- Other groups affected by the Chernobyl accident (clean-up workers, population of radiation contaminated areas, children irradiated before birth, or born to exposed parents);
- Operational staff of operating nuclear power plants in Ukraine;
- The staff of the 30 km zone and those engaged in transforming the «Shelter» in radiation safe site;
- Personnel of mines and factories of nuclear cycle and the population living in areas of plant and tailings.

As of 01.01.2010 in the organs of Labour and Social Welfare of Ukraine were registered 2,254,471 citizens affected by the Chernobyl disaster, including 260,807 the Chernobyl clean-up workers (including 65,666 people of 1st category, 154,238 people of 2nd category and 40,903 persons of 3rd category). There are 1,993,664 sufferers of Chernobyl disaster, including: 45,161 persons of category 1, 64,660 people of category 2, 460,465 people of category 3, 922,762 people of category 4. Children-victims of the Chernobyl disaster are registered as 498 409 persons.

The current situation leaves no other way to Ukraine than the continued deployment of the full nuclear fuel cycle and expanding the use of nuclear energy. The development of this industry is only possible when using the internationally recognized technology and experience of medical radiation protection.

Such experience was earned as a result of work to overcome the health consequences of the Chernobyl disaster, it is unique in the world as the preferred international heritage of Ukraine and consists of the following results:

- study of the basic patterns of migration of radionuclides in the environment in post-accident period;
- long-term study of the impact of dose-forming radionuclides on human health after the accident;
- monitoring of people affected by the Chernobyl disaster, with the primary survey of children and persons of child-bearing age;
- study of patterns of development and course of diseases, mortality from diseases determining the health state of the population affected by the Chernobyl disaster, and develop medicines to alleviate the negative effects of the disaster in the remote period after exposure;
- identification of risk factors for most common diseases leading to disability among persons affected by the Chernobyl disaster;
- improvement of existing and development of new economical and minimally invasive methods of diagnosis and treatment, rehabilitation and prevention, aimed to preserv and restor the health of persons affected by the Chernobyl disaster;
- design of principles of complex evaluation of the effectiveness of measures to mitigate the effects of technological accidents;
- study of acute effects (acute radiation syndrome, ARS), clean-up workers without ARS and associated fatal effects in general populations exposed to much lower doses;
- evaluation of radiation-induced cataracts in clean-up workers exposed to relatively high doses and possibly increased risk of cataracts in those exposed to radiation doses that do not exceed 0.25 Gy;
- detection of thyroid cancer in persons exposed to ^{131}I in childhood and adolescence;
- evidence of increased risk of leukemia among clean-up workers of early and more distant periods.

The study of radiation effects have gained international recognition at 56th (2008) and 57th (2010) sessions of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). It should be noted that scientists of the most affected countries – Ukraine and Belarus put up a united front.

3.2.1. The health state of the Chernobyl NPP accident clean-up workers

According to the annual clinical examination of affected troops 314,192 clean-up workers of the Chernobyl accident are registered in SRU, among them 207,486 – liquidators of 1986–1987.

Epidemiological studies after the accident revealed in clean-up workers growing rate and radiation risks of stochastic and non-stochastic effects of irradiation – leukemia, some forms of solid cancers, non-tumor diseases. Descriptive analysis of long-term monitoring of tumors in affected populations shows the excess of national rates of this pathology only in the clean-up workers of 1986–1987 participation. Among all the forms the largest increase was in cases of thyroid cancer – 5.6 times. Incidence of breast cancer in female liquidators of 1986–1987 exceeded the expected level 1.5 times (Table 3.25).

Analysis of the radiation risks of leukemia in liquidators, jointly held by RCRM and U.S. National Cancer Institute under an agreement between the Governments of Ukraine and the United

States 1999, based on an assessment of 162 cases of leukemia among liquidators diagnosed during the period 1986–2006 found by case-control study in the cohort of over 110 thousand clean-up workers and confirmed by international hematological examination.

Table 3.25.

Incidence of certain forms of cancer in Chernobyl accident clean-up workers (data of SI «RCRM of AMS of Ukraine)

Group of clean-up workers (observation period) and nosology according to ICD-10	Number of cases		Standardized incidence rate (SIR %)	95% confidence interval
	expected	actual		
Clean-up workers of 1986-1987 (2004-2007): malignant neoplasms (C.00-C.96)	6,649	7,190	108.1	105.6-110.6
Clean-up workers of 1986-1987 (2004-2007): thyroid cancer (C.73)	53	299	564.2	500.2-628.1
Female clean-up workers of 1986-1987 (2004-2007): breast cancer (C.50)	149	226	151.7	131.9-171.5

A reliable excess risk of leukemia was determined in the first fifteen years after exposure (Table 3.26). The results were confirmed in Russian liquidators by research of a group of International Agency for Research on Cancer of United Nations Organization. In the next 5 years a trend towards reduction of radiation risks of leukemia among the liquidators was noted, coinciding with the survey data of victims of the atomic bombing.

Table 3.26.

Risks of leukemia in liquidators of the accident (according to Ukrainian-American project, October, 2010)

Observation period	Excess relative risk, ERR	95% confidence interval	Degree of probability, p
1986 – 2000	3,44	0,47 – 9,78	< 0,01
1986 – 2006	1,37	0,08 – 3,78	0,03

Analyzed number of leukemias registered in the cohort of liquidators for the period 1986–2006 demonstrated an increase in the incidence of lymphoid type leukemia – chronic lymphoid leukemia (CLL) compared to non-lymphoid type.

According to statistics, the incidence of CLL in the Ukrainian population holds a dominant position.

Preliminary analysis of the incidence among the male clean-up workers (20 years and over) showed the change of structure with increasing number of individuals with CLL compared to similar indices in Ukraine as a whole: the incidence of CLL among the male population of Ukraine was 42 %, and among the liquidators, about 60 %; acute myeloid leukemia and chronic myeloid leukemia in the population of Ukraine were 12 % and 13 %, and among liquidators – 6 % and 17 % respectively. Other oncohematological diseases play negligible role in the structure of morbidity among liquidators (Fig. 3.10, 3.11).

Results of hematopoietic system monitoring among clean-up workers have shown that in early postemergency period in peripheral blood of 25 % examined were recorded reduction in the number of leukocytes (leukopenia) and in 12 % – leukocytosis. In 9.5 % of persons increased content of red blood cells and hemoglobin level were recorded, in 9 % – thrombocytosis in 14.5 % – lymphocytosis and in 10.5% – monocytosis. In the remote observation periods after the accident were determined: leukocytosis in 24 %, leukopenia in 19,7 %, thrombocytopenia in 7,6 %, thrombocytosis in 2.4%. In 15 % of cases bi- and pancytopenia were found. For 2010 remains stable percentage of patients with leucopenia, thrombocytopenia and anemia and slightly increased the number of people with lymphocytosis.

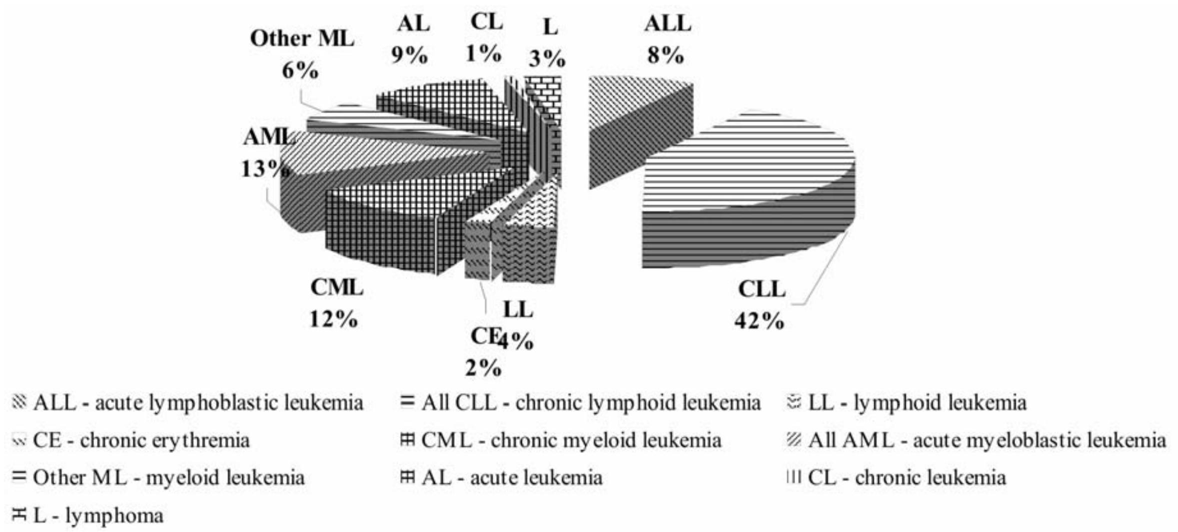


Fig. 3.10. *Structure of the leukemia cases among men aged 20 and older in Ukraine in 2005.*

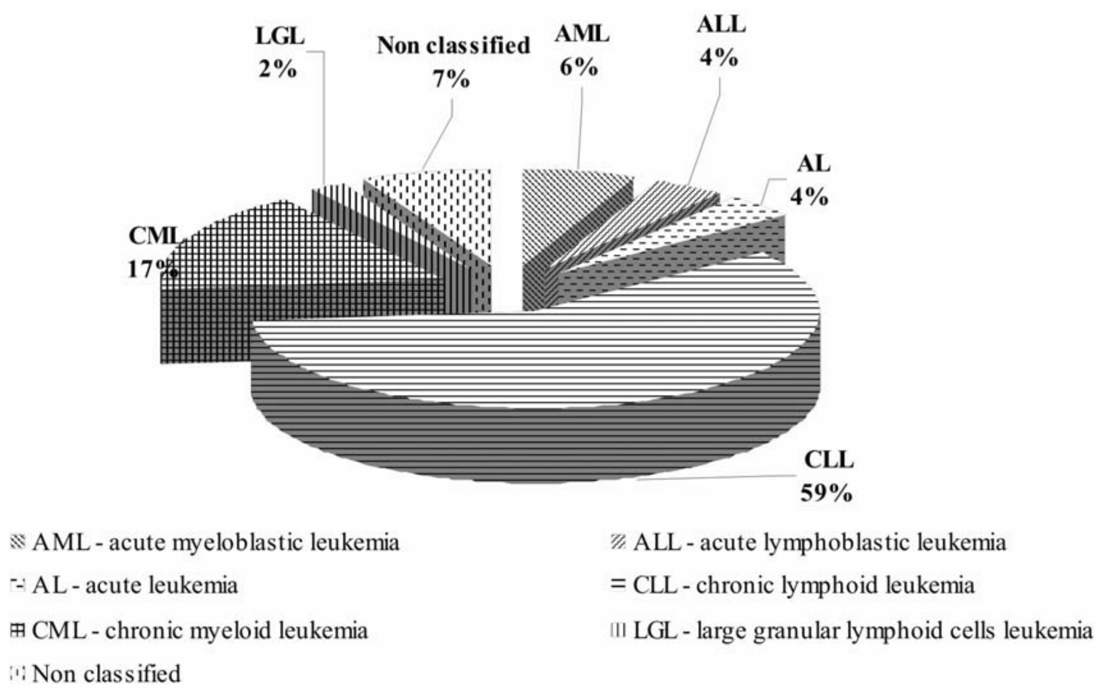


Fig. 3.11. *Structure of the leukemia cases identified in the cohort of liquidators of the accident (1987-2006) (data of SI «RCRM of AMS of Ukraine)*

For the whole period of observation at a relative normalization of the quantitative indices qualitative abnormalities were characteristic in the nucleus and cytoplasm of the cell elements. Megakaryocytes were recorded with increasing number of «old» cells, the presence of giant platelets, cells with polymorphic grain, and in part of examined – aggregates of platelets, and accumulation of micro- makroforms.

Non-tumor morbidity of clean-up workers

From 1988 to 2008 among clean-up workers proportion of healthy people decreased from 67.6 % to 5.4 %, chronic non-cancer pathology respectively increased from 12.8 % to 83.3 % (Fig. 3.12).

Worsening of clean-up workers health was associated with complex radiation and non-radiation factors such as age at the time of exposure, time at risk and others.

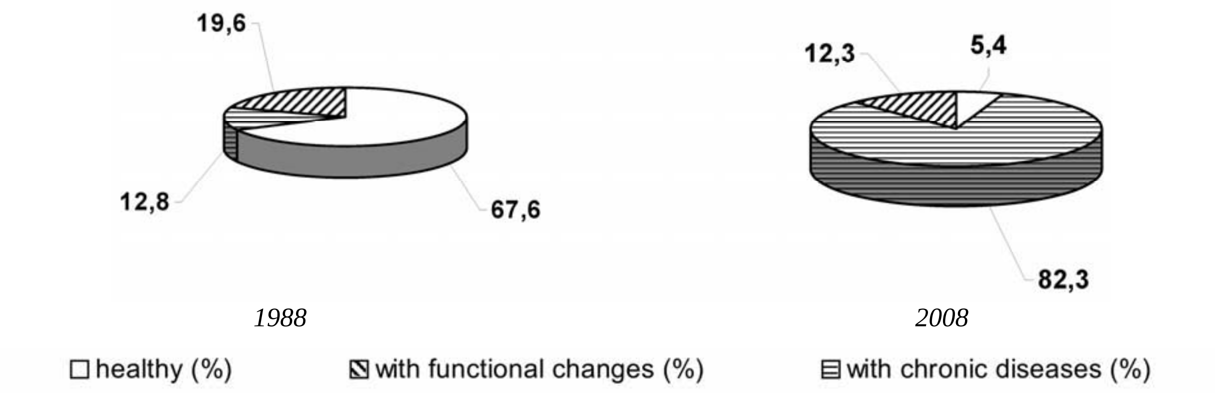


Fig. 3.12. *Dynamics of integral health indices of the Chernobyl clean-up workers of 1986-1987 during 1988-2008 (the data of SI «RCRM of AMS of Ukraine»)*

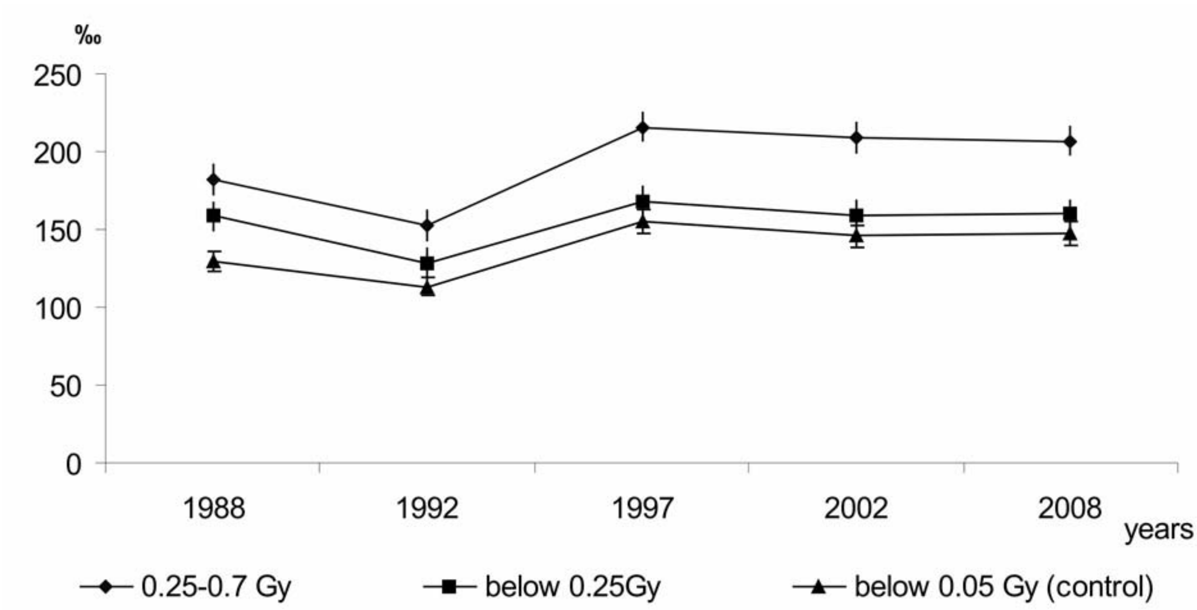
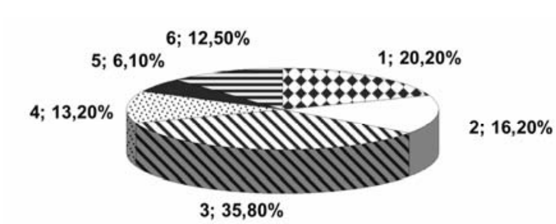


Fig. 3.13. *Dynamics of the non-cancer morbidity level of the Chernobyl clean-up workers of 1986–1987 in the cohort as a whole depending on the whole body absorbed (data of «RCRM of AMS of Ukraine»)*

Based on the cohort epidemiological studies carried out during the 1988-2008, it appears that post-accident period was characterized in this contingent by growing level of non-tumor diseases (Fig. 3.13), especially among those who received external radiation dose 0.25–0.7 Gy.

The main contribution to the health state worsening of 1986–1987 clean-up workers cohort made diseases of the digestive, circulatory, nervous system and sensory organs, musculoskeletal and endocrine systems (Fig. 3.14).



1 – cardiovascular diseases,
2 – diseases of the nervous system and sensory organs,
3 – diseases of the digestive system,
4 – diseases of the musculoskeletal system,
5 – diseases of endocrine system,
6 – other diseases

Fig. 3.14. *Structure of non-cancer morbidity of 1986–1987 clean-up workers in in 2008 (data of «RCRM of AMS of Ukraine»)*

Effect of radiation on development of clean-up workers non-cancer morbidity is illustrated by the dynamics of individual classes and groups of diseases – diseases circulatory system (Fig. 3.15), digestive (Fig. 3.16), endocrine system, primarily due to non-cancer diseases of the thyroid gland (Fig. 3.17).

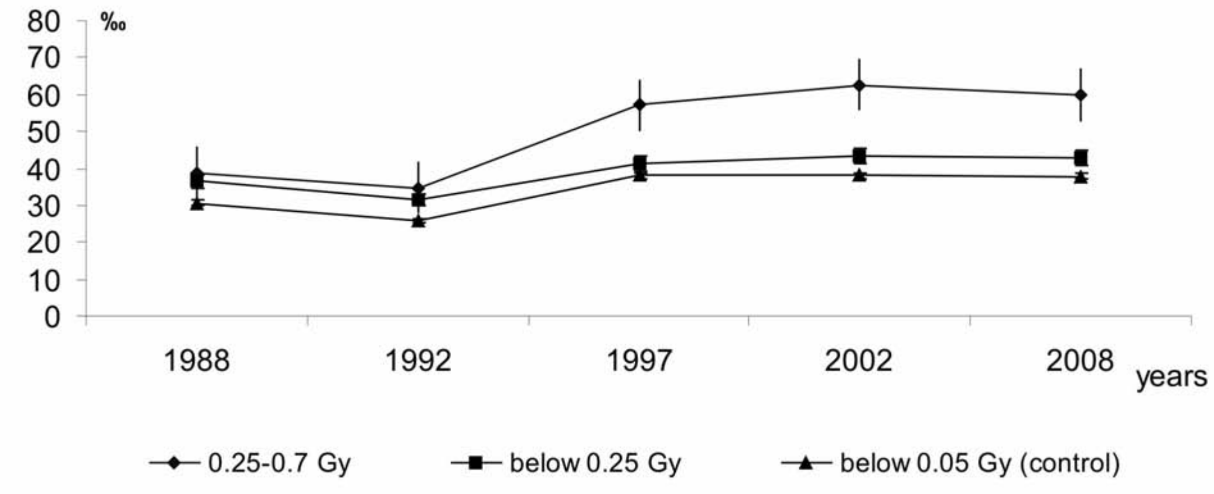


Fig. 3.15. *Dynamics of the level of cardiovascular diseases in Chernobyl clean-up workers of 1986–1987, depending on the dose of whole body irradiation (data of SI «RCRM of AMS of Ukraine»)*

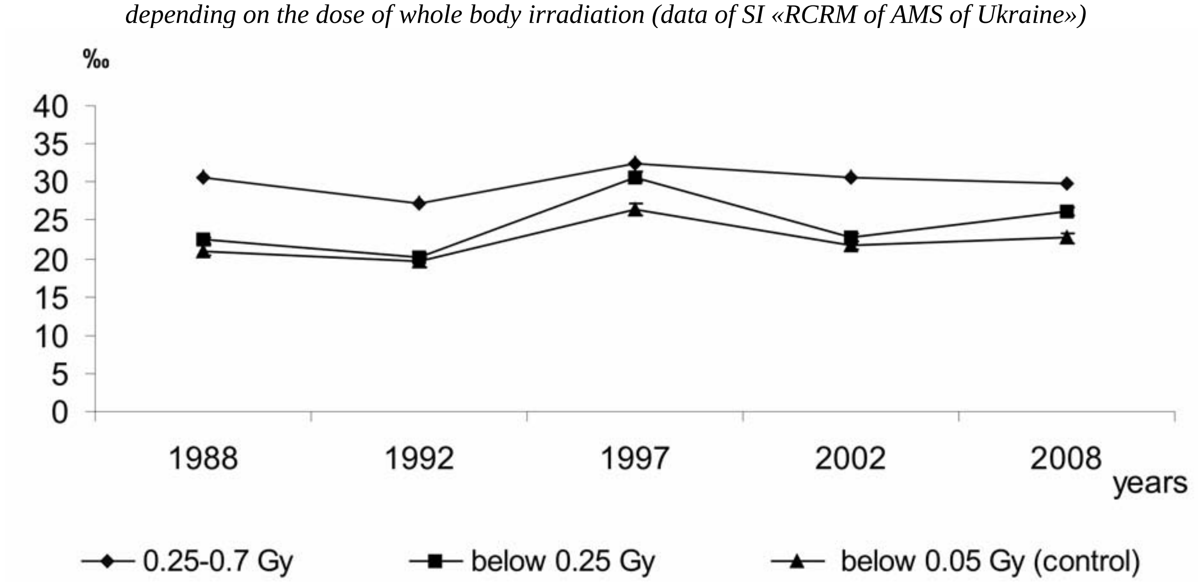


Fig. 3.16. *Dynamics of the level of digestive system diseases in Chernobyl clean-up workers of 1986–1987, depending on the dose of whole body irradiation (data of SI «RCRM of AMS of Ukraine»)*

When analyzing the effect of age factor on the development of endocrine system diseases significant effects at lower doses of radiation (0.1–0.249 Gy) was found in persons whose age at the time of irradiation was 18–39 years, which may indicate a higher sensitivity of this age group population .

On the basis of risk-analysis a highly significant dose-related effects of non-tumor diseases in the Chernobyl clean-up workers of 1986–1987 were revealed in the range of absorbed doses of 0.25–0.7 Gy: endocrine system diseases – 1.24 times, mental disorders – 3.57 times, cardiovascular diseases – 1,25 times, respiratory system diseases – 1.29 times, the digestive system disesases 1.54 times, urinary system diseases – 1.43 times higher, than in non-irradiated control.

Calculations of additional cases of individual non-tumor diseases in clean-up workers of 1986-1987 caused by the radiation factor, based on the values of excess absolute risk (EAR • 10^3 person, Gy.), attributive risk (ATR in %) for 25-year period after exposure give the total number of 81 631 such cases, including diseases such as cardiomyopathy (28 280), coronary heart disease (3587), acquired hypothyroidism, thyroiditis (8067), cerebrovascular disease (5943), vertigo syndromes and other diseases of vestibular apparatus (18 010), neurotic disorders, psychopathy (4967), obstructive chronic bronchitis (1112), acquired renal cyst (2695), chronic prostatitis (8970).

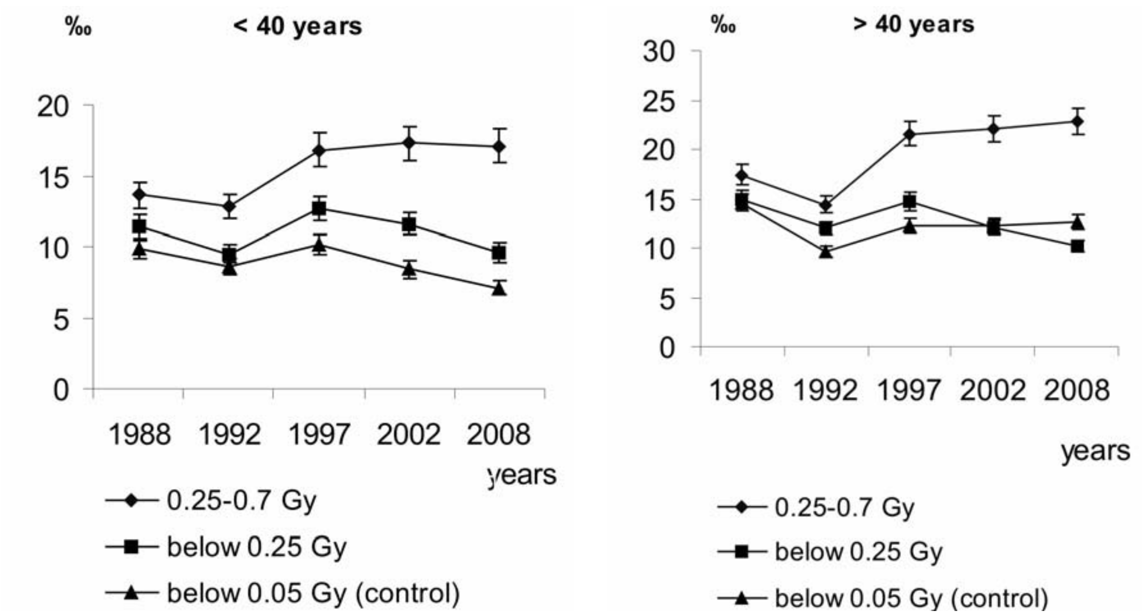


Fig. 3.17. *Dynamics of the level of endocrine system and metabolism diseases in Chernobyl clean-up workers of 1986-1987, depending on the dose of whole body irradiation (data of SI «RCRM of AMS of Ukraine»)*

Development of non-tumor diseases in clean-up workers was conditioned not only due to the influence of radiation, but also complex non-radiation factors such as age, poor working conditions, bad habits, stress, poor nutrition, concomitant disease, etc. (Fig. 3.18–3.19).

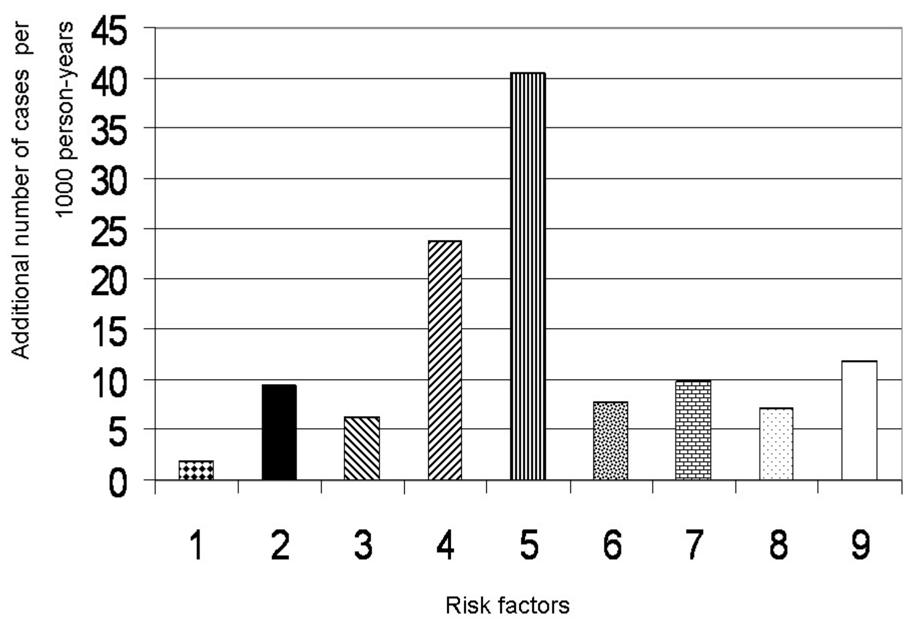


Fig. 3.18. *Extra number of cases (per 1000 person-years) of cerebrovascular disease at various risk factors (according to Clinical-Epidemiological Register of SI «RCRM of AMS of Ukraine»)*
1 – dose of external irradiation 0.25–0.49 Gy; 2 – dose of external irradiation 0.5–0.99 Gy; 3 – age 40–49; 4 – age 50-59; 5 – age 60-69; 6 – essential hypertension, 7 – diabetes, 8 – smoking, 9 – emotional overstrain

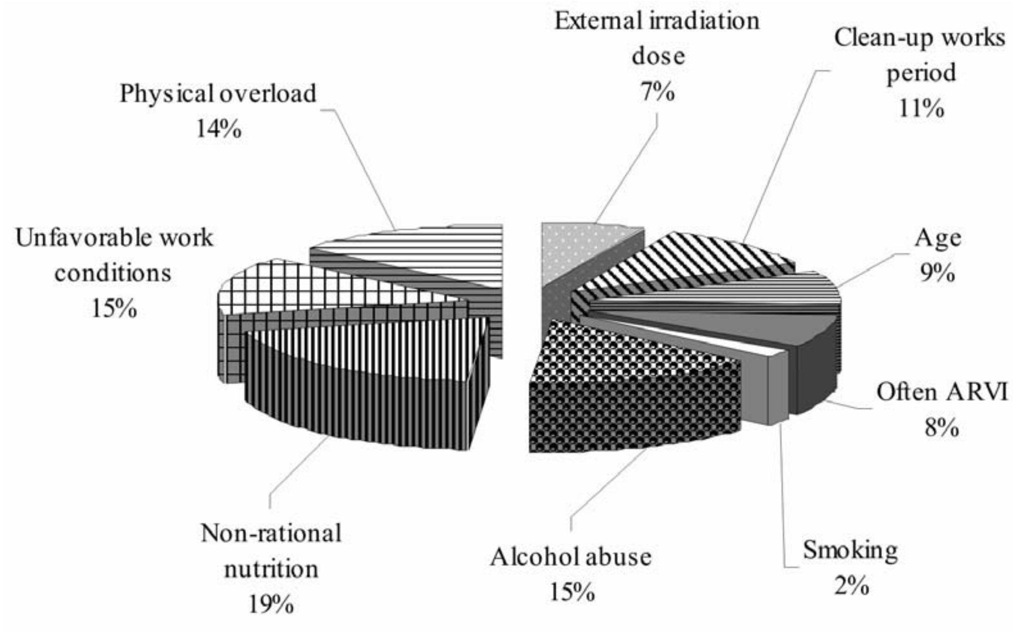


Fig. 3.19. *Structure of risk factors for chronic obstructive bronchitis in clean-up workers of the Chernobyl accident*

The disability of clean-up workers significantly increased during the period from 1988 to 2008 with a maximum growth in 2002 (Fig. 3.20). A decrease of disability rate from 2003 to 2008 can be mainly due to the influence of various «realization factors» and «extinction».

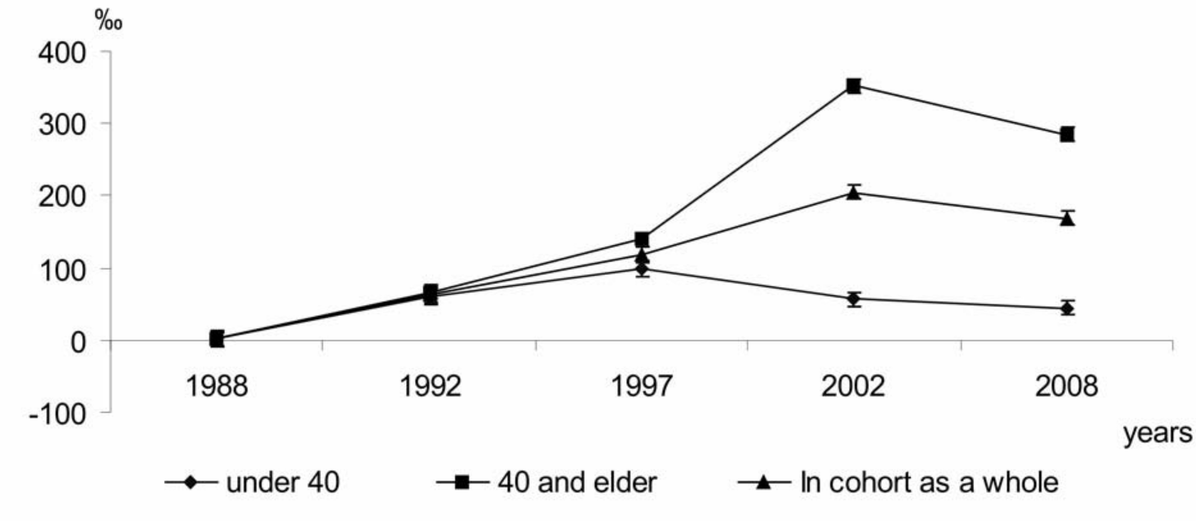


Fig. 3.20. *Dynamics of disability of Chernobyl clean-up workers of 1986-1987 for the period of 1988-2008 depending on age at the time of participation in clean-up works (data of SI «RCRM of AMS of Ukraine»)*

In the structure of the causes of disability leading role play diseases cardiovascular, nervous system and sensory organs, digestive, endocrine system (Fig. 3.21).

Mortality of clean-up workers from non-tumor diseases for the period 1988–2008 increased from 2.2 ‰ to 12.0 ‰ (Fig. 3.22).

The highest mortality rate from non-tumor diseases, its dynamic growth after exposure identified among those whose age at the time of irradiation was 40–60 years, that obviously associated with the influence of factor «aging».

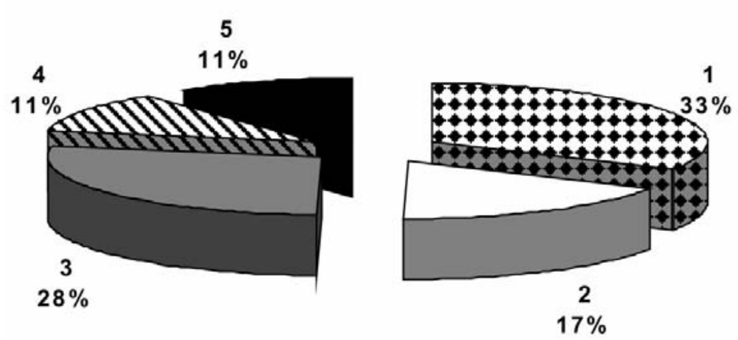


Fig. 3.21. Structure of disability from non-tumor diseases in Chernobyl clean-up workers of 1986–1987 in 2008 (data of SI «RCRM of AMS of Ukraine»)
1 – cardiovascular diseases, 2 – diseases of the nervous system and sensory organs, 3 – diseases of the digestive system, 4 – respiratory diseases, 5 – other diseases

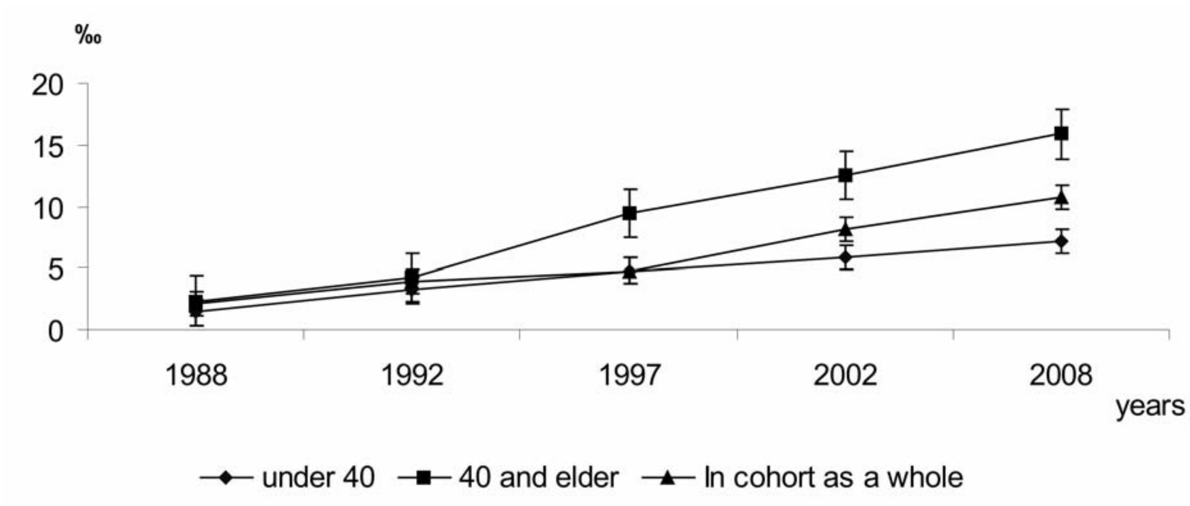


***Fig. 3.22.** The dynamics of Chernobyl clean-up workers of 1986–1987 mortality during the 1988-2008 from non-tumor diseases, depending on age at the time of participation in clean-up works (data of SI «RCRM of AMS of Ukraine)*

In the structure of causes of death of the Chernobyl clean-up workers of 1986–1987 cardiovascular diseases played a key role (their contribution to the structure of mortality is about 80 %) as well as respiratory, digestive, nervous system and sensory organs, endocrine system (Figure 3.23).

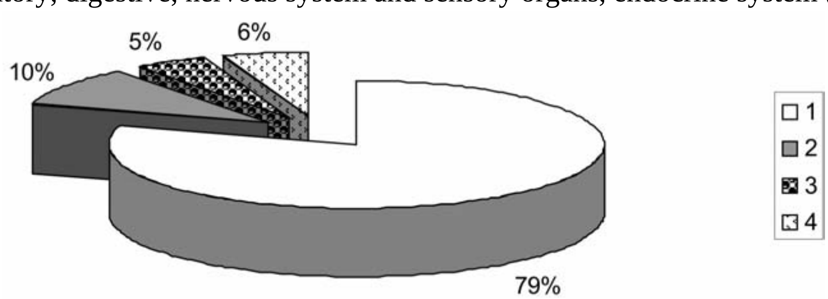


***Fig. 3.23.** The structure of mortality of Chernobyl clean-up workers of 1986–1987 from non-tumor disease in 2008 (data of SI «RCRM of AMS of Ukraine)*
1 – cardiovascular diseases, 2 – diseases of the digestive system, 3 – respiratory diseases, 4 – other diseases

The highest mortality of clean-up workers from non-tumor diseases registered among those who received doses of external whole body irradiation in the range from 0.05 to 0.7 Gy, primarily concerned subcohort of dose 0.25–0.7 Gy (Fig. 3.24).

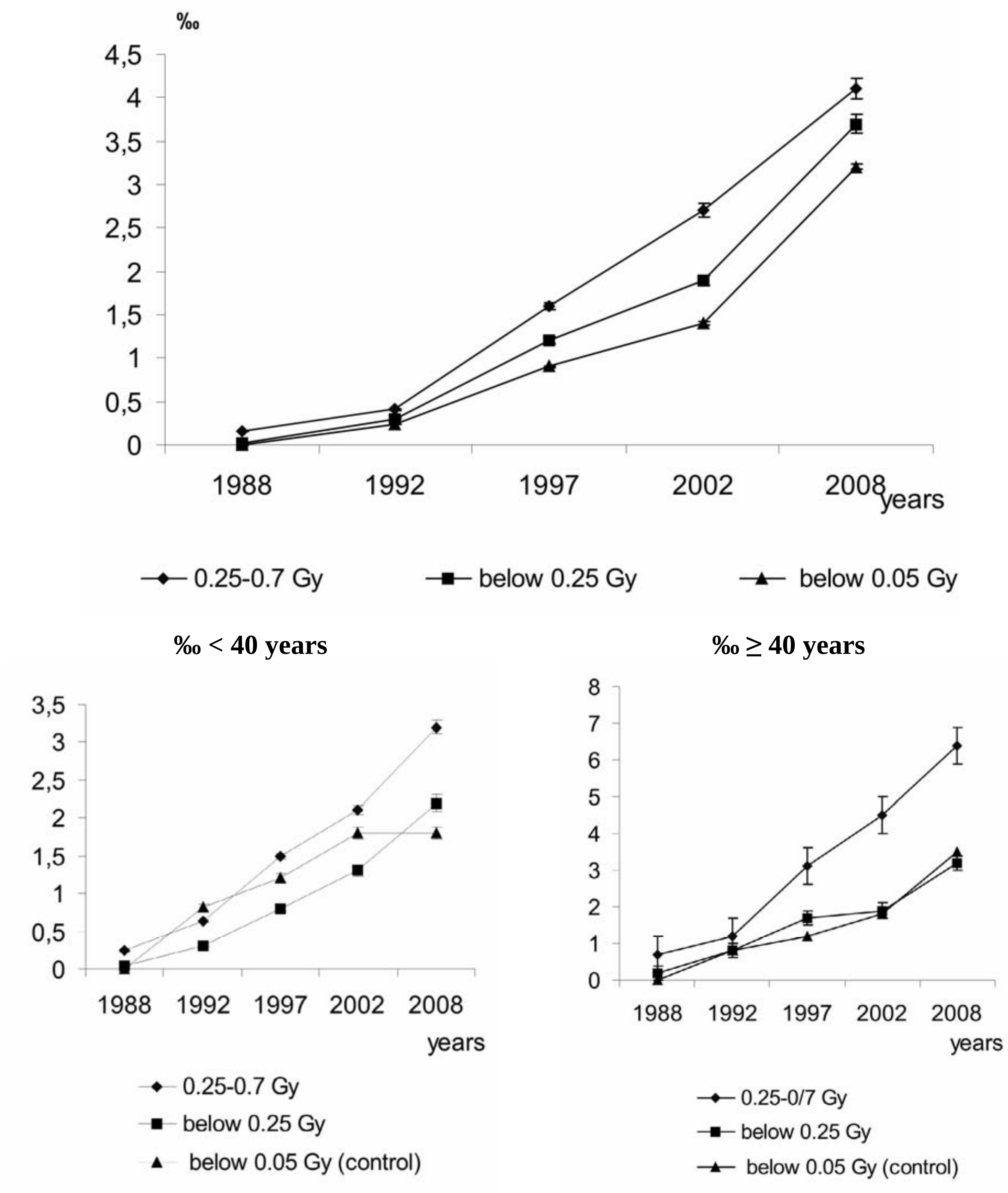


Fig. 3.24. *The dynamics of Chernobyl clean-up workers of 1986–1987 mortality from non-tumor diseases in the period 1988–2008, depending on age at the time of participation in the clean-up works and the whole body external exposure (data of SI «RCRM of AMS of Ukraine)*

A risk-analysis revealed a highly significant dose-related effect of the Chernobyl clean-up workers of 1986–1987 mortality from non-tumor diseases and cardiovascular diseases (Table 3.27).

At this stage of monitoring reliable dose-dependent effects of mortality risk in people aged under 40 years at the time of the Chernobyl accident were not established. This can be explained by possible implementation of the risk at more distant stage. Possible dose-dependent effects of mortality from cardiovascular diseases were found in the subcohort of clean-up workers aged 40–60 years at the time of exposure.

Table 3.27.

Credible relative risks (RR) of mortality from non-tumor diseases in the Chernobyl clean-up workers of 1986-1987 cohort in general (regardless of age) at doses of the whole body irradiation 0.25-0.7 Gy (average D = 0.3 Gy) for 5, 10, 15, 20 years after exposure (data of SI «RCRM of AMS of Ukraine)

Classes and nosologic forms of diseases	ICD-9 code	Relative risk (RR)	Confidence interval
Diseases of the cardiovascular system:	390-459	2.4	(1.21;3.8)
- essential hypertension	401-405	1.34	(1.19;3.1)
- coronary heart disease	410-414	2.81	(1.9;3.72)
- cerebrovascular disease	430-438	2.41	(1.3; 3.7)

Described values of the excess relative risk of mortality from cardiovascular diseases, coincide with the other data obtained in the Life Span Study of Hiroshima and Nagasaki nuclear bombing survivors [1] and radiation-exposed troops, according to Russian Health And Demographic Register [2].

3.2.2. Health state of evacuated in infancy at the time of the accident

It is known that the body of children and adolescents is more sensitive to the effects of negative external factors compared to the functionally and morphologically identifiable adult.

Assessment of absolute risk of developing (primary disease) men and women evacuated from the 30-km Chernobyl zone being children and adolescents, for the period of 1993–2007 shows that the highest absolute risk of disease observed for the nervous, digestive, circulatory system.

Among the diseases of sensory organs and nervous system the most common is retinal angiopathy. For a number of common diseases angiopathy, including retinal angiopathy is not a complication, but an integrated part of the pathological process and can be identified before the appearance of other symptoms.

Prevalence and relative risk of retinal angiopathy were analyzed in groups from cohort of 3,773 evacuees from Pripyat city living in Kyiv who were comprehensively surveyed in 1992–1998.

Groups were formed according to age at the time of disaster: first childhood (4–7 years), second childhood (girls 8–11 years, boys 8–12 years), adolescence (girls 12–15 years, boys 13–16 years) teenagers (16–20 years old girls, and boys 17–21 years). «Adolescent» and «teenagers» groups were internal controls for the groups of exposed in childhood, which were also compared with each other. In addition, the relative risk of angiopathy for all 4 groups of evacuees were estimated in comparison with control, data of survey of 105 persons who had no exposure to ionizing radiation.

The research in all 4 groups revealed the prevalence of retinal vascular pathology. In the group of irradiated at the age of 4-7 years it was 258.62, 320.79 at the age of 8-12 years, 262.22 at the age of 11–16 years and at the age of 17–21 years 267.39 per 1000 investigated persons. The prevalence of angiopathy, contrary to the habitual norms, was the largest in the group of exposed at the age of 8–12 years, but not in groups of older persons.

The relative risk (RR) for each group of exposed persons in comparison with the control was higher just in exposed at the age of 8-12 years and amounted to 2.60 (1.54, 4.37) with $\chi^2 = 16.89$ and p = 0.00 004, while for irradiated at the age of 4–7 years – 2.09 (1.06, 4.13) with $\chi^2 = 4{,}64$ and p = 0.0312. When comparing the relative risks in exposed children in other two groups of evacuees, it appeared that for irradiated in 8–12 years RR is 1.22 with confidence interval 1,03; 1,45, $\chi^2 = 5{,}25$ and p = 0.0219 compared to exposed adolescents, the difference is significant. For all exposed in childhood in comparison with «teenagers» group relative risk also was significantly higher (RR = 1.2 with confidence interval 1.01; 1.42, $\chi^2 = 4.47$ and p = 0.03439).

Thus, irradiated in childhood, especially at the age of 8–12 years, have a high risk of vascular diseases of the retina.

According to the survey in remote period relative risks of non-cancer diseases were analyzed separately for men and women evacuated from the 30-km zone of Chernobyl NPP under 18 years depending on the age at the time of evacuation (Table 3.28).

The women evacuated in childhood, compared with women evacuated in adolescence, had significantly higher risk of morbidity in the class of diseases of skin and subcutaneous tissue. Conversely, for women evacuees in their teens when compared to evacuated in childhood higher risk of mental disorders, diseases of the nervous system and sense organs, respiratory, digestive system diseases, diseases of the genitourinary system.

Similarly, for men, evacuated in childhood (when compared to evacuated in adolescence) a significantly higher risk was found for cardiovascular diseases and skin and subcutaneous tissue. In the men evacuated in their teens, compared with evacuated children, significantly higher risk of diseases of the nervous system and sensory organs, digestive and urinary systems.

Table 3.28.

Relative risks of non-cancer morbidity for evacuees from the 30-km zone of Chernobyl NPP in adolescence (data examination during 1993-2007 years) compared with evacuated in childhood (data of SI «RCRM of AMS of Ukraine)

Classes, groups and nosological forms of diseases	**ICD-9 code**	**Men**		**Women**	
		RR	**CI**	**RR**	**CI**
Diseases of the endocrine system	240-279	1.08	0.80;1.47	1.20	0.99; 1.45
Mental disorders	290-319	0.95	0.64; 1.41	1.49	1.10; 2.03
Diseases of the nervous system and sensory organs	320-389	1.56	1.39; 1.75	1.46	1.31; 1.61
Diseases of the circulatory system:	390-459	0.78	0.67; 0.92	1.04	0.92; 1.17
Respiratory diseases	460-519	1.09	0.85; 1.40	1.42	1.12; 1.81
Digestive diseases	520-579	1.38	1.23; 1.55	1.70	1.52; 1.91
Diseases of the genitourinary system	580-629	2.06	1.45; 2.93	2.42	1.97; 2.96
Diseases of skin and subcutaneous tissue	680-709	0.62	0.49; 0.80	0.71	0.57; 0.88
Diseases of the musculoskeletal system and connective tissue	710-739	1.32	0.87; 2.00	1.20	0.90; 1.59

Thus, it is proved that the effect of ionizing radiation in the groups exposed to the Chernobyl accident is significantly modified by such factor as the age of exposed, with the most dangerous age period, based on data analysis of incidence and prevalence of pathological conditions in long term is not early infancy, but the age from 8 to 12 years and adolescence (from 12 to 15–16 years).

3.2.3. Health Effects of the Chernobyl disaster in various contingents of the affected child population

Medical consequences of the Chernobyl disaster have been studied in various cohorts of children evacuated from the 30-km zone of Chernobyl NPP, children-residents of contaminated areas, children who experienced prenatal exposure and children born to exposed parents. Total in the post-accident period more than 50 thousand suffered children were supervised by RCRM.

Changes in the health state of children exposed to radioactive iodine and other unfavorable factors of the Chernobyl accident

In the early phase of the Chernobyl accident (**04/26/1986 – 01/09/1986**) Children evacuated from the area of «alienation» Chernobyl NPP in the early days complained of irritation in the throat sensation of metallic taste in the mouth (55.7 %), tussiculation; (31.1 %), fatigue (50.1 %), headache (39.3 %), dizziness (27.8 %), sleep disturbance (18.0 %), syncope (9.8 %), nausea and vomiting (8.0 %), defecation disorders (6,9%). In 31.0 % of children respiratory syndrome was detected in 32.2 % – hyperplasia of lymphoid tissue in 18.0 % – functional disorders of the cardiovascular system, in 9.4 % –

the gastrointestinal tract, in 9.8 % – liver enlargement, in 3.2 % – the spleen, in 34.2 % – quantitative and in 92.2% – qualitive modified haemograms were found.

In the early years (1986–1991) functional disorders of other organs and systems were the most typical. In children evacuated from the 30-km zone, and the dwellers of contaminated areas they were unidirectional in nature. In 70.3 % of them the signs of vegetative-vascular dysfunction were found, in 40.0 % – functional changes of the heart, in 53.5 % – a violation of non-respiratory ventilation and lung function and in 82.4 % – functional disorder of the digestive system. They have evolved against the background of the free radical processes intensification in the body, moderate suppression of T-cell immunity and dysimunohlobulinemias.Chronic pathology was rarely registered. The high number of children were found to be at risk of developing diseases of thyroid, immune, respiratory, digestive systems, which were implemented since 1989–1990 (Fig. 3.25).

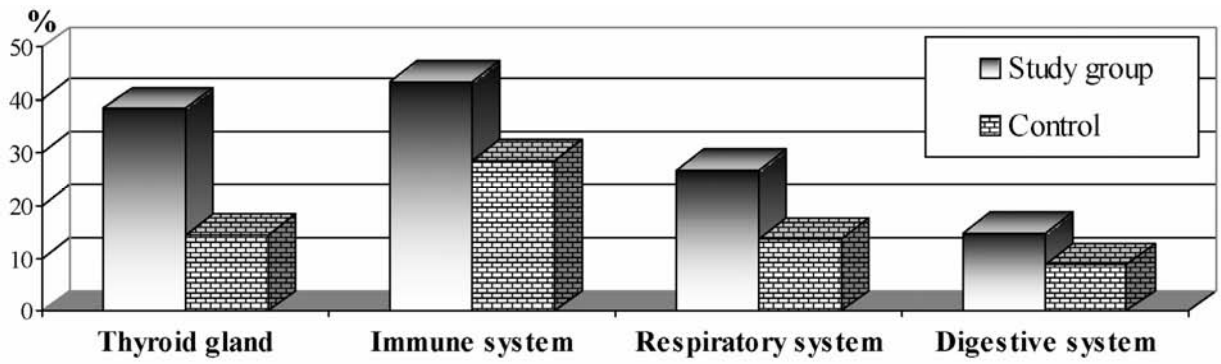


Fig. 3.25. *Percentage of children at risk of developing pathology of the most exposed organs and systems (data of SI «RCRM of AMS of Ukraine)*

Next five years (**1992–1996**) were characterized by transformation of functional disorders in chronic somatic pathology. Quantity of healthy children decreased and the number of children with chronic somatic pathology increased, both among evacuees from the 30-km zone, and among children residents of contaminated areas. The lowest level of health had children with thyroid radiation dose exceeding 2.0 Gy (Fig. 3.26).

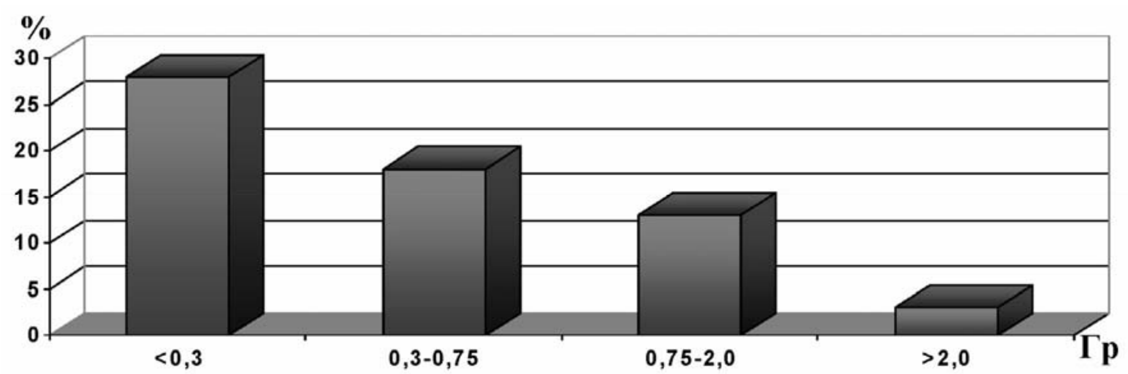


Fig. 3.26. *Number of healthy children with different doses of irradiation of the thyroid gland (data of SI «RCRM of AMS of Ukraine)*

In **1997–2001** a steady trend to decrease of children's health was observed, both evacuees from the 30-km zone of Chernobyl, and the inhabitants of contaminated areas. Distribution by groups of health in 2001 was as follows: among the evacuees from the 30-km zone was not a single child of I group of health, II group was set to 23.4 %, III – to 63.9 % IV – to 12.7 %. Among children – residents of contaminated areas I group of health was determined in 6.3 %, II – in 26.1 %, III – in 57.5 % and IV – in 10.1 % .

In a contingent of children, residents of Narodychi area, distributed into 2 subgroups (by 600 people in each) according to collective dose of 2.6 person-Sv (I subgroup), and 9,4 person-Sv (II subgroup), significantly higher incidence of respiratory diseases (2.0 times), vegetative-vascular dysfunction (1.52 times), fibrosis of liver tissue (2,3 times) and disorders of the blood system (2,5 times) in the subgroup of children with the collective dose of 9.4 person-Sv were found. Chromosome instability in somatic cells, depending on the dose of radiation was revealed (Fig. 3.27).

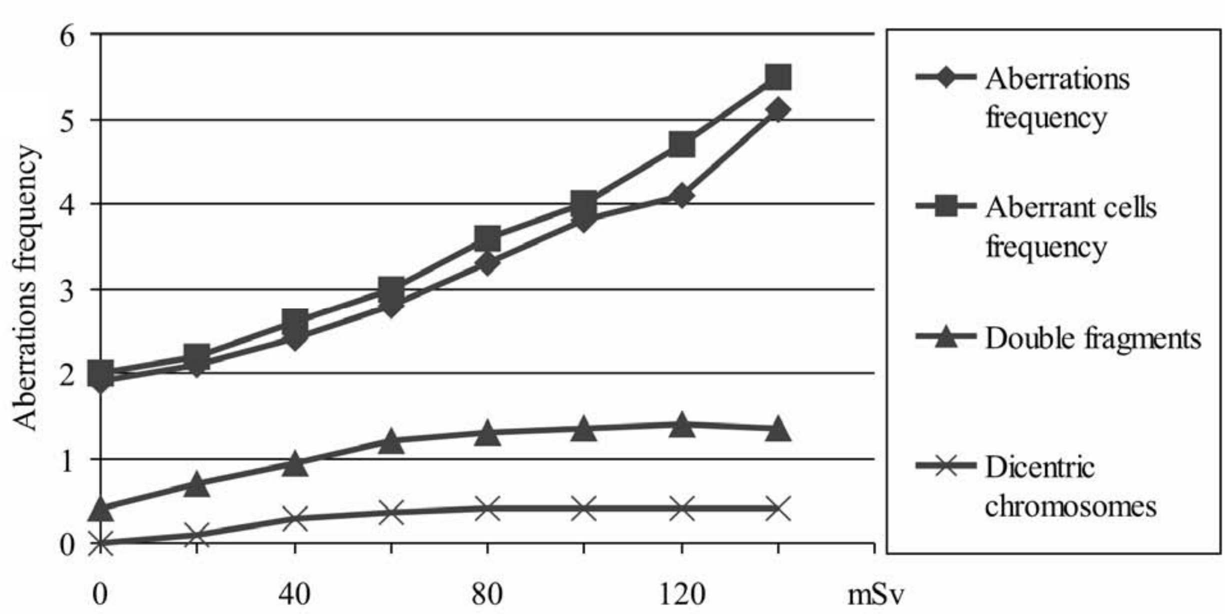


Fig. 3.27. *Dependence of the frequency of chromosomal aberrations in peripheral blood lymphocytes from the dose of radiation (data of SI «RCRM of AMS of Ukraine)*

The peculiarrities of somatic pathology were found : the occurrence of diseases in younger age; polysystemic, multiorgan nature of lesions and the prolonged, relapsing course with relative resistance to therapy. Low level of health in these contingents remained throughout the whole period of childhood. At the age of 17–18 chronic somatic pathology was revealed in 76.6 % of evacuees from the 30-km zone of Chernobyl NPP and 66.7 % of the inhabitants of contaminated areas, and the level of pathological lesions reached 5.7.

Thus, children exposed radioiodine and other unfavorable factors of the Chernobyl disaster came in reproductive age, burdened with numerous chronic diseases, which can not but affect the health of their offspring.

Assessment of the health of children born to parents as children evacuated from Pripyat city and 30-km zone of Chernobyl NPP (I group) and children-dwellers of 3rd and 2nd zones of radioactive contamination, whose parents at the time of the accident were children, have lived and still live in these areas (II group), really showed that number of healthy among them did not exceed 10 % and the index of pathological lesions reached 5.39.

Physical development, which is one of the main criteria of health status in 62.40–62.58 % of children differed by dysharmony. The frequency of violations of harmonic physical development at the I group grew by children who had body mass deficit relative to growth, and in the second group, in addition, due to the increased number of children with growth deficiency. Almost a quarter (24.6 %) of children – residents of contaminated areas, dysharmony in physical development coupled with a lag of biological age comparing to the passport age.

Phenotypic features of children of both groups were characterized by increased frequency of variants with multiple morphogenetic dysmorphias, among them an important place occupied small anomalies of development (SAD) of musculoskeletal system, connective tissue and organ dysplasia.

The immune status of these children was determined by the presence of immune imbalance: reducing the relative number of $CD3^{+}56^{+}$ lymphocytes, deregulation of immunoregulatory subpopulations, decreased levels of IgA and reduced the phagocyt number.

The formation of chronic somatic diseases in children born from people exposed in childhood, was conditioned by a complex of unfavorable factors. Prominent of them are burdened heredity, unfavorable micro-social environment, numerous medical and biological risk factors in the mother, some pathological conditions of the child in the infant period, certain features of early childhood. Probable correlations between the dose of thyroid gland of mother, the dose of whole body radiation of mother and/or father and the development of immunodeficiency states in their children.

No increase in the number of people with quantitative changes in blood count (lymphocytosis, monocytosis, eosinophilia) was found during the study of erythrocyte, leukocyte and platelet links of hematopoiesis in children who were evacuated from the city of Pripyat and 30-km zone in the early period after the accident and those living in the most contaminated areas of Kyiv, Zhytomyr and Chernigiv regions in dynamic monitoring of 1986, 1996, 2009. However, over the last 10 postaccidental years proportion of children with qualitative changes in the elements of hematopoiesis grew from 40 % to 69 % in the form of increased number of aberrant cells and degenerative forms.

The part of children with deficiency anemia increased: in 1996 the number of such children has reached 25 % in 2003 – 31 % in 2009 – 46.5 %. In addition, in children of elder age with deficiency anemia reduced number of red blood cells depended on the degree of total contamination areas – air, water and soil (Fig. 3.28).

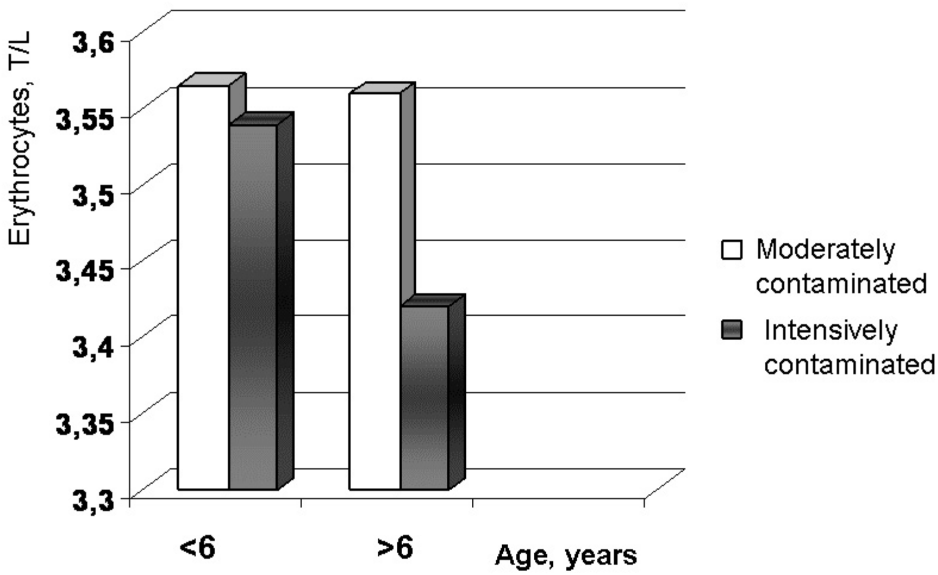


Fig. 3.28. *The number of red blood cells in children of all ages with deficiency anemia, taking into account total environmental contamination (data of SI «RCRM of AMS of Ukraine).*

Increased number of monocytes in the blood count of children who live in the ecologically unfavorable regions was also established.

Over the past 5 years the number of children with high iron content in blood serum increased from 2.0 % to 6.4 %, indicating the need for dynamic monitoring of these children as the risk group of myelodysplastic syndrome.

Defined changes may be caused by an imbalance of trace elements, heavy metal toxicity, prolonged exposure to low doses of ionizing radiation, poor nutrition of pediatric population, leading to metabolism disorder (lipid, carbohydrate, protein, mineral) and contribute to change the hemopoetic system functioning.

According to the data of Ministry of Public Health of Ukraine, there are 494.2 thousand children who were born from parents of survey groups 1–3. Every year, diseases of blood and blood-forming organs in this cohort are diagnosed approximately in 27–29 %, 18–22 % of them are iron-deficient anemias. In the dynamics of post-accident period 20–30 cases of leukemias and lymphomas are registered yearly, which corresponds to population data in Ukraine in general (5.2–5.4 per 100 000 children).

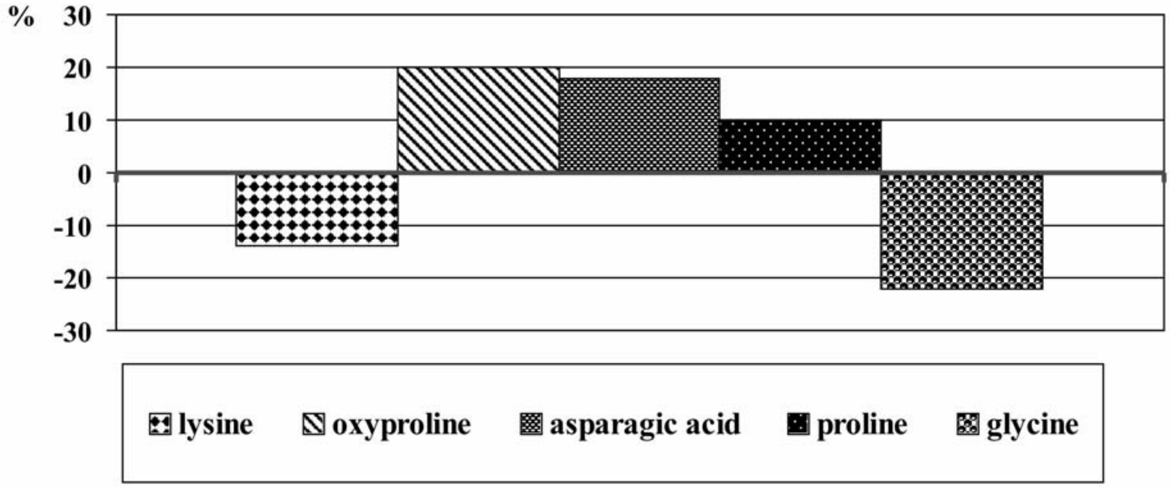


Fig. 3.29. *Relative deviation of bone collagen amino acids content in patients with acute leukemia from the standard (the data of SI «RCRM of AMS of Ukraine)*

Analysis of leukemia incidence rates of children living in contaminated areas of Kyiv, Zhytomyr, Chernigiv regions of Ukraine for post-accident period found no difference in the frequency of acute myeloid and lymphoblastic leukemia and versions of chronic myeloid leukemia before and after the accident, and compared to the levels in Ukraine in general. But it should be noted that since 2003 has increased the number of children who become ill at the age of one year, and older than 12 years.

For children with leukemia of that age groups established disorders of formation of bone structures, in particular mineral and organic components starting from the early stages of fibroblast formation, changes in regulation of collagen synthesis (decrease of osteocalcine) and its structure. Content of oxyproline, proline and aspartic acid in the urine of patients increased, while the glycine and lysine decreased (Figure 3.29), indicating the disintegration of collagen and the lack of plastic material for the processes of its formation as an integral part in the mechanism of carcinogenesis.

In 32 % of children with acute leukemia changes in the endocrine system, coupled with the unfavorable course of disease were observed. Criteria of the risk group formation of oncohematologic diseases are being improved among the surveyed exposed to ionizing radiation, and preventive measures to reduce the frequency of diseases of the blood are developed and implemented.

The data on new treatment and prevention measures in children with anemia and various types of leykemoid reactions have shown a positive effect in 72.5 % of cases, partial – in 17.1 % and no effect of treatment in 10.4 % of the examined, indicating the need for further improvement and individualization of preventive and therapeutic measures in children with changes in the blood.

Children exposed during fetal development

In the dynamics of post-accident period 1,144 children who have suffered acute and prolonged exposure during fetal development were observed.

Doses on fetal thyroid gland in group I (evacuated from Pripyat) and group II (the inhabitants of radioactively contaminated territories) did not differ significantly and ranged from 0.0 to 335.0 cGy. Depending on the gestational age the average dose to thyroid gland of the fetus were: up to 8 weeks –

0.0 cGy, from 8 to 15 weeks – 31.14 cGy, from 16 to 25 weeks – 84.49 cGy, more than 25 weeks – 62.30 cGy.

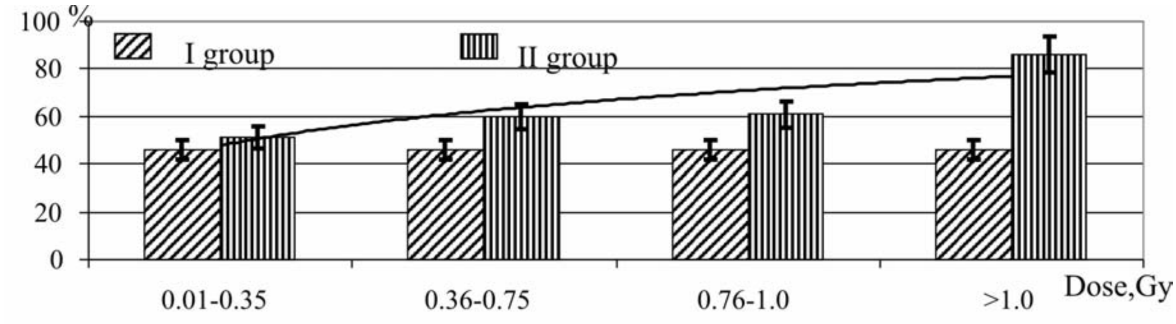


Fig. 3.30. *Percentage of children with chronic somatic pathology in fetal exposure of the thyroid gland in different doses range (data of SI «RCRM of AMS of Ukraine)*
I group – evacuated from Pripyat; II group – residents of radioactively contaminated areas

The exposure of thyroid during fetal development significantly influenced on the health status of children. Chronic somatic pathology was likely to occur more frequently after irradiation of fetal thyroid in doses of over 0.36 Gy, and at doses above 1.0 Gy it had been registered in almost all children (Fig. 3.30).

Frequency of physical development disturbances of children depended on the dose of thyroid gland of the fetus (Fig. 3.31).

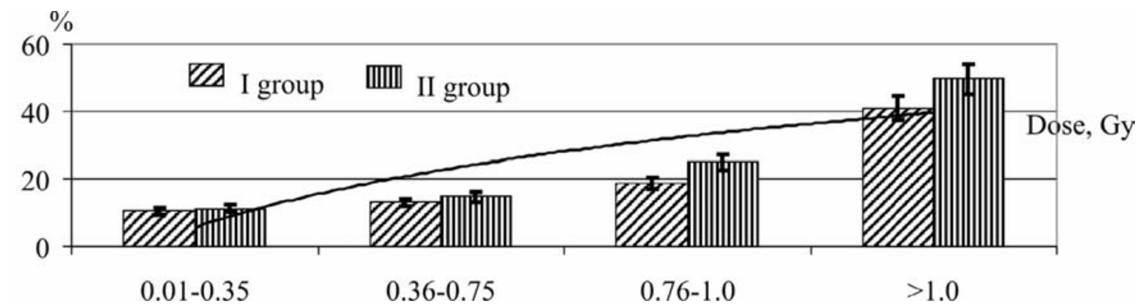


Fig. 3.31. *Percentage of children with disturbances in physical development after fetal thyroid irradiation in different doses range (data of SI «RCRM of AMS of Ukraine)*
I group – evacuated from Pripyat; IIgroup -residents of radioactively contaminated areas

Echostructure of thyroid of children exposed in utero showed the higher frequency of detection of linear fibrosis elements in all terms of supervision than control data. If the dose of the thyroid gland of the fetus exceeded 0.76 Gy, children had more often infringement of its ehostructure by elements of linear fibrosis than at the dose of 0.36 Gy, (Fig. 3.32).

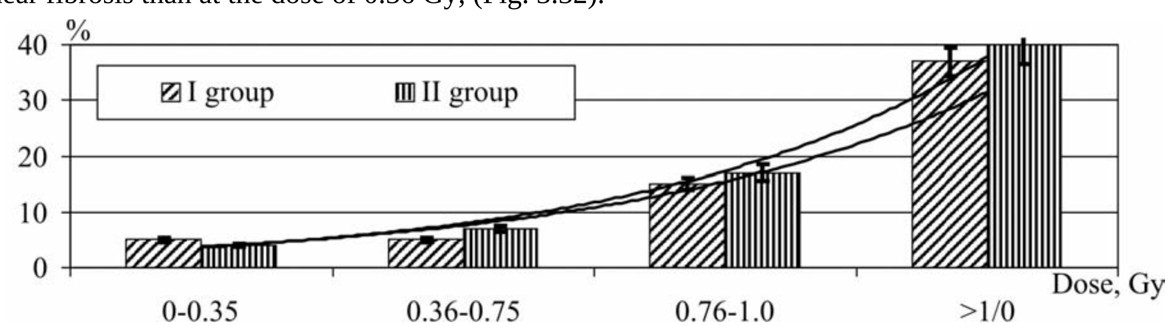


Fig. 3.32. *The frequency of thyroid ehostructure disorders in children with its irradiation at different doses (data of SI «RCRM of AMS of Ukraine)*
I group – evacuated from Pripyat; II group – residents of radioactively contaminated areas

The dependence of the number of small anomalies of development of fetal gestational age at the time of exposure was defined (Fig. 3.33).

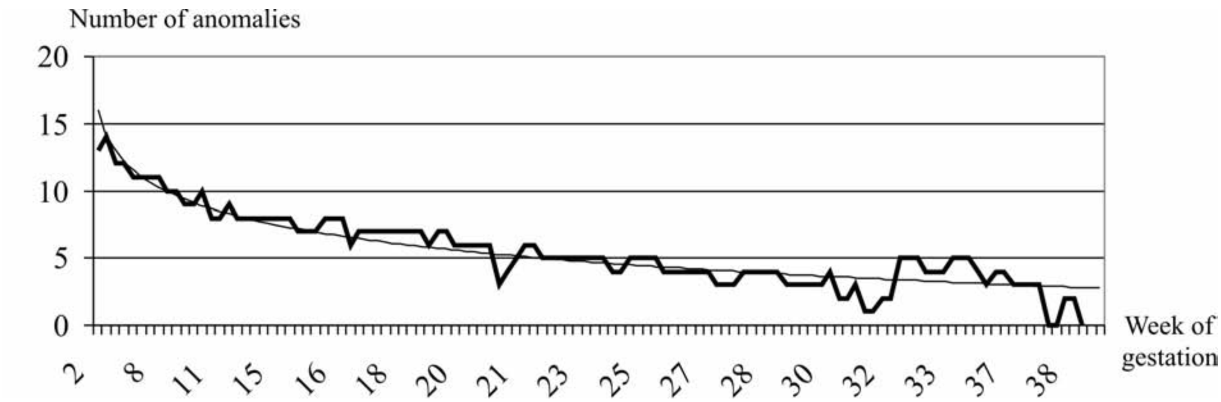


Fig. 3.33. *Dependence of the number of small anomalies of development on fetal gestational age at the time of exposure (data of SI «RCRM of AMS of Ukraine)*

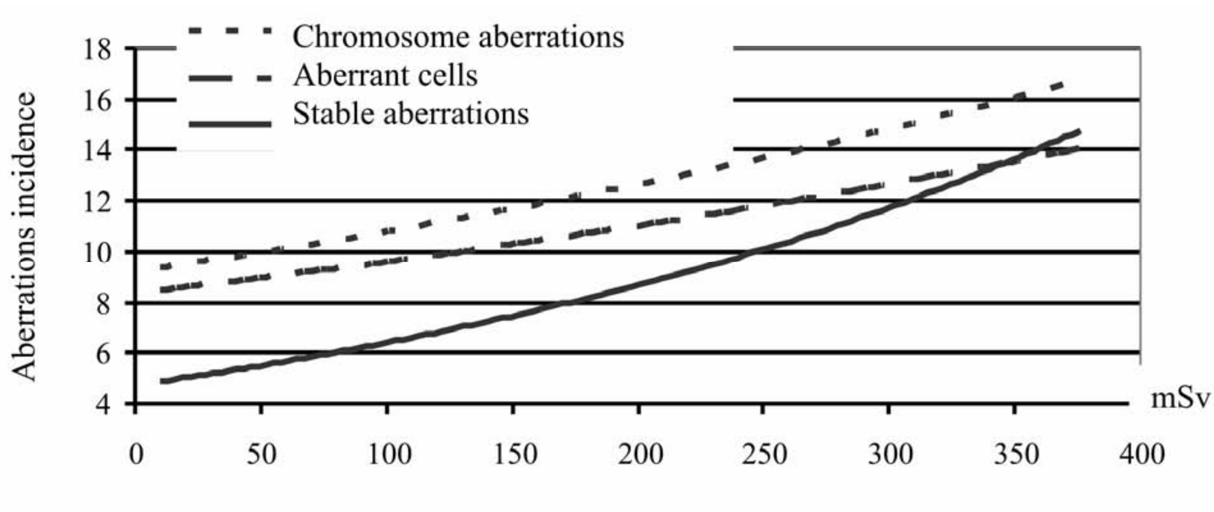


Fig. 3.34. *Dependence of chromosome aberration frequency on doses of red bone marrow of the fetus (data of SI «RCRM of AMS of Ukraine)*

Marked increase in the frequency of chromosomal aberrations, which depended on the dose of irradiation of red bone marrow of the fetus was found (Fig. 3.34).

Thus, the development of chronic somatic pathology, physical impairment, formation of phenotypes with multiple small abnormalities, increasing the number of chromosomal aberrations in somatic cells and changes of thyroid ehostructure were associated with radiation dose of children during fetal development.

Health status of children born to exposed parents

Statistics of the Ministry of Health and SRU indicate adverse changes in the health status of children 0-14 years old, born from exposed individuals (1st, 2nd and 3rd of the first groups of primary registration).

A significant increase in incidence rates and prevalence of diseases was in children born to exposed parents (4th group of primary registration) (Fig. 3.35).

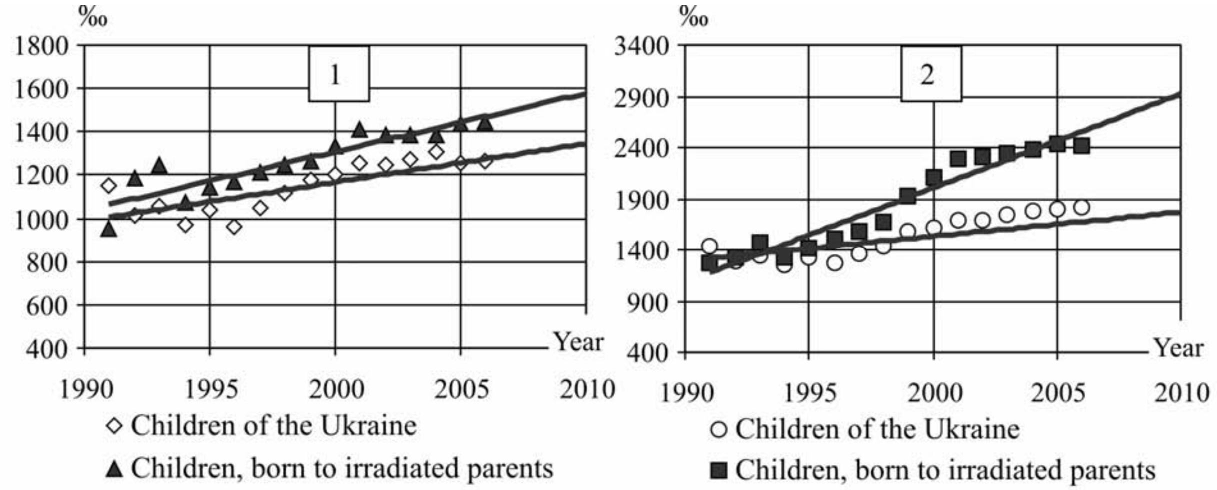


Fig. 3.35. *Trends of incidence rates (1) and prevalence (2) of diseases in children born to exposed parents and children of Ukraine (the data of SI «RCRM of AMS of Ukraine)*

Table 3.29.

The growth of the incidence and prevalence of diseases in children born from irradiated parents and children of Ukraine (data of SI «RCRM of AMS of Ukraine)

Indices	The average absolute increase		Average growth rate, %	
	Ukraine	**affected children**	**Ukraine**	**affected children**
Morbidity	6.7±10.7	52.3±20.6 *	0.84±1.73	7.03±3.23*
Prevalence of diseases	21.7±20.2	85.8±20.0 *	1.55±1.42	6.30±1.57*

Note. *- The difference likelihood ratios (p<0,05)

However, the growth of these parameters in children of 4th group of primary registration was more rapid than in children of Ukraine's population (Table 3.29). As estimated negative trends will be stored in the near future.

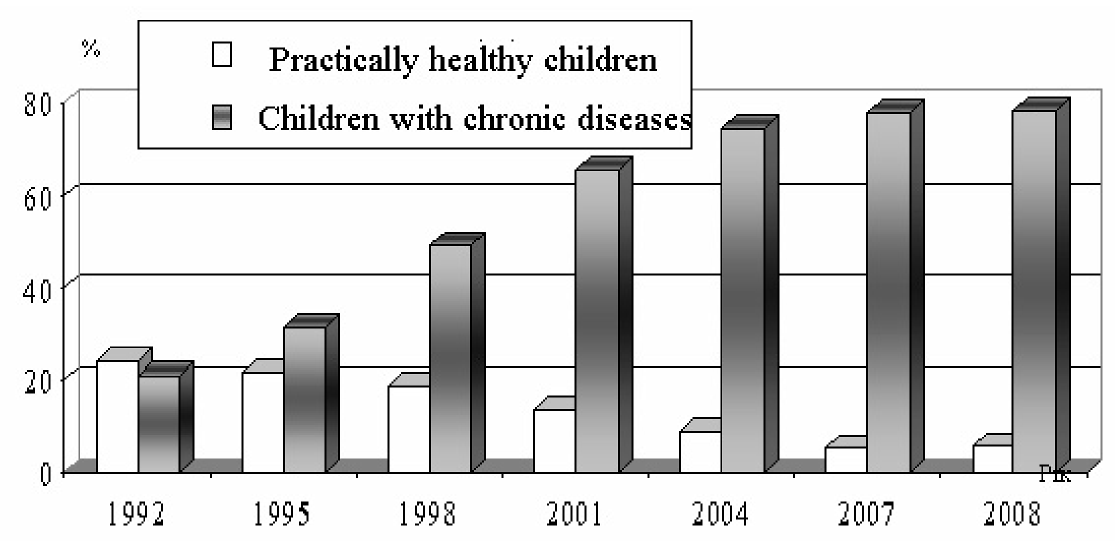


Fig. 3.36. *Weight of healthy children and children with chronic somatic pathology among the born to exposed parents in the dynamics of post-accident period (data of SI «RCRM of AMS of Ukraine»)*

Attracts attention a sharp rise in registration of certain classes of disease in 2009 compared to 1992 in suffered children with respect to child population as a whole, namely: endocrine diseases – 11.61 times, diseases of the musculoskeletal system – 5.34 times, the digestive system – 5,00 times, mental and behavioral disorders – 3.83 times, cardiovascular diseases – 3.75 times, urogenital system – 3.60 times.

In this contingent of children the course of adaptation to the environment, since the neonatal period was more strained. Already at the first year of life among them formed numerous group of often ill, which the age of 6-7 reached from 49.2 to 58.7 %, and the immune status was characterized by high frequency of many immunological parameters variations beyond the physiological oscillations (75.0–45.7 %), which is the basis for the formation of chronic somatic pathology (Fig. 3.36).

In the dynamics of post-accident period, the weight of healthy children decreased from 24.1 % in 1992 to 5.8 % in 2008, and the number of children with chronic diseases increased from 21.1 % in 1992 to 78.2 % in 2008.

In SRU are 13,136 children born to the Chernobyl clean-up workers of 1986–1987, among them in 1,190 (90.6 per 1000) recorded inborn birth defects (IBD). The highest frequency of IBD was observed in the first post-accident years (Fig. 3.37). In the course of time that has elapsed since the cessation of father’s contact with radiation, the number of children with birth defects reduced.

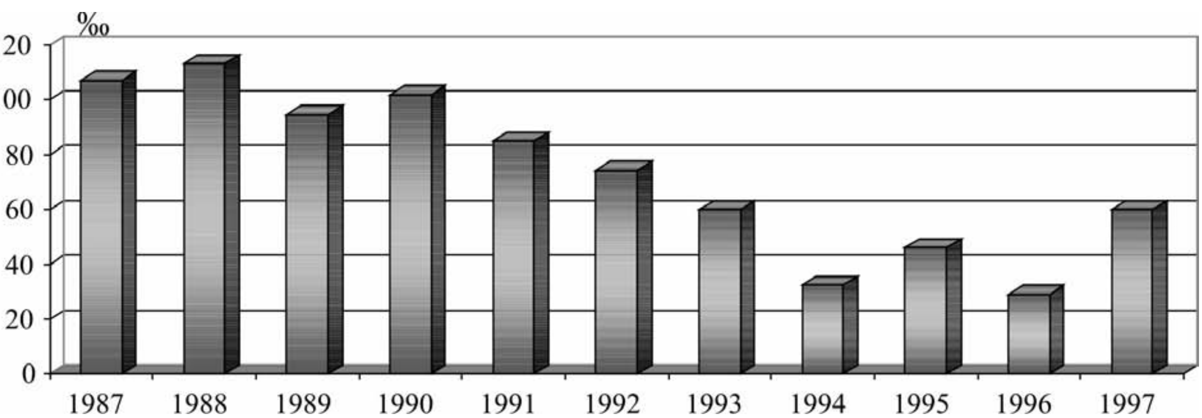


Fig. 3.37. *The frequency of inborn birth defects in children born to parents who participated in the liquidation of the Chernobyl accident in 1986 (data of SI «RCRM of AMS of Ukraine)*

By abscisse axis – the birth year of clean-up workers’ offsprings

Phenotype of children born to clean-up workers exposed to doses of 100–1000 mSv was characterized by the presence of multiple stigmata of dysembriogenesis. Growth of frequency of chromosomal aberrations appeared mainly by increasing the number of chromosomal type damage. Between the number of aberrations detected in the child and the father had been positive correlation (d = 0.620). Using the strategy of multylocus DNA fingerprint a 5.6 times increase of microsatellite-associated sequences variability in the genome of children born in post-accident period in clean-up workers families was found. The incidence of new bands depended on the time elapsed since the cessation of father’s contact with the effect of radiation before proband conception and father’s absorbed dose. This dependence was of nonlinear nature.

Radiation violation induced in parental germinal cells may emerge at different stages of ontogenesis of descendants. In postnatal ontogenesis «small» mutations are probably implemented that are in a heterozygous condition, which causes destabilization of the totality of hereditary structures.

Maybe this phenomenon underlies the so-called «physiological inferiority» and reduced viability of offspring of irradiated parents. The consequence of inherited genome instability in offspring of exposed individuals may be the presence of multiple dysmorphies, organ dysplasia, increased frequency of chromosomal aberrations and mutations of microsatellite DNA fraction. All this contributes to the violation of adaptation to living conditions, increasing the risk of development and implementation of multifactorial disease and reduce health level of children born to exposed parents.

Thus, the dynamic in the state of health of the affected pediatric population is characterized by persistent negative trends:

- A steady trend of morbidity growth and reduction of quuantity in practicallly healthy children, the lowest level of health established in children with high-dose irradiation of the thyroid gland;
- Peculiarities of formation and course of chronic somatic diseases, namely: the emergence in a more younger age, polysystem, multiorgan nature of lesions, relapsing course with relative resistance to therapy;
- The existence of reliable correlations between health state, physical development, formation of phenotypes with multiple minor anomalies, increased number of chromosomal aberrations in somatic cells of children and their dose exposure during fetal development;
- In children born from exposed persons formed phenomenon of genomic instability, characterized by predisposition to multifactorial diseases, formation of morphogenetic variants with multiple small anomalies of development, increased frequency of chromosomal aberrations in somatic cells and the frequency of mutations in microsatellite-associated DNA fraction.

3.2.4. Diseases of thyroid gland

Among the adult population of Ukraine affected by Chernobyl, the most common (40-52 %) is the thyroid gland (TG) pathology, whereas in normal population, according to official statistics from the Ministry of Health of Ukraine, it occurs much less often. To increased prevalence of thyroid diseases contributed the complex influence of negative factors of the accident, first of all, ionizing radiation and deficiency of several micronutrients, especially iodine and selenium.

A sumation (combination) of external γ-irradiation and internal exposure to radionuclides influence on tropic structure hormone-producing cells, which led to the destruction of various stages of hormonal regulation, both central and peripheral tissues of the endocrine system. Radiation damage to these tissues realized via activation of a genetic predisposition through interaction with negative environmental factors.

Part of the absorbed dose was formed in the early days-months of the accident, and another prolonged – over the years, which complicates assessment of its impact. Extremely high concentrations of iodine isotopes in the air in the first days-weeks of the accident and existing iodine deficiency contributed significantly to the accumulation of radioactive iodine in the thyroid and destruction of thyreocytes, that caused in clean-up workers with high doses of radiation (more than 1 Sv) development of acute radiation thyroiditis, and early implementation of ionizing radiation in the form of thyroid cancers. In persons with radiation dose (0.25–1) Sv a long transient euthyroid hyperthyroxinemia was observed during the first 3–5 post-accidental years (1986–1991). This was a prerequisite for the gradual development of delayed chronic pathological processes in the thyroid and other endocrine organs, especially thyroiditis, nodular goiter.

Due to nutritional deficiency of iodine, selenium in the pre-accident period a large number of people had functional tension of the thyroid gland in the form of hyperplasia of endocrine (hormone-producing) cells, contributing to a greater capacity for accumulation of isotopes.

After the Chernobyl accident non-stochastic pathology developed by stages – according to the pathophysiological changes occurring in the tissues of the central and peripheral parts of the endocrine system.

During the primary response to a complex of negative factors of the accident, which lasted until August 1986, there was an increase of peripheral concentrations of hormones in the blood because of partial endocrine cells destruction.

Increased synthesis of peripheral hormones on the background of lack of response of the central parts of regulation – a violation of feedbacks because of the lack of synthesis of releasing factors and pituitary tropic hormone – was typical for the next period of compensative peripheral hormones hyperproduction, which lasted from September 1986 to 1989.

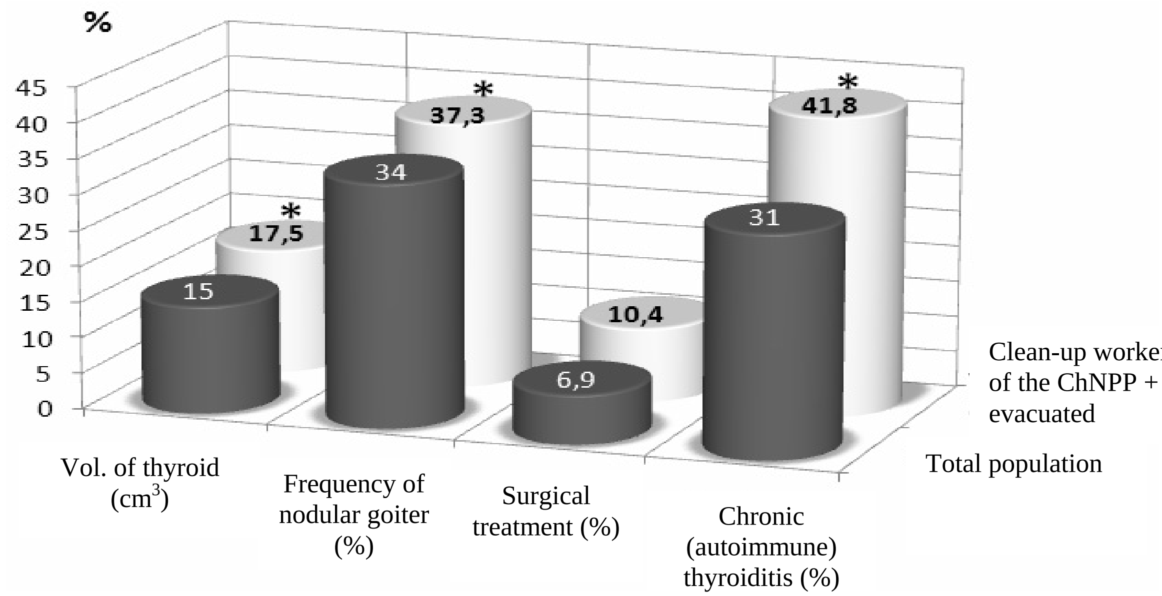


Fig. 3.38. *The frequency of thyroid cancer among clean-up workers of the Chernobyl accident (1986–1987) and evacuated from the 30-km exclusion zone (data for 2006) compared to the general population of Ukraine, which was not involved in influence of ionizing radiation (data of SI «RCRM of AMS of Ukraine).*

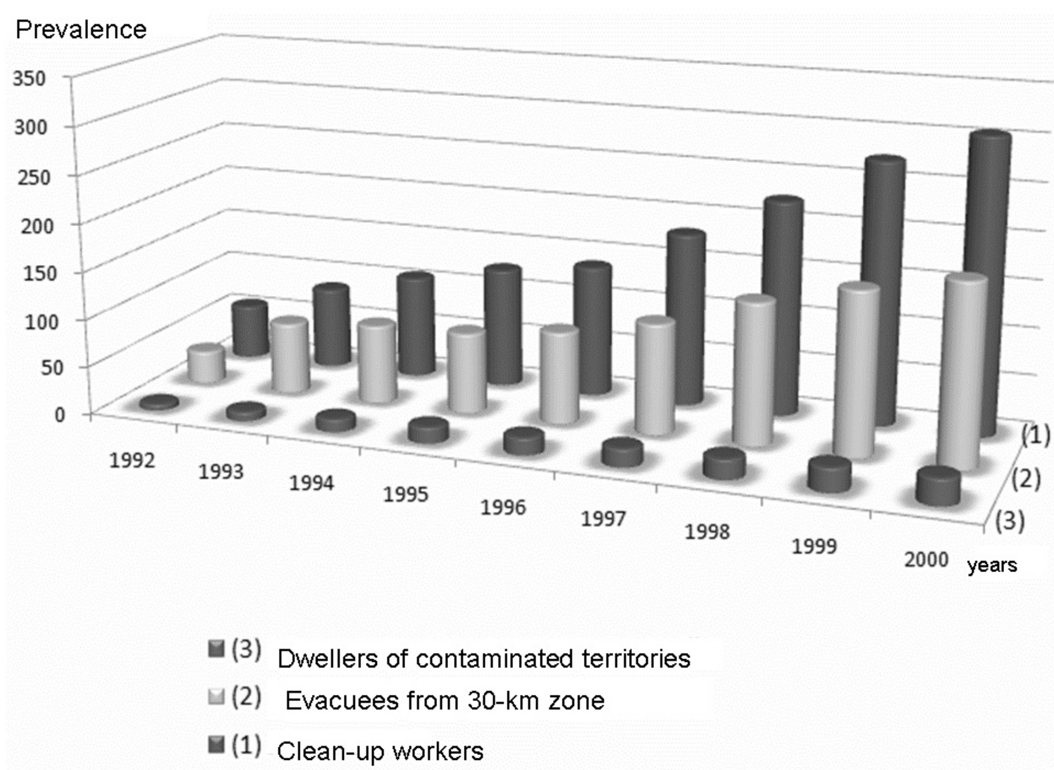


Fig. 3.39. *Prevalence of chronic thyroiditis in Ukraine are among the sufferers of the Chernobyl accident of different categories (adults and children per 10,000), according to the Ministry of Health of Ukraine.*

In the next period (1990–1995 years) of subclinical disorders of endocrine tissues functions restoration of the central regulation of hormone production, decrease of functional capacity of peripheral endocrine tissues, the development of subclinical conditions of thyroid and other organs were observed.

Since 1996 to this time a clinical manifestation of radiation induced endocrine disorders as a burst of endocrine diseases detection against the background of a strong decline of functional capacity of peripheral endocrine tissue, disorders in the central links of hormonal regulation.

In 1992–1996 he a risk of thyroid disease in patients who suffered from the Chernobyl accident, increased 9 times, type 2 diabetes – in 2,4 times. The annual growth rate of endocrine diseases in clean-up workers was 3–5 times higher than in the adult population as a whole. According to SRU (68, 145 persons, the observation period of 1988–2009), an increased rate of non-tumor thyroid disease mostly due to chronic (autoimmune) thyroiditis, nodular goiter, acquired hypothyroidism were also found (Fig. 3.38, 3.39).

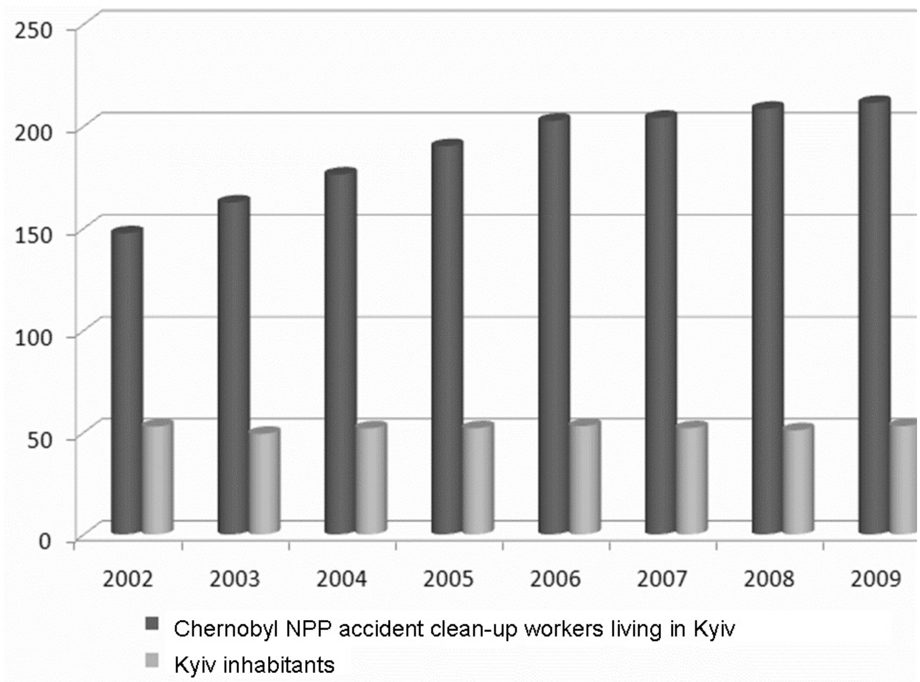


Fig. 3.40. *Prevalence of chronic (autoimmune) thyroiditis among clean-up workers of the Chernobyl accident and the residents of Kyiv (adults and children per 10,000; data of SI «RCRM of AMS of Ukraine).*

During the period from 1997 to the present chronic thyroiditis incidence among clean-up workers continues to grow, while among residents of Kyiv its level kept stable (Fig. 3.40). The most rapid increase in the prevalence of thyroid disease recorded in the clean-up workers, who in 1986 was under 20. The important risk factor for chronic thyroiditis and acquired hypothyroidism in clean-up workers of 1986-1987 and evacuees from the 30-km exclusion zone are the whole body external exposures in the range 0.25–1 Gy.

Status of the thyroid system in children

During the first year after the accident in the affected children was observed early reaction to thyroid irradiation as hyperthyroxinemia without clinical manifestations, short-term «stress» hiperthyreotropinemia with following resumption of interconnections in the system thyreotropin-thyroxine. In 12–18 months after the accident thyroxine content was normalized and in the following years oscillated within the physiological norm. Further levels of thyreotropinemia averages did not differ from that of the norm against the backdrop of ongoing hyperthyroxinemia. At doses of radiation of thyroid over 2 Gy average thyroxine level in blood significantly grew with increasing dose, reaching a maximum at doses over 15 Gy.

Hormonal changes at the stage of 1986–1991 had no clinical display in the change of thyroid diseases among children and adolescents. Between 1992–1996 only in 0.8 % cases was noted reduced free thyroxine and in 0.2% – increase of pituitary thyroid stimulating hormone without any clinical manifestations. Cases of chronic thyroiditis, hypothyroidism recorded rarely, but without reliable increase in the frequency of these diseases that can be explained by the positive sanogenetic role of processes of rehabilitation and compensation in the growing organism.

In the absence of significant changes in the rate of diseases such as hypothyroidism, chronic thyroiditis and thyrotoxicosis in children affected by the Chernobyl accident in 1999–2003 researches were conducted on detection of hidden thyroid failure, the principles of treatment and rehabilitation of children with thyroid diseases affected by the Chernobyl accident and permanently living in contaminated areas with a shortage of iodine in the environment.

In the period 2004–2006, it was found that the feature of thyroid system functioning in children born to liquidators who had been exposed to factors of the Chernobyl accident of iodine period, were tension is the central regulation of hypothalamic-pituitary axis, which were found in 35.5 % of examined, as certified by the presenceof hypersecretory reaction of thyreotropin on trial with thyreotropin-releasing hormone and may be indirect evidence of neuroendocrine structures physiological inferiority prone to manifestations of thyroid disease. Delayed in time cytogenetic effect detected with long-term cultivation of cells, shows the transmission of chromosomal instability to descendants of irradiated parents that could promote the thyroid diseases in children with a hidden functional failure of hypothalamic-pituitary-thyroid system.

Cancer of the thyroid gland in children and adolescents of Ukraine

Today a significant increase in the incidence of thyroid cancer (TC) after the Chernobyl catastrophe among high risk groups (0–18 years old at the time of the accident) is finally proved; it is recognized as the main health consequences of the Chernobyl accident by leading medical and scientific institutions in the world.

In 25 years after the Chernobyl accident children and adolescents who have experienced the most significant effect of radioactive iodine, moved to the category of adults, so now special attention should be payed to information on the TC among young adults, finding out the dynamics of changes in macro-microscopic characteristics and invasive properties of tumors.

The development of malignant tumors is clearly stochastic effects of radiation, but people who were exposed to the Chernobyl accident in childhood, especially up to 4 years of age, there was a clear dependence of the additional degree of TC incidence on thyroid irradiation. More higher prevalence of thyroid cancer in higher doses in people aged under 18 at the time of the Chernobyl disaster was observed during the screening and research for the Ukrainian-American thyroid project. Moreover, morbidity in children born before the accident, is 15 or more times higher than the rates in children born after the accident, which further confirms the nature of radiation «children postchernobyl» thyroid cancer.

Analysis of clinical and morphological data register of Institute of Endocrinology and Metabolism named by V.P. Komissarenko, Academy of Medical Sciences of Ukraine found that in Ukraine during post-chernobyl period (1986–2008) 6049 persons were operated born in 1968–1986 (0–18 years old at the time of the accident) with morphologically confirmed diagnosis of «thyroid cancer» among them 4480 (74.1 %) were in childhood (0–14 years; Fig. 3.41) and 1569 (25,9%) – in adolescence (15–18 years old at the time of the accident; Fig. 3.42).

Ratio of women: men for these age groups increased by age at the time of accident: 3560:920 (3,9:1) for children and 1312:257 (5,1:1) for adolescents. The incidence gradually increased from 1990 to 2008. The number of new cases of thyroid cancer in children at the time of the Chernobyl accident in

2009 was 463 (as in the previous 2008). The number of cases in adolescents at the time of the accident was 129 and also did not differ from the previous year.

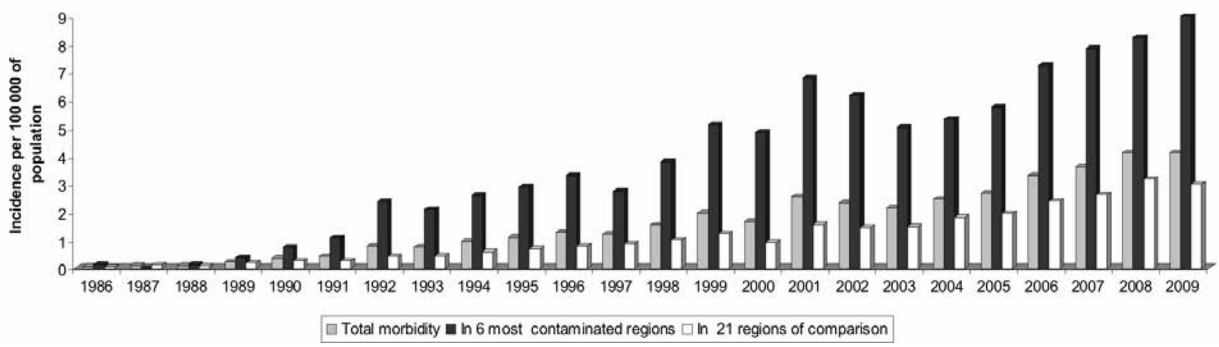


Fig. 3.41. *Incidence of thyroid cancer (per 100 thousand of child population aged 0-14 at the time of the Chernobyl disaster; data of SI «Institute of Endocrinology and Metabolism named by V.P. Komissarenko, Academy of Medical Sciences of Ukraine»)*

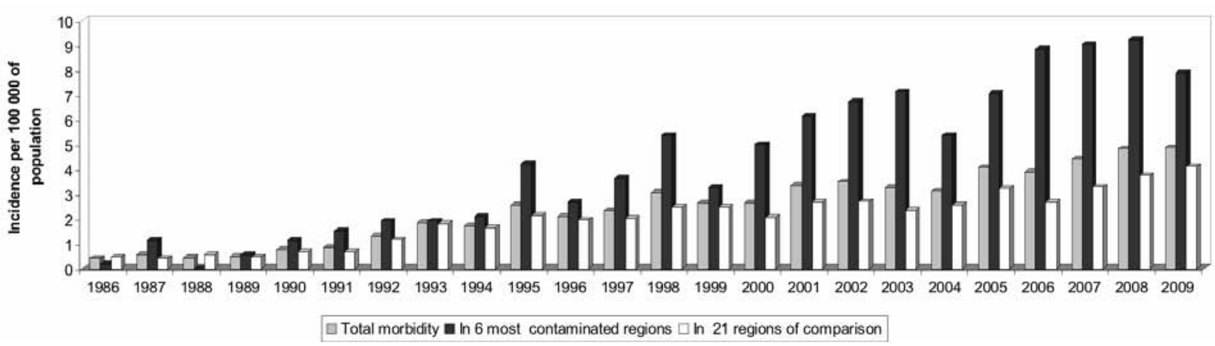


Fig. 3.42. *Incidence of thyroid cancer (per 100 thousand of child population aged 15–18 at the time of the Chernobyl disaster; data of SI «Institute of Endocrinology and Metabolism named by V.P. Komissarenko, Academy of Medical Sciences of Ukraine»)*

More likely relative index, i.e. incidence per 100 thousand children and teenagers at the time of the accident also rose steadily from 1990 to 2008. In 2009, the incidence was 4.13 in children and 4.87 in adolescents, not exceeding the figures for 2008 (Fig. 3.41, 3.42). Thus, it is possible that in 2008–2009 the peak incidence of thyroid cancer in radiation-risk group was determined, and in 2010 a gradual reduction of such diseases will be expected.

Increase in the incidence of TC to some extent could be explained by a gradual increase in the age of designated cohort during 1986–2008. But the difference between the incidence of TC in the six most affected northern regions compared with the rest of the country not only conserved, but increased in 2006–2008 compared with the previous period of research in children and adolescents at the time of the accident (Fig. 3.41, 3.42), indicating an association between increased TC incidence and radiation factor, not with increasing age over time that has elapsed since the accident.

By the age at the time of surgery (Fig. 3.43) in recent years TC in children and adolescents was found only among born after the Chernobyl disaster. In adults born after the accident first cases of TC were reported in 2006. During 2006–2009 their number amounted to 91 compared with 2223 cases identified among people who were children and adolescents at the time of the accident (Fig. 3.43).

Total number of cases of TC, registered over the years 1986–2009, was 6448, among them 6049 were born before the accident and 399 – after the accident. In young adults born before the accident the incidence of TC and morbidity in Ukraine in general and in the most contaminated regions in 2009 remained at the 2008 level (Fig 3.43).

Incidence among children, adolescents and young adults of 19–22 years old, born after the Chernobyl accident (in 1987 and subsequent years) in all years of observation was significantly lower than in the corresponding age groups born before 1987 (Fig. 3.43).

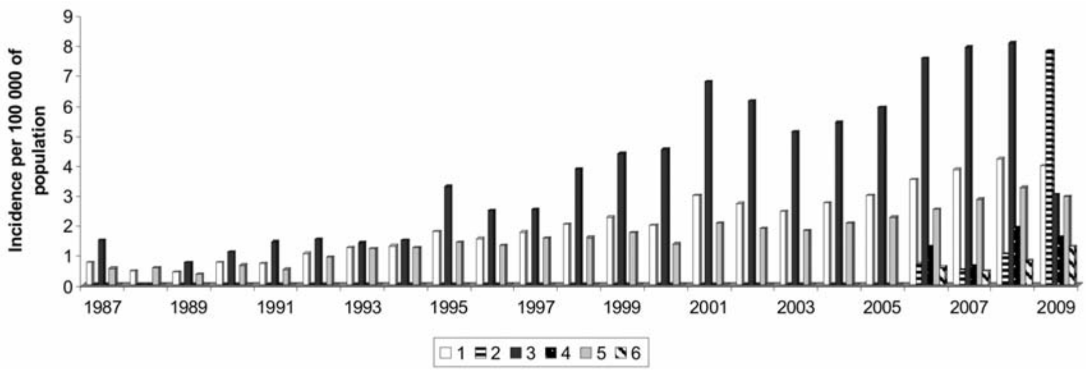


Figure 3.43. *Incidence of thyroid cancer (per 100 thousand population, 19–40 years old at the time of surgery: born before 1987 and in 1987 and later; data of SI «Institute of Endocrinology and Metabolism named by V.P.Komissarenko, Academy of Medical Sciences of Ukraine)*
1 – Ukraine, born before 1987; 2 – Ukraine, born in 1987 and later; 3 – 6 most polluted regions, born before 1987; 4 – 6 most polluted regions, born in 1987 and later; 5–21 region of comparison, born before 1987, 6–21 region of comparison, born in 1987 and later.

According to morphological characteristics of TC operated in 1990–2008 in patients whose age at the time of the accident did not exceed 18 years, 92.2 % of cases were papillary carcinoma,

With time that has elapsed since the accident, raised the age of exposed, but also significantly changed the morphological characteristics of papillary carcinoma towards a gradual reduction of the percentage of carcinomas of a solid structure from 24.4 % in 1990-1995 to 5.7 % in 2006–2009 ($p<0.01$ per test $\chi 2$) and increase the percentage of papillary carcinomas and mixed typical structure: from 12.0 % in 1990–1995 to 34.0 % in 2006–2009 and 25.5 % in 1990–1995 to 43.8 % in 2006–2009 respectively ($p<0,05$). With the increase in latent period varied the combination of structural components of the mixed variant of papillary carcinoma as well: the percentage of tumor of solid-follicular structure significantly decreased (from 72.7 % in 1990–1995 to 25.4 % in 2006–2009, p<0 01), while the percentage of tumor of papillary-follicular structure increased (from 10.9 % in 1990–1995 to 43.8 % in 2006–2009, $p<0,01$).

Analysis of the invasive properties of papillary carcinomas has established two major dependencies: age and time.

Under the age dependency extrathyroid signs of invasion, presence of regional and distant metastases consistently significantly declined from children of 4–14 years old to adults of 19–40 years old at the time of surgery.

Over time dependence by combining all cases of patients of 4–40 years a reduction of the mentioned above parameters was determined with the increase of latent period (time elapsed from the Chernobyl accident to the surgery). Of special interest are the data on reduction the percentage of patients with the occurence of distant metastases from 23.0 % in 1990–1995 to 1.8 % in 2006–2009 ($p<0,001$).

Moreover, the percentage of encapsulated tumors increased from 7.4 % in 1990–1995 to 29.4 % in 2006–2008 ($p<0,001$) as well as «small» carcinomas up to 10 mm: from 4.1 % in 1990–1995 to 29.4 % in 2006–2009 ($p <0,001$).

Thus it can be summarized that the morbidity of thyroid cancer per 100 thousand children and adolescents (age at the time of the accident) were highest in 2006–2008 and stabilized in 2009.

Meanwhile, saving significant difference in morbidity levels between the most and least affected regions of the country (2.5 times in children and 1,9 times in adolescents), evidence for the fact that in

Ukraine 24 years after the Chernobyl disaster was kept effect of the radiation factor on the incidence of thyroid cancer among persons at high risk.

The data also show that with time elapsing after the Chernobyl disaster and age of patients at the time of surgery, prevailing among thyroid cancers papillary carcinomas experienced significant morphological changes, which reflecttd the reduction of aggressive disease, as evidenced by a significant decrease in the percentage of cases with signs of extrathyroid spread, appearence of regional and distant metastases.

The gradual accumulation of cases among persons born after the Chernobyl accident, compared with adequate relevant age group each year adds evidence to support the radiation nature of TC in children and adolescents exposed to radiation from the Chernobyl disaster.

3.2.5. Epidemiological studies of health of the population living in contaminated territories

Stohastic effects

Taking into account the radiation nature of increase the incidence of TC in the remote period after the Chernobyl accident should a more detailed description of this phenomenon is needed. In Ukraine as a whole growing of TC incidence in the male population has doubled, and women – three times greater than the expected spontaneous rate (Fig. 3.44).

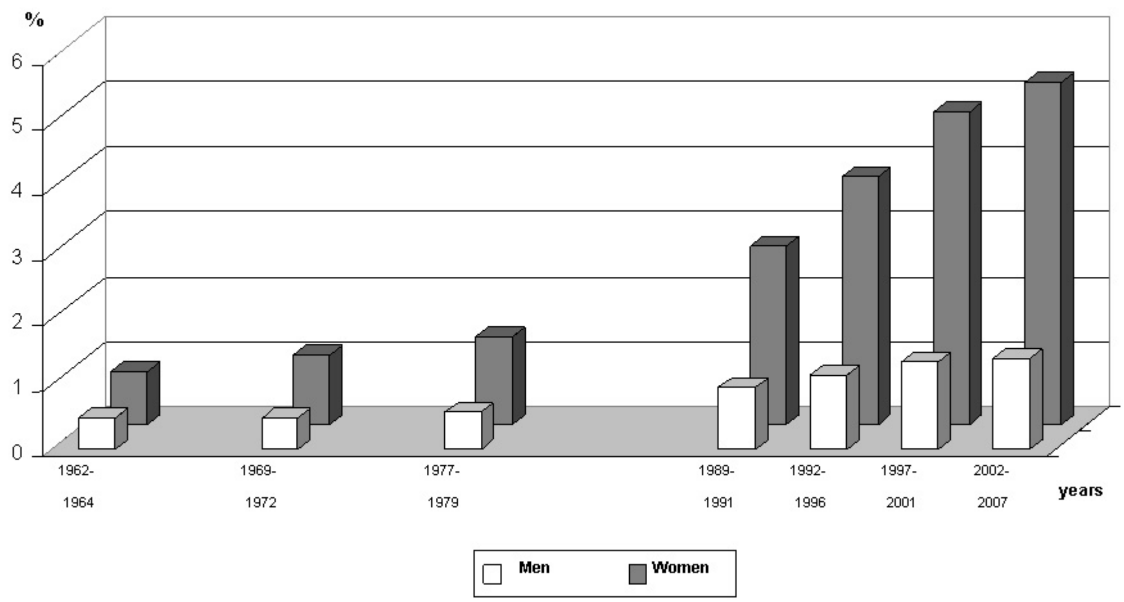
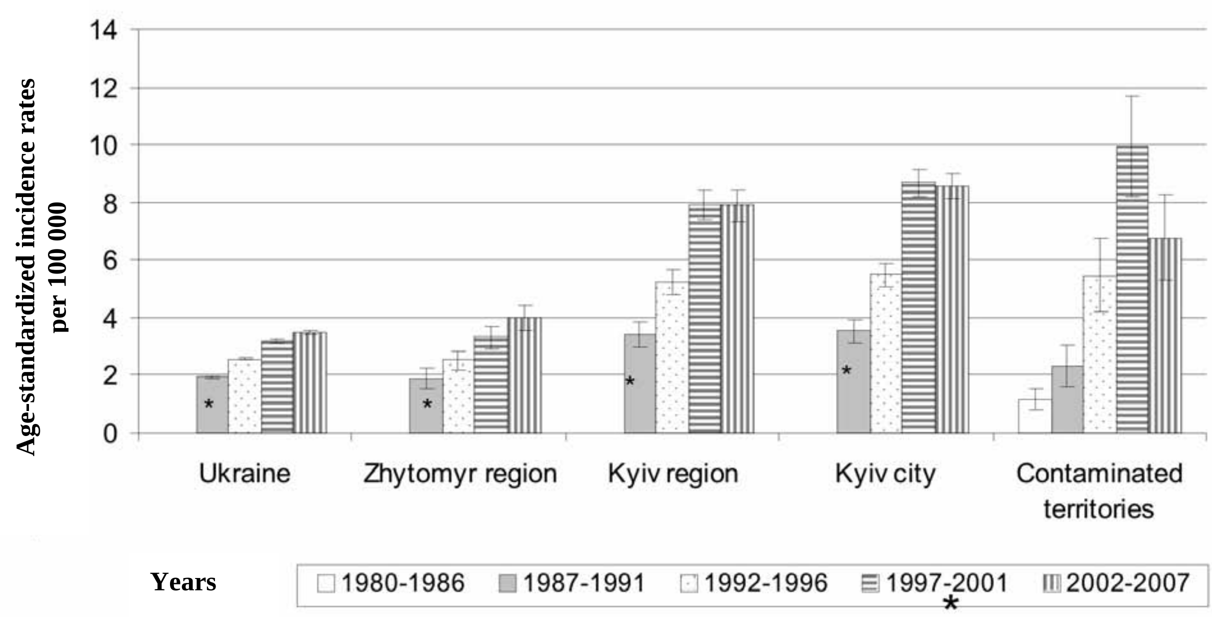


Fig. 3.44. *Standardized by age the average annual incidence of thyroid cancer in Ukraine per 100 000 population for separate time periods (men and women, data of SI «RCRM of AMS of Ukraine»).*

Next Fig. 3.45 reflects the dynamics of the incidence of TC in the most contaminated area.

In the inhabitants of those territories in the pre-accident period (1980–1986) morbidity of TC were 1.2 per 100 000 inhabitants. In the post-accident years a rapid growth rate of this disease was seen: in the 1987–1991 – 2 times, in 1992–1996 – 4.5 times, in 1997–2001 – 8.3 times. Some decrease in this index of 2002–2007 compared with the previous period (at 34.1 %), probably due to a complexity of factors such, for example, migration from these areas populations with the highest risk of developing this pathology (young families with children). It is necessary also to specify a possible termination of period of time under the radiation risk of the youngest irradiated age group.



Note. * only 1989-1991

Fig. 3.45. *Incidence of thyroid cancer in the population of Ukraine, Zhytomyr, Kyiv region, Kyiv city and most contaminated with radionuclides territories during 1980–2007 (data of SI «RCRM of AMS of Ukraine).*

Among affected by the Chernobyl disaster a significant increase in the incidence of TC was marked compared to the country as a whole: in the evacuees – 4.4 times, in residents of most contaminated areas – 1.35 times that is conneected to the exposure of the thyroid by radioactive iodine (Table 3.30).

Table 3.30.

Incidence of thyroid cancer (ICD-10 C.73) of the main population groups of Ukraine affected by Chernobyl accident (data of SI «RCRM of AMS of Ukraine)

Group of affected and the period of observation	Number of cases		Standardized incidence rate (SIR %)	95% confidence interval
	expected	actual		
Evacuated from the exclusion zone (2000–2007)	52,3	231	441.7	384.7–498.6
Dwellers of the most contaminated areas (2002–2007)	71	96	135.2	108.2–162.3

According to analysis of long-term monitoring other forms of malignant neoplasms in affected populations have not exceeded national levels. In most evacuees and residents of contaminated areas (RZT), these values were significantly lower than in Ukraine in general (Table 3.31). However, there is a risk of negative trends in the incidence of cancer in more remote period of observation.

Table 3.31.

The incidence of malignant neoplasms (ICD-10 S.00-S.96) in the main population groups of Ukraine affected by Chernobyl accident (data of SI «RCRM of AMS of Ukraine)

Group of affected and the period of observation	Number of cases		Standardized incidence rate (SIR %)	95% confidence interval
	expected	actual		
Evacuated from the exclusion zone (2000-2007)	3318	2718	81.9	78.9-85.0
Dwellers of the most contaminated areas (2002-2007)	4753	3678	77.4	74.9-79.9

Table 3.32.

Incidence of breast cancer (ICD-10 C.50) in groups of female population of Ukraine affected by Chernobyl accident (data of SI «RCRM of AMS of Ukraine)

Group of affected and the period of observation	Number of cases		Standardized incidence rate (SIR %)	95% confidence interval
	expected	actual		
Evacuated from the exclusion zone (2000-2007)	344	238	69,2	60,4-78,0
Dwellers of the most contaminated areas (2002-2007)	460,5	295	64,1	56,8-71,4

Incidence rate of breast cancer in evacuated and residents of radiation contaminated areas were lower than the national level, despite the continuing trend to increase of the absolute number of cases (Table 3.32). It should be noted that these categories of sufferers in pre-accident period lived in areas with relatively low incidence of breast cancer.

Non-tumor morbidity

According to researches carried out within 25 years after the Chernobyl accident, health state of evacuated population considerably deteriorated at the post-evacuation period. The key factor of disability and mortality are the non-tumor diseases. According to SRU at the expense of non-tumor diseases from 1988 to 2008 the number of healthy among evacuees has decreased from 67.7 % to 21.5 %, with chronic diseases increased from 31.5 % to 78.5 % (Fig. 3.46) .

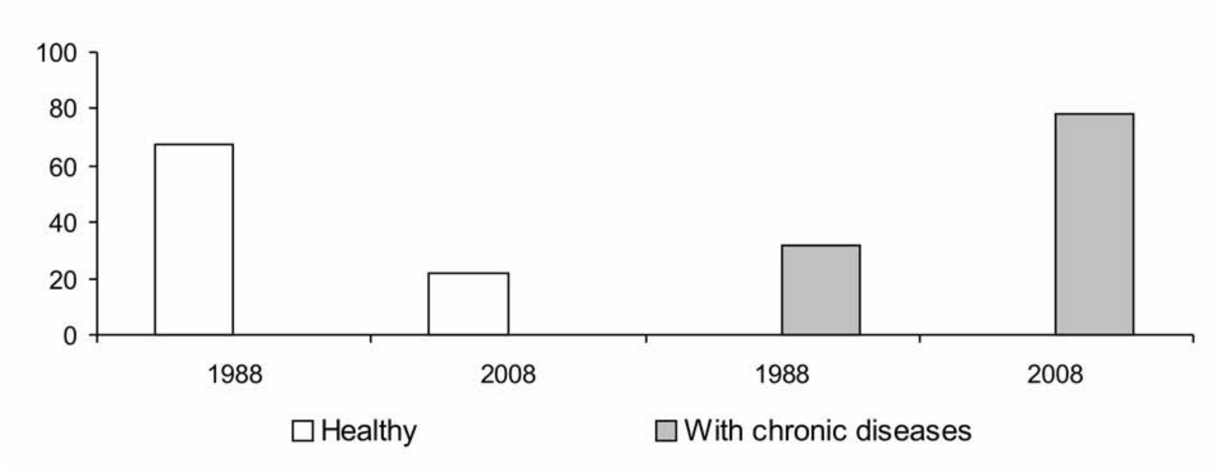


Fig. 3.46. *Integral health indices (%) of the evacuated adult population in 1988 and 2008 (data of SI «RCRM of AMS of Ukraine).*

Epidemiological analysis of changes in non-cancer incidence by five-year period of observation (Fig. 3.47) showed that the highest level of disease was registered in 1998–2002. The gradual reduction of most rates from 1988 to 2007 in evacuees could be due to the implementation of disease newly diagnosed at the previous stages and partial mortality of cohort.

However, growth of individual diseases in the dynamics shows that the development of non-tumor diseases in this troops of suffered is still prolonged, especially it concerns people, who at the time of the accident were children and teenagers. The of influence»small» doses of irradiation on the development of non-tumor diseases (distant in time the effects of low doses of ionizing radiation) and a set of non-radiation factors cannot be excluded.

Between 1988–2007 a significant change of evacuees' non-cancer morbidity was registered for individual classes and nosological forms.

In 2003–2007 compared with all previous stages incidence of toxic nodular goiter were significantly higher. Statistically higher against the first and second stages was morbidity in acquired hypothyroidism, diseases of digestive organs, including liver, biliary tract and pancreas. The incidence of thyroiditis, nervous system and sensory organs, including vegetative-vascular dystonia, cerebrovascular disease, respiratory diseases, ulcers of stomach and duodenum, urinary and musculoskeletal system significantly exceeds the level of the first stage only. For other diseases recorded statistically lower levels.

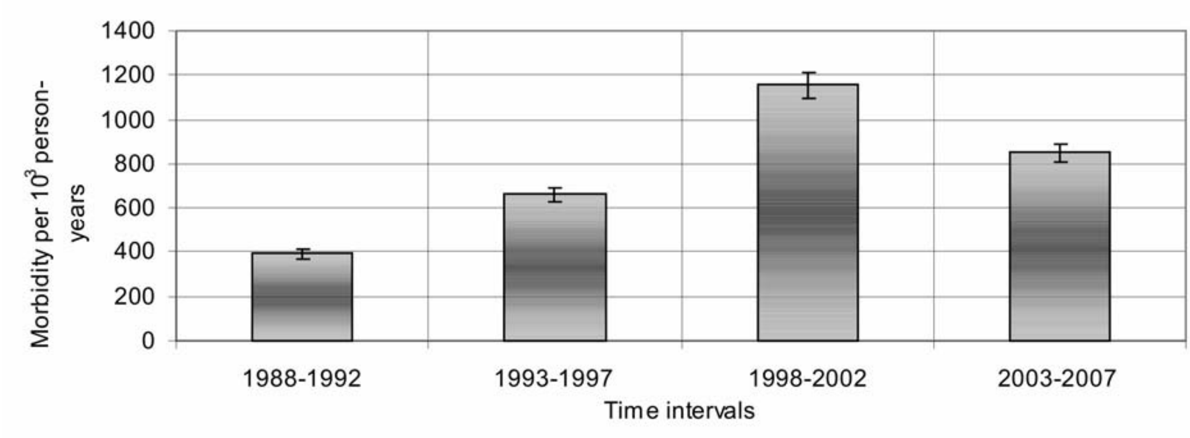
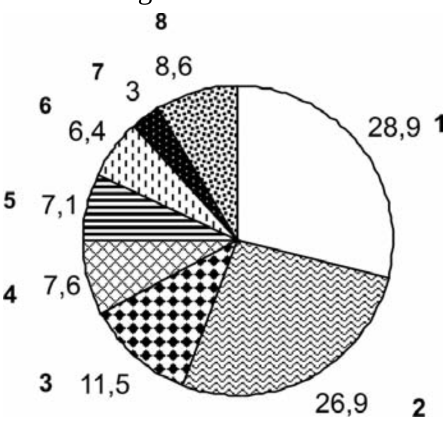
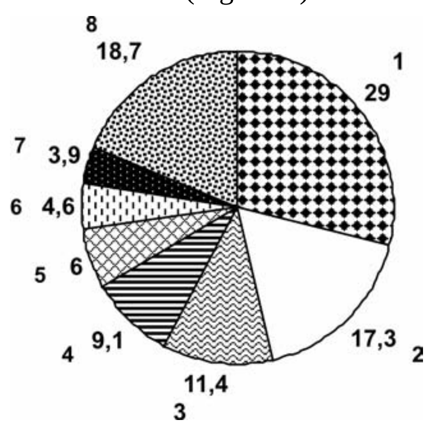


Fig. 3.47. *Dynamics of non-cancer morbidity of adult evacuees by five-year periods of observation (data of SI «RCRM of AMS of Ukraine).*

Similar changes were observed in the structure of non-cancer diseases (Fig. 3.48).





1988 рік		*2007 рік*	
1	*cardiovascular diseases;*	*1*	*digestive system diseases*
2	*respiratory diseases;*	*2*	*cardiovascular diseases;*
3	*digestive system diseases*	*3*	*respiratory diseases;*
4	*diseases of nervous system and sensory organs;*	*4*	*diseases of the musculoskeletal system;*
5	*diseases of the musculoskeletal system;*	*5*	*diseases of nervous system and sensory organs;*
6	*endocrine diseases;*	*6*	*endocrine diseases;*
7	*genitourinary system diseases;*	*7*	*genitourinary system diseases;*
8	*other diseases.*	*8*	*other diseases.*

Fig. 3.48. *Structure of non-cancer diseases (%) of the evacuated adult population in 1988 and 2007 (data of SI «RCRM of AMS of Ukraine).*

In 1988 the largest share in the structure consistently accounted for the diseases of circulatory, respiratory, digestive, nervous system and sensory organs, musculoskeletal, endocrine and urogenital systems. Their contribution to the overall structure was 91.4 %.

In 2007, mentioned pathology also had the largest share, but changed its position in the structure. The contribution of cardiovascular diseases decreased and they relocated in the structure of the second rank place. The first place belonged to diseases of the digestive system. Decreased proportion of respiratory disease, but increased – diseases of the nervous system and sensory organs, and to some degre – the endocrine and urogenital systems.

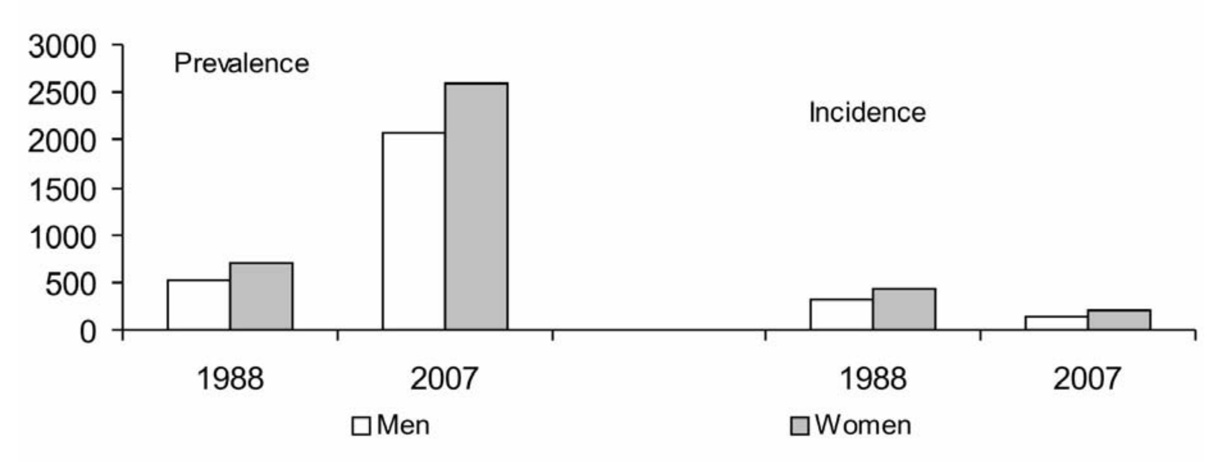


Fig. 3.49. *Incidence and prevalence of non-tumor diseases among the adult evacuated population, depending on the gender in 1988 and 2007 (data of SI «RCRM of AMS of Ukraine).*

Gender differences in the dynamics of prevalence and incidence of non-tumor disease consisted in the fact that the prevalence of disease among women exceeded the corresponding rates for men by 20.0 %, incidence – by 30.9 % (Fig. 3.49).

The greatest differences of prevalence were found in levels of endocrine system diseases, including thyroid (1.6 times). Women recorded higher more than 2 times values of nontoxic nodular goiter, thyrotoxicosis and goiter with or without acquired hypothyroidism, thyroiditis. Women have also higher levels of diabetes mellitus (1.8 times), genitourinary system (2.1 times). The level of cataract in women was higher 1.7 times, cerebrovascular disease – 1.5 times. However, the incidence of gastric ulcer and duodenum was higher in men.

According to figures of newly diagnosed diseases again most excess were observed in women in the level of thyroid disease (2 times), including acquired hypothyroidism – 3.3 times, thyrotoxicosis – 3.6 times, non-toxic nodal goiter – 2.8 times. More than 2 times higher were cataract, cerebrovascular diseases, diseases of liver, biliary tract, pancreas, urinary system. At all stages a higher level of non-tumor diseases was in persons 40 years and older compared with younger contingent (Fig. 3.50).

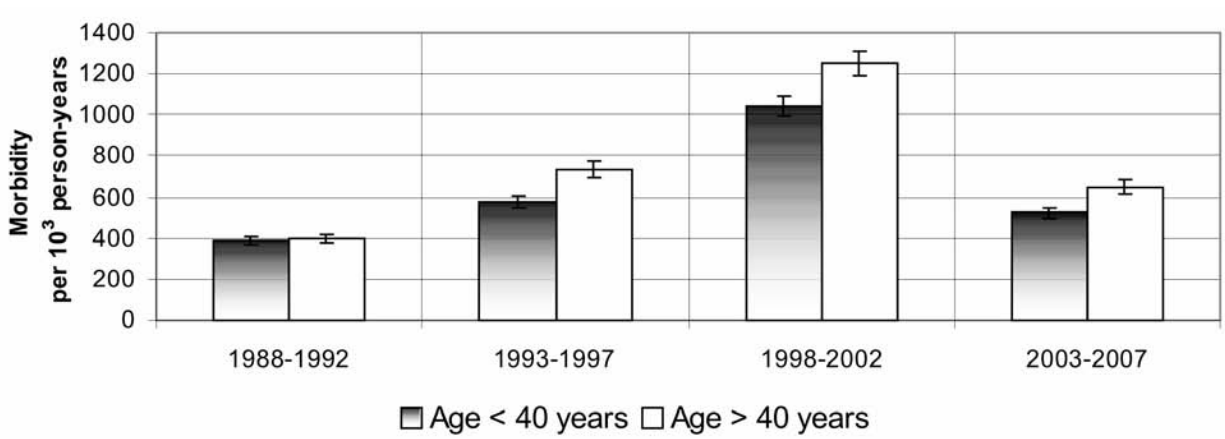


Fig. 3.50. *Dynamics of non-cancer morbidity of evacuated adult population by age in five-year period of observation (data of SI «RCRM of AMS of Ukraine).*

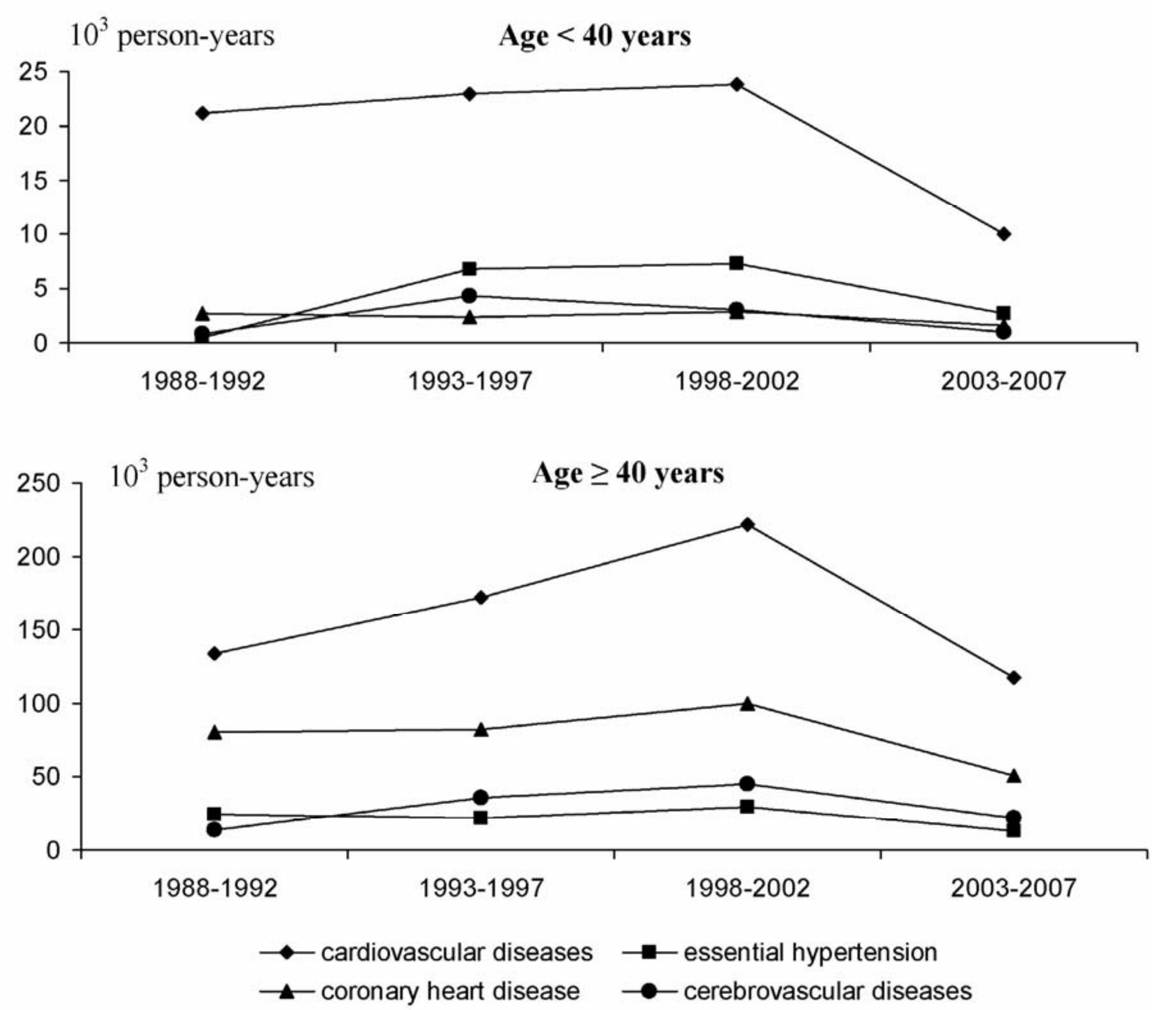


Fig. 3.51. *Dynamics of cardiovascular disease in adult evacuees by five years observation period depending on age (data of SI «RCRM of AMS of Ukraine).*

Especially significant difference observed in the level of diseases of cardiovascular system, including coronary heart disease and cerebrovascular disease (Fig. 3.51).

Significant differences registered in the dynamics of some forms of thyroid diseases. Since 1993–1997 the rates of nontoxic nodular goiter, acquired hypothyroidism, thyroiditis were higher in persons over 40 years (Fig. 3.52).

Significant dose-related effects of certain non-tumor diseases were found in the adult evacuated population with irradiation of thyroid and external whole body irradiation. Thyroid irradiation doses 0.3 – <2.0 Gy demonstrated reliable connection the dose to cardiovascular diseases, including coronary heart disease and cerebrovascular pathology, diseases of the musculoskeletal system. With increasing doses to the thyroid gland to 2.0 Gy the risks of named diseases increased, a credible risk of mental disorders and diseases of the digestive system was registered as well (Table 3.33).

Doses of whole body external irradiation significantly influenced on the development of non-cancer morbidity of evacuees. According to the results of risk analysis a growth of relative risks (RR) of certain non-tumor diseases were found and increase of their number with reliably verified risk while increasing exposure doses. The maximum risk for most diseases found in the dose range 0.25–0.32 Gy (Table 3.34).

Compared with the control lowest quantity of disease with a statistically confirmed risk was registered in dose subcohort 0.05–0.099 Gy. With increasing doses up to 0.1–0.249 Gy the number of diseases with ssignificant RR increased due to such nosological forms as cataracts, essential hypertension, cerebrovascular pathology, diseases of urinary system.

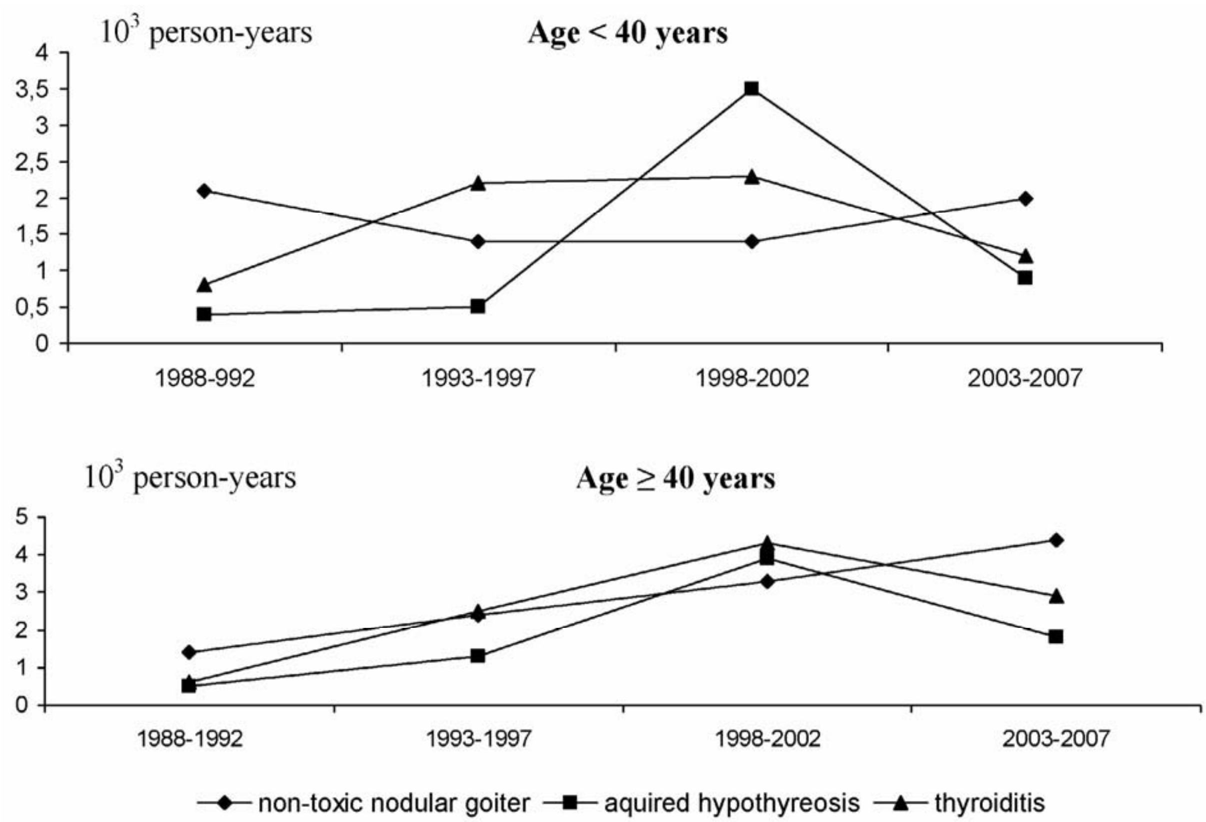


Fig. 3.52. *Dynamics of certain forms of thyroid diseases in adult evacuated population by observation period of five years depending on age (data of SI «RCRM of AMS of Ukraine).*

Table 3.33.

Relative risks of certain non-tumor diseases in the adult evacuees in the period of 1989-2005 depending on the thyroid gland exposure (data of SI «RCRM of AMS of Ukraine)

Classes and nosological forms of diseases	ICD-9	Relative risk indices for exposure doses	
		0.3 – < 2.0 Гр	≥ 2.0 Гр
Diseases of circulatory system	390-459	1,89* (1,64-2,18)	2,91* (2,51-3,37)
- Coronary heart disease	410-414	3,22* (2,50-4,15)	4,38* (3,37-5,68)
- Cerebrovascular disease	430-438	2,00* (1,41-2,86)	4,83* (3,46-6,73)
Diseases of digestive system	520-579	1,02 (0,86-1,22)	1,40* (1,15-1,71)
- Diseases of liver, biliary tract and pancreas	571-577	1,06 (0,82-1,35)	1,34* (1,01-1,79)
Diseases of the musculoskeletal system	710-739	1,22* (1,01-1,49)	2,69* (2,21-3,26)
Mental disorders	290-319	1,10 (0,65-1,88)	1,82* (1,02-3,26)

Note. * – $p < 0,05$

Table 3.34.

Relative risks (RR) of some non-tumor diseases in the adult evacuees within the period 2003 – 2007 depending on the dose of whole body irradiation (dose subcohort of comparison <0.05 Gy; data of SI «RCRM of AMS of Ukraine)

Nosological groups. forms of diseases	ICD-9	Indices of relative risk (RR) and confidence interval (CI) for exposure doses (Gy)			
		0.05 – 0.099	0.1 – 0.199	0.2 – 0.249	0.25 – 0.32
		RR (CI)	RR (CI)	RR (CI)	RR (CI)
Diseases of the thyroid gland	240-246	1.07 (0.78; 1.48)	1.10 (0.86; 1.41)	0.92 (0.71; 1.18)	1.37 [x] (1.06; 1.77)
- Acquired hypothyroidism	244	1.05 (0.38; 2.89)	0.69 (0.30; 1.59)	0.94 (0.43; 2.07)	1.14 (0.50; 2.63)
- Thyroiditis	245	0.46 (0.16; 1.29)	0.81 (0.43; 1.53)	0.92 (0.50; 1.72)	1.49 [x] (1.09; 2.79)
- Diabetes mellitus	250	0.57 (0.26; 1.25)	0.65 (0.38; 1.25)	0.41 (0.23; 0.74)	1.28 [x] (1.05; 2.19)
- Vegetative-vascular dystonia	337	2.04 [x] (1.12; 3.71)	4.44 [x] (2.72; 7.25)	1.45 (0.86; 2.43)	1.17 (0.66; 2.06)
- катаракта	366	1.73 (0.74; 4.04)	2.74 [x] (1.38; 5.45)	1.58 (0.78; 3.21)	2.94 [x] (1.45; 5.96)
- Essential hypertension	401-405	0.89 (0.64; 1.24)	1.35 [x] (1.07; 1.72)	1.01 (0.79; 1.29)	1.20 (0.93; 1.55)
- Ischemic heart disease	412-414	1.30 (0.97; 1.74)	1.24 (0.98; 1.57)	1.19 (0.94; 1.51)	1.27 [x] (1.01; 1.63)
- Cerebrovascular disease	437-438	1.45 (0.97; 2.16)	1.75 [x] (1.27; 2.42)	1.56 [x] (1.13; 2.16)	1.94 [x] (1.39; 2.71)
- Gastritis. duodenitis	535	1.52 [x] (1.01; 2.28)	1.15 (0.82; 1.62)	1.52 [x] (1.09; 2.12)	1.66 [x] (1.17; 2.35)
- Liver. biliary tract diseases	571-576	1.12 (0.91; 1.39)	0.92 (0.77; 1.09)	1.01 (0.85; 1.19)	1.27 [x] (1.06; 1.51)
- Diseases of the pancreas	577	0.88 (0.62; 1.27)	0.84 (0.64; 1.11)	0.83 (0.63; 1.08)	1.14 [x] (1.06; 1.50)
- Diseases of urinary system	580-599	1.37 (0.87; 2.17)	1.44 [x] (1.00; 2.08)	1.69 [x] (1.18; 2.43)	1.90 [x] (1.30; 2.77)
- Diseases of the prostate gland	600-602	1.30 (0.73; 2.32)	1.12 (0.70; 1.79)	1.52 (0.97; 2.40)	2.03 [x] (1.28; 3.24)
Osteopathies. hondropathies	733.0. 733.1	1.10 (0.82; 1.78)	1.17 (0.93; 1.47)	1.09 (0.86; 1.37)	1.39 [x] (1.09; 1.77)

Note. ^{x} – $p < 0,05$

The largest number of non-tumor diseases with reliably confirmed connection with the dose determined in the dose subcohort 0.25–0.32 Gy. Statistically significant RR was identified for thyroid disease, cataracts, coronary heart disease, cerebrovascular disease, gastritis, duodenitis, diseases ofliver and biliary tract, pancreas, urinary and prostate diseases, osteopathy, chondropatiy. With increasing dose grows the value of RR or apocryphal risk becomes significant.

Calculation results of excesses relative and absolute risks per unit dose also evidence reliable dose dependence of certain non-tumor diseases in the adult evacuees.

The highest reliably confirmed excess of absolute risks for evacuees at the maximum dose (0.25–0.32 Gy) was found for coronary heart disease, essential hypertension, liver and biliary tract diseases, the musculoskeletal system diseases. At the same time too high was also an excess of absolute risk for diseases of the endocrine system, including thyroid gland, urogenital system, osteopathies and chondropathies2.

Calculation results of excess relative risk per unit dose also prove for reliable evidence of dose dependence of certain non-tumor diseases in the adult evacuated population. Excess of relative risk of cataracts appeared to be the highest. Also rather high were excess of relative risks for diabetes, thyroiditis, cerebrovascular, urinary tract and prostate gland diseases.

Research SI «RCRM of AMS of Ukraine» proved that the irradiation caused accelerated development of age-dependent eye diseases – involutory cataracts, macular degeneration and retinal angiopathy. Irradiation dose acts as a synergistic factor to age.

The relative risk of involutory cataract is 1.139 (1.057, 1.228) per 1 year of stay at risk, 2.895 (2.529, 3.313) for 1 year of calendar year of age, 1.681 (1.033, 2.735) per 1√ (d * t), where d – dose in Gy, t – time spent at risk, years.

The relative risk of macular degeneration – 1.727 (1.498, 1.727) per 1 calendar year of age, 6.453 (3.115, 13.37) per 1√ (d * t), where d – dose in Gy, t – time spent at risk, years.

Dose-dependency of the retinal angiopathy incidence was shown for the first time, relative risk of disease in the group of irradiated at a dose of 30–70 cGy in comparison with irradiated at a dose of 0.3 Gy was 1.65 (1.02, 2.67) at $\chi^2 = 4.15$, p = 0.041.

Non-tumor mortality

Results of epidemiological studies of mortality from non-tumor diseases in the adult evacuees in the period of 1988–2007 have shown a gradual increase. The highest levels were found at the stage of 2003–2007 (Fig. 3.53). At the same time mortality rate of male and female almost equaled.

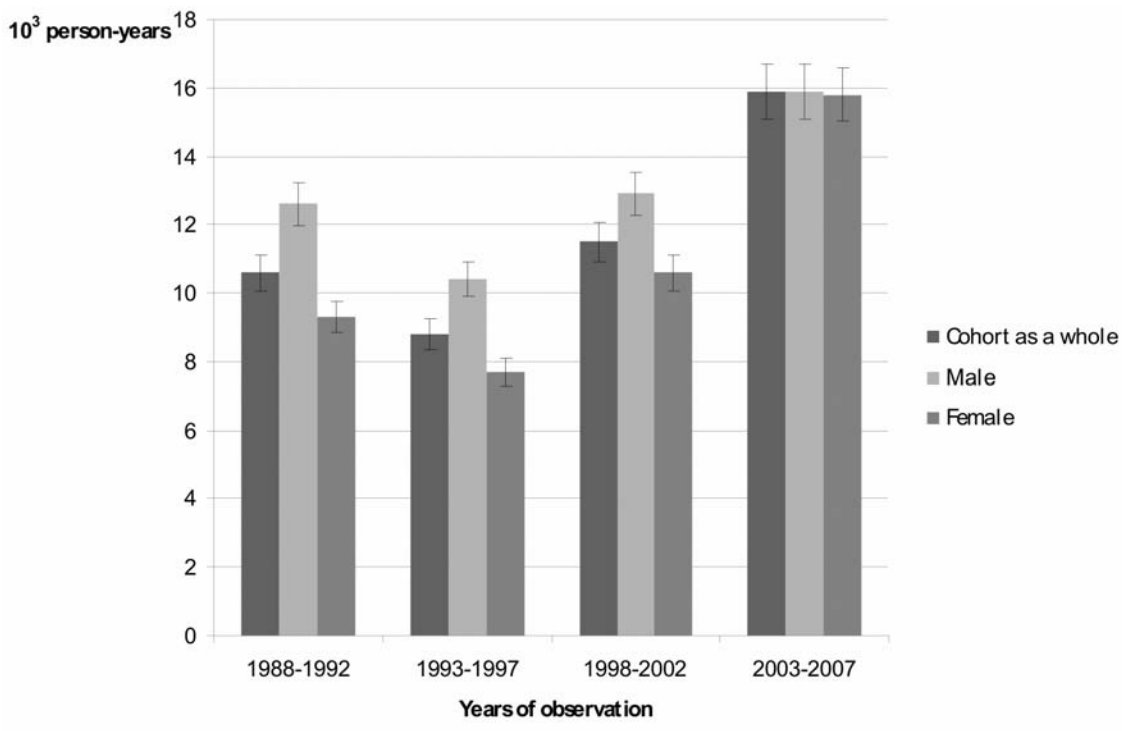


Fig. 3.53. *The dynamics of mortality from non-tumor diseases of the adult evacuated population by five-year period of observation (data of SI «RCRM of AMS of Ukraine).*

During all periods of research cardiovascular morbidity was leading in the structure of mortality. Its contribution in different years ranged from 45 % to 83 %. In 2007, the percentage of cardiovascular disease increased to 89 % (Fig. 3.54).

Certain position in the mortality structure of evacuees is occupied also by diseases of the nervous system and sensory organs, respiratory and digestive systems. Contribution of respiratory diseases in different years varies from 1.3 % to 12.5 %, digestive system – from 0.7 % to 8.1 %, nervous system and sensory organs from 0.2 to 4.0 %.

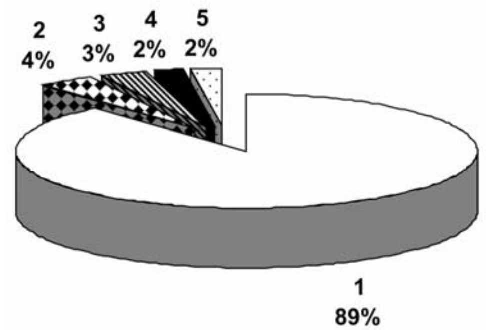


Fig. 3.54. *Structure of mortality (%) from non-tumor diseases of adult evacuees in 2007 (data of SI «RCRM of AMS of Ukraine)*
1 – cardiovascular diseases, 2 – ddiseases of the digestive system, 3 – diseases of the nervous system and sensory organs, 4 – respiratory diseases, 5 – other diseases.

Among cardiovascular diseases first place occupied coronary heart disease (39.5 %). Thus, in 2007 the death rate from coronary heart disease in men was observed in 66 % of cases, in women – in 60.3 %. Essential hypertension owned 11 %, cerebrovascular diseases – 3.4 %. Cardiovascular disease, especially coronary heart disease pllays the dominant role in shaping the causes of death, at that mortality of evacuees (11.8±0.22 per 10^3 person-years) at the stage of 2003–2007 from cardiovascular diseases in general exceeds the initial rate of 1988–1992 (6.9±0.2 per 10^3 person-years) almost 2 times. The mortality rate of essential hypertension during the first three periods stayed almost equal and significantly increased at the stage of 2003–2007 (Fig. 3.55).

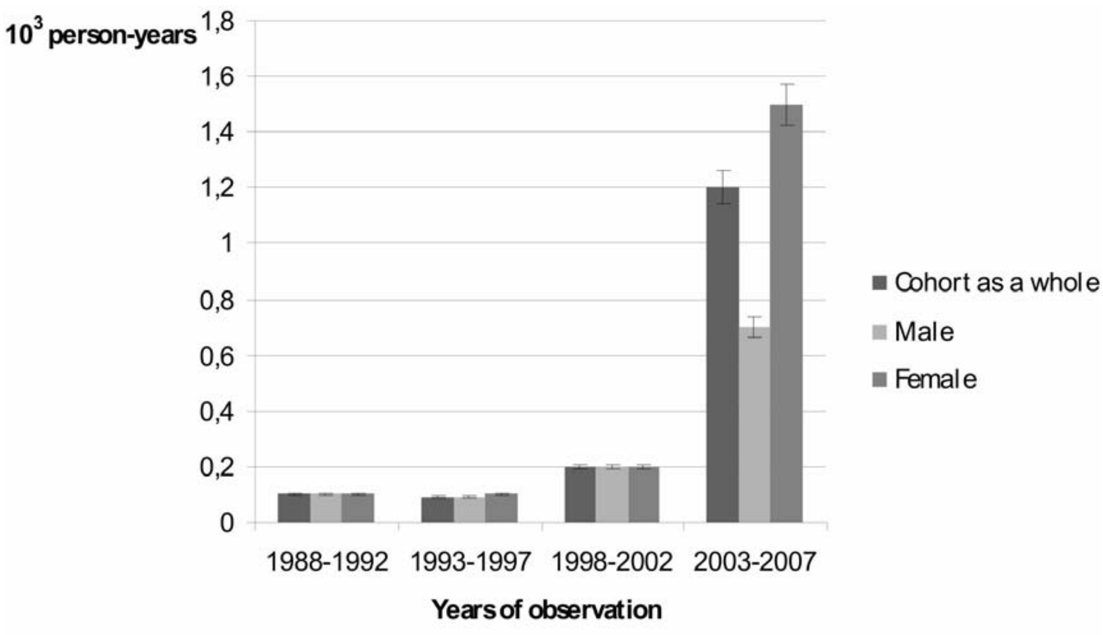


Fig. 3.55. *The dynamics of mortality from essential hypertension of adult evacuees by five-year period of observation (data of SI «RCRM of AMS of Ukraine).*

A significant increase of mortality was also noted from diseases of the nervous system and sensory organs, respiratory diseases, mainly due to chronic bronchitis with emphysema and diseases of the digestive system mostly due to liver disease, biliary tract and pancreas. Mortality from diseases of the endocrine system was mainly stipulated by diabetes.

Indices of mortality from urogenital diseases, musculoskeletal system, skin and subcutaneous tissue diseases, mental disorders were minimal throughout the study period.

Analysis of mortality by gender showed a higher level of indices in men. However, at the stage of 2003–2007 the total mortality of men and women became equal (see Fig. 3.53).

The mortality significantly depended on age. In persons under 40 years at all stages it was significantly lower compared with older age. However, its gradual increase recorded in both cohorts. The highest level was recorded in 2003–2007.

The greatest difference in mortality were found for cardiovascular diseases. In persons of 40 and older the mortality from this class of diseases, as well as from essential hypertension and coronary heart disease in 2003–2007 was significantly higher against all the previous stages. Mortality from cerebrovascular disease was almost identical in all periods of study (Fig. 3.56).

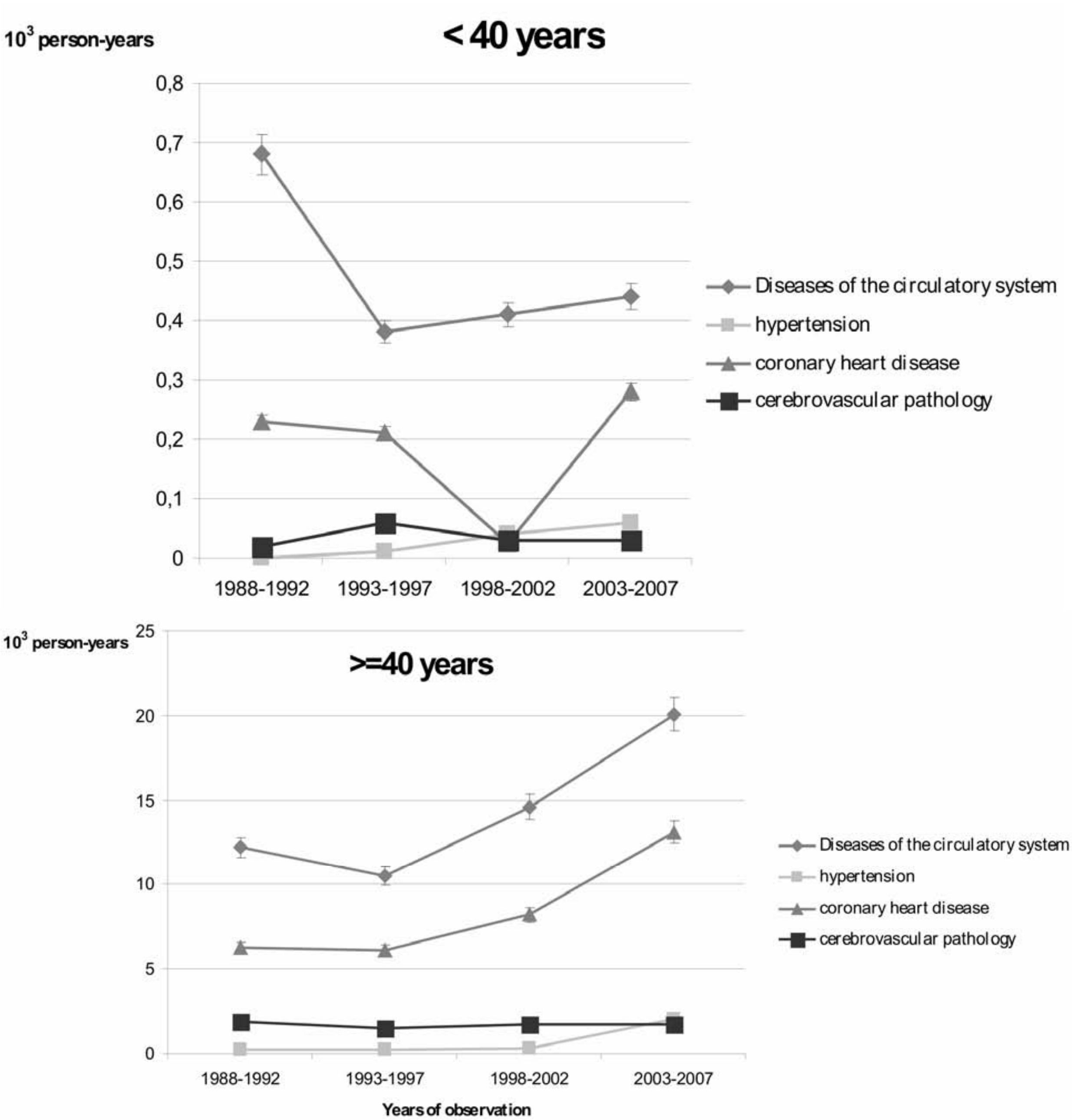


Fig. 3.56. *The dynamics of mortality from cardiovascular diseases in adult evacuated population by five years observation period depending on age (data of SI «RCRM of AMS of Ukraine).*

In persons of younger age a reliable increase in mortality has been observed only from the essential hypertension. The death rate from coronary heart disease and cerebrovascular pathology were almost equal at all stages of research.

In both age cohorts a significant increase of mortality was also established from disease of nervous system and sensory organs, respiratory and digestive systems (Fig. 3.57), however, at the higher level of indices in persons of 40 years and older.

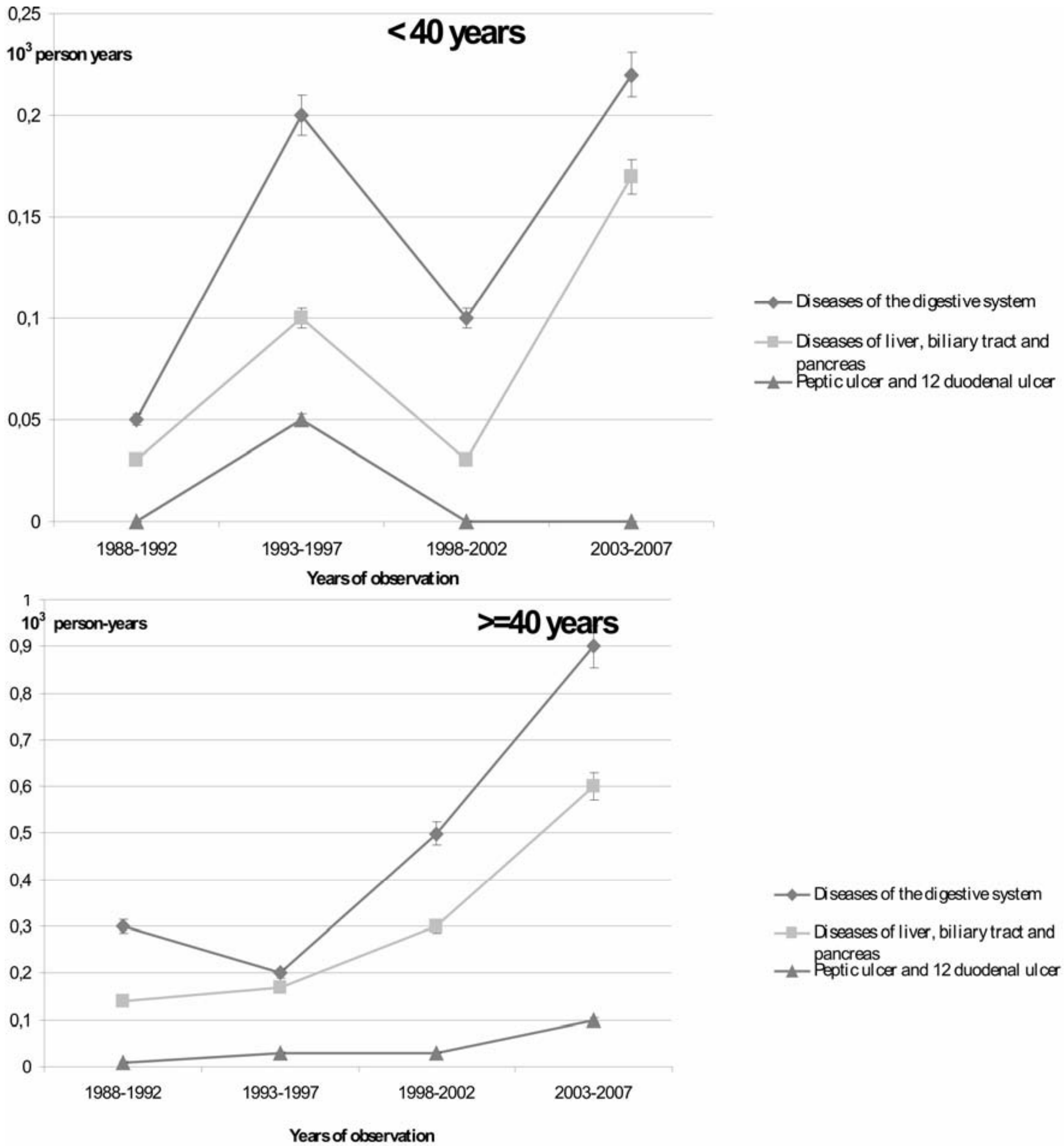


Fig. 3.57. *The dynamics of mortality from diseases of the digestive system of adult evacuees by five-year observation periods, depending on age (data of SI «RCRM of AMS of Ukraine).*

In addition, the olders marked significant increase of mortality from stomach and duodenum ulcers, the youngers – from bronchial asthma.

In 1993–1997 and 2003–2007 in both age cohorts mortality from thyroid disease was registered, but in the 1993–1997 rates were higher in older persons (0.11 ± 0,03 against 0.04 ± 0,02), and in 2003–2007 – at the age of up to 40 years (0.02 ± 0.01 against 0.007 ± 0.005). Mortality was determined by thyrotoxicosis with or without goiter.

A study of mortality risks from non-tumor diseases depending on the external whole body exposure established reliable dependency on certain nosologies. According to estimates of absolute, relative risks and their excesses the closest connection was found to cardiovascular diseases, including coronary heart disease, digestive and urinary tract diseases (especially prostate diseases). The maximum value of absolute and relative risks of mortality from coronary heart disease registered in the dose range of 0.2–0.249 Gy.

When determining the absolute excess risk per dose unit (EAR for 10^3 person-years, Gy) statistically significant excessn were recorded for cardiovascular diseases, including coronary heart disease and diseases of the digestive system (Table 3.35).

In the dose range 0.25–0.32 Gy the excess absolute risk of mortality from cardiovascular diseases was maximal. Almost the same level EAR mortality reaches separately from coronary heart disease. Excess absolute risk of mortality from diseases of the digestive system was 2 times smaller.

Table 3.35.

Excess absolute risk of mortality for individual classes and forms in the adult evacuees in 2003-2007 at whole body irradiation doses of 0.25-0.32 Gy (data of SI «RCRM of AMS of Ukraine)

Name of diseases	ICD-9	Excess absolute risk, EAR for 10^3 person-years, Gy
Diseases of the circulatory system	390–459	6.0 (3.5; 10.5)
- Coronary heart disease	412–414	5.8 (2.8; 12.0)
Diseases of the digestive system	520–579	2.9 (1.9; 9.0)

The authentic excess of mortality for diseases of the endocrine system, ischemic heart disease, gastritis and duodenitis, urinary diseases, prostate cancer were established by calculations of relative excess risk per unit dose (ERR-Gy^{-1}) (Table 3.36).

Table 3.36.

Excess relative risk of mortality for individual classes and forms in the adult evacuees in 2003-2007 with the doses of whole body irradiation 0.25-0.32 Gy (data of SI «RCRM of AMS of Ukraine)

Name of diseases	ICD-9	excess relative risk, ERR Gy^{-1}
Diseases of the endocrine system	240–279	1.50 (1.21; 1.85)
Coronary heart disease	412–414	3.12 (2.23; 4.38)
Gastritis, duodenitis	535	2.19 (1.54; 3.12)
Diseases of urinary system	581–599	2.99 (2.04; 4.37)
Diseases of the prostate gland	600–608	3.42 (2.14; 5.47)

Apparently, the highest excess relative risk per unit dose was set for coronary heart disease, prostate and urinary tract diseases. Excess of deaths from diseases of the endocrine system was almost 2 times lower.

Presented results of evaluation of dose-dependent effects of non-cancer morbidity and mortality from non-tumor diseases in the adult evacuees are not conclusive, inasmuch as require additional studies aimed to determine the impact of so-called complex mix of factors – age, bad habits, unhealthy working conditions, insufficient nutrition and motor activity, psychosocial stress and more. However, it can be argued that irradiation of thyroid doses exceeding 0.3 Gy (especially 2.0 Gy and above), as wellas external whole body radiation doses higher than 0.05 Gy (particularly 0.25 Gy and above) are promoting the development of dose-dependent effects on certain non-tumor diseases. These data are consistent with the studies carried out in other countries (Russia, Belorussia, Japan) on radiation-exposed contingents [3–5].

3.3. Early and long-term effects associated with irradiation

3.3.1 Acute radiation syndrome

In 1986 a diagnosis acute radiation syndrome (ARS) was established on 237 individuals. After a thorough retrospective analysis (in 1989) the real number of victims with such diagnosis decreased to 134 persons. Of these 28 patients died during the first three months after the accident. Within 25 years monitoring after the accident 39 people died, who had lived in Ukraine (Fig. 3.58).

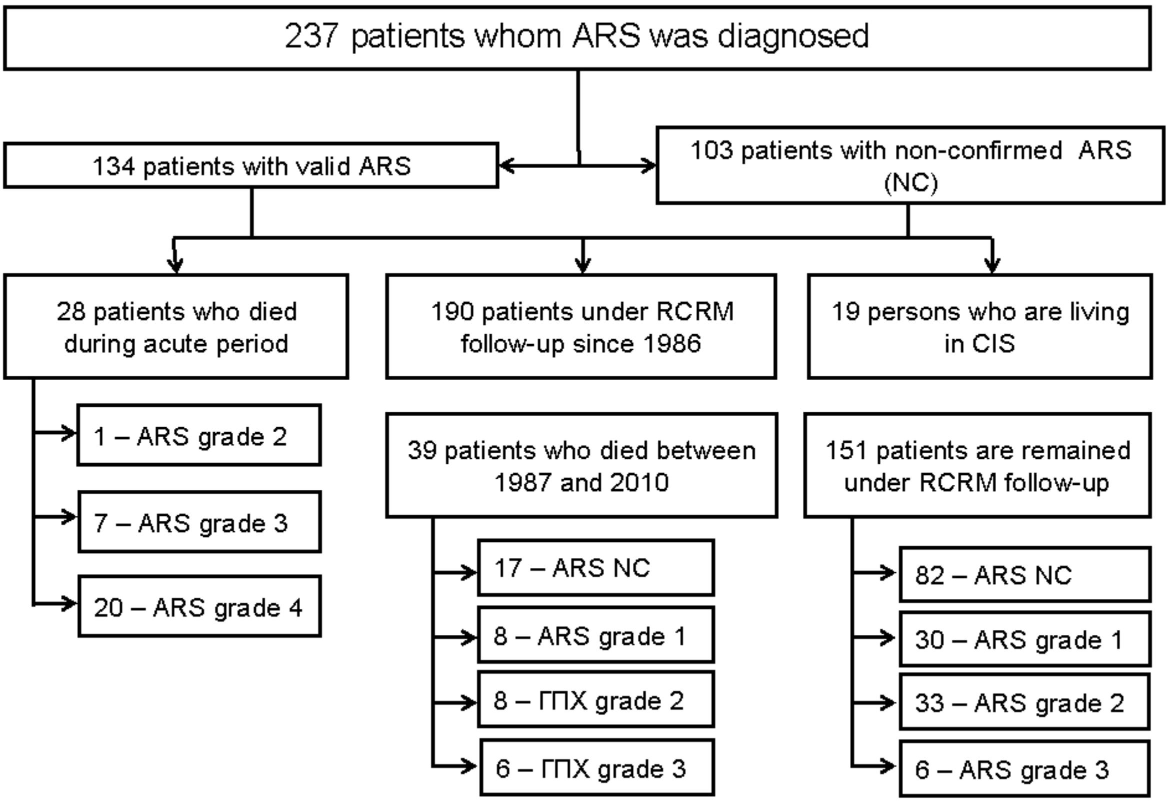


Fig. 3.58. *Dynamics of the number of people who have suffered acute radiation syndrome as a result of the Chernobyl accident (ARS – acute radiation syndrome; ARS NC – non-confirmed acute radiation syndrome) according to the data of SI «SCRM of AMS of Ukraine».*

Total (without ARS distribution of confirmed and unconfirmed) the most frequent causes of death were cancer (15 cases) and death from cardiovascular complications (12 cases). Among other reasons of fatality were marked liver cirrhosis, pulmonary tuberculosis (quickly progressing form), encephalitis, fat embolism after a broken leg, accidents, traumas (Table 3.37).

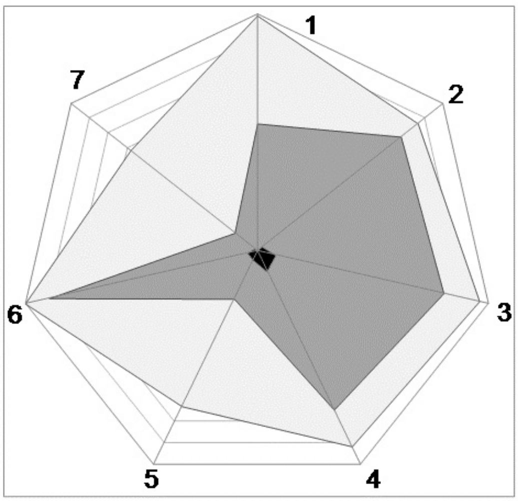
Within the 25 years of studies the functional status of major organs and body systems, metabolism and homeostasis in this category of people were investigated, a comprehensive assessment of their health, mental and physical performance was given, risk factors development and peculiarities of stochastic and non-stochastic pathology were identified, and the system of rehabilitation of patients after ARS was developed.

Those who underwent ARS and remain alive, are suffering from chronic diseases of internal organs and systems (from 5–7 to 10–12 diagnoses at a time). In the first five years after the accident a sharp increase was seen in diseases of cardiovascular, digestive, nervous and hepatobiliary systems. In the next 20 years, growth was much lower, but in 25 years after the accident percentage of patients with somatic pathology reaches 85–100%. (Fig. 3.59).

Table 3.37.

Causes of death of patients diagnosed with ARS, who were under the supervision of RCRM

Causes of death	Number of deaths with the ARS grade				Total
	0	1	2	3	
Cardiovascular disease	5	3	2	2	12
Oncological and oncohematological diseases	8	2	3	2	15
Somatic and neurological disease, infections	2	1	3	1	7
Injuries and accidents	2	2		1	5
Total	17	8	8	6	39



No	System	1986	1991	2009
1	Eyes	0	53.9	99.4
2	Cardiovascular	2.7	77.5	86.3
3	Digestive	8.1	80.6	95.7
4	Hepatobiliary	9.5	74.6	91.7
5	Respiratory	4.1	22.5	72.9
6	Nervous	4.1	90.1	100
7	Endocrine	1.4	12.2	68.1

Before the accident

1991 (5 years after the accident

2009 (23 years after the accident)

Fig. 3.59. *The frequency of non-cancer diseases in people who have suffered acute radiation syndrome (data of «RCRM of AMS of Ukraine»).*

Table 3.38.

Cases of cancer and hematologic malignancies in patients who had undergone ARS

Disease	Number of cases	total quantity	
		cases	deaths
Myelodysplastic syndrome	3	5	5
Acute myelomonoblast leukemia	1		
Hypoplasy of hemopoiesis	1		
Colon cancer	3	16	10
Stomach cancer	2		
Cancer of the thyroid gland	2		
Kidney cancer	1		
Cancer of the larynx	1		
Lung cancer	1		
Prostate cancer	1		
Nevrynoma of mandible	1		
Soft tissue sarcoma of the hip	1		
Basalioma of head	1		
Bladder cancer	1		
Maxillary sinus cancer	1		

Cancers were mainly solid tumors of different localization (Table 3.38). Five cases of malignant blood diseases realized in the first 10 years after the accident, and in the next 15 years development of solid tumors took pllace. At that the age of 53 % of patients died from malignant tumors and cardiovascular diseases was lower than the average life expectancy in Ukraine.

Typical radiation cataract developed in 24 patients in post-accident years: in 10 persons with ARS of 3rd grade of gravity, in 8 people with 2nd grade of ARS, in 3 people with ARS of 1st grade and in 3 people with non-confirmed ARS (ARS NC). Virtually all cases of radiation cataracts (96 %) realized during the first 15 years after exposure (Fig. 3.60). The study of lens pathology showed that beam cataracts are more likely to be stochastic effects of irradiation than deterministic.

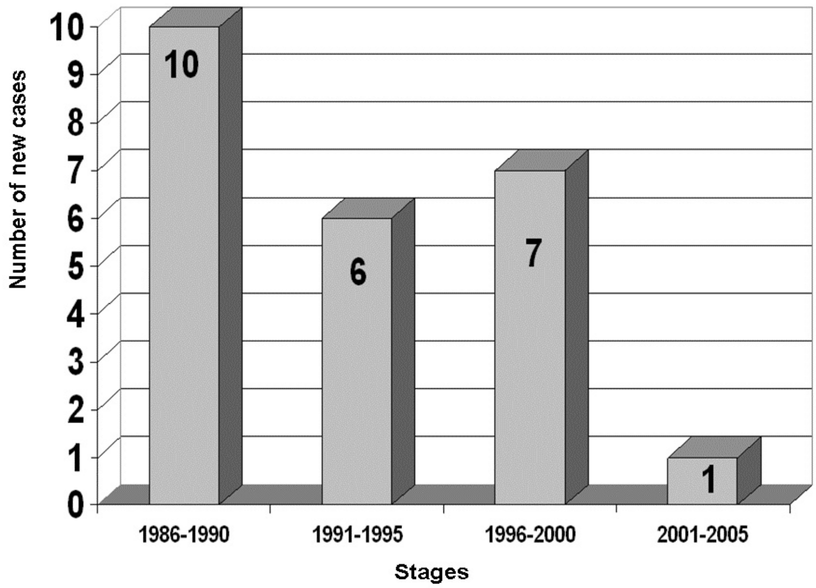


Fig. 3.60. *Number of new cases of radiation cataract at the stages of observation.*

The prevalence of radiation cataract in the remote period after irradiation increased depending on the logarithm of dose and time of stay at risk.

Dynamic surveillance of hematopoietic system of ARS convalescents in the dose range from 1 to 3 Gy in early and remote post-accident period showed that in the bone marrow and peripheral blood gradual normalization of quantitative indices took place, while maintaining numerous qualitative irregularities in cellular elements at the level of nucleus and cytoplasm (Fig. 3.61–3.64).

The degree of irregularities in the nucleus of cells is a prognostic criterion of injury caused by ionizing radiation. These materials correlated with the basic laws of radiobiology and showed that the higher dose absorbed, the greater was the cell cycle delay connected with the loss of not only stem cells from bone marrow, but also a part of commited cells and, partially, interphase cell death.

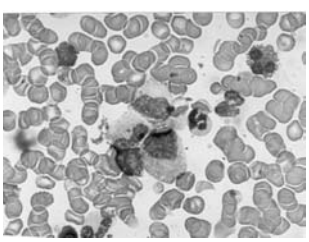


Fig. 3.61. *Photomicrograph of bone marrow cytological preparation of the patient St-ARS. Hypogranulyar myelocyte, hypogranulyar stab neutrophils, vacuolized promonocyte, degranulation of eosinophilic granulocytes. Colouring by Romanovsky-Gimza. × 1000.*

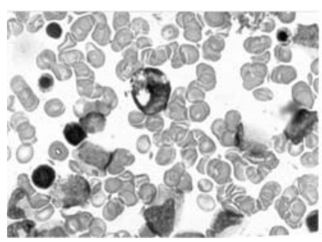


Fig. 3.62. *Photomicrograph of bone marrow cytological preparation of the patient St-ARS. Vacuolized eosinophilic myelocyte. Colouring by Romanovsky-Gimza. × 1000.*

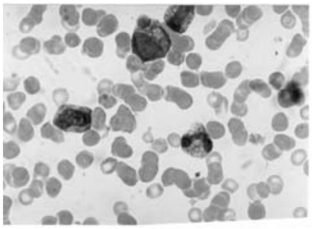


Fig. 3.63. *Photomicrograph of bone marrow cytological preparation of the patient M-ARS. Toxogenic granularity of myelocytes, and metamyelocyte and stab neutrophil. Partial degranulation of the cytoplasm area of stab neutrophil. Colouring by Romanovsky-Gimza. ×1000.*

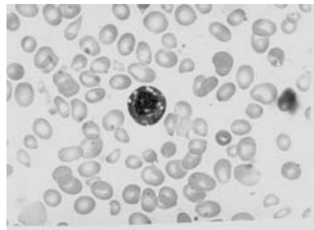


Fig. 3.64. *Photomicrograph of bone marrow cytological preparation of the patient Syd.-ARS. Vacuolization of cytoplasm of polichromatophile normoblast. Colouring by Romanovsky-Gimza. ×1000.*

In young cells capable to mitotic division changes in chromatin structure were marked as a flaky like mass, and in the cells that lost the ability to divide a hypercondensation of chromatin was registered, often with the formation of 1–3 local electron-transparent areas. These characteristics were inherent to cells in apoptosis. In the cytoplasm of part of granulocytes primary and secondary granules were found, but more often met degranulated cell with vacuolated cytoplasm. Sometimes vacuoles even deformed nucleus of granulocytes (Fig. 3.65–3.67).

In bone marrow there were islands of erythropoiesis, which differ from the norm by a shortage of erythroid elements around macrophages. There were changes in megacariocyte branch of hematopoiesis that were expressed by platelet maturation disorders, vacuolization and loss of mucopolysaccharides.

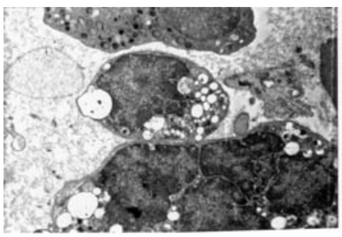


Fig. 3.65. *Electron photomicrograph of patient M-v. Groups of neutrophils. Vacuolization of cytoplasm. Partial deformation of nuclei. x 15000.*

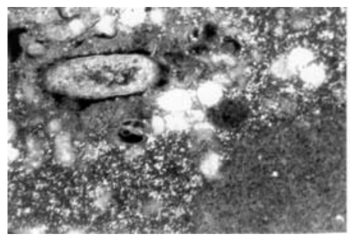


Fig. 3.66. *Electron photomicrograph of patient M-v. A plot of neutrophil. Degenerative changes in the nucleus and cytoplasm. Large nucleolus in the nucleus of neutrophil. x 7500.*

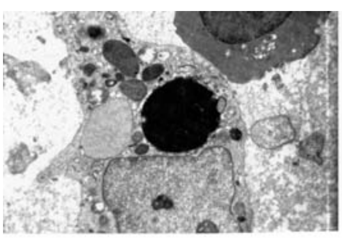


Fig. 3.67. *Electron photomicrograph of patient M-v. Erythropoiesis islet, macrophage in contact with only one erythropoetic cell. x 15000.*

Terms of bone marrow restoration is 1–3 years and to trace them in the dynamics continues to be of intense interest of scientists. Transition to recovery demonstrates the appearance of increased numbers of young generations of cell in the bone marrow and alternation in trepanobiopsy samples of bone marrow hypo- and hyperplastic areas. Such processes of bone marrow regeneration, including a comprehensive analysis of the morphofunctional indices may evolve in several ways, namely: a) towards a full recovery with normalization of peripheral blood, b) by hypoplastic way with residual cytopenia and c) bone marrow suppression with pancytopenia and development of onco-hematological diseases in the future.

In the post-accident period in ARS convalescents and persons with unconfirmed ARS various hematological syndromes were observed, usually associated with a lower content of mature peripheral blood cells. The frequency of cytopenia in convalescents of 1st – 3rd grades ARS was higher than in the group with non-confirmed ARS (Fig. 3.68).

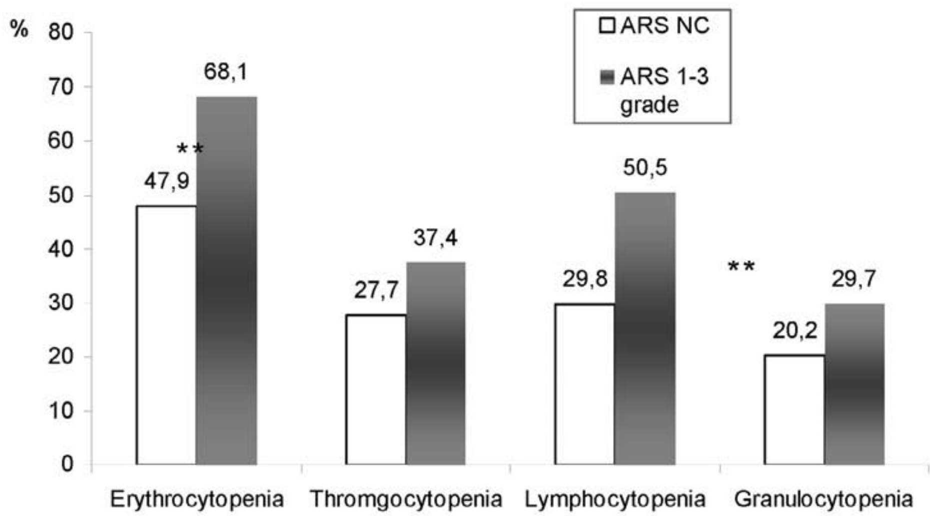


Fig. 3.68. *The frequency of hematological syndromes in ARS convalescents and patients with ARS NC in the remote period after exposure (data of SI «RCRM of AMS of Ukraine»).*

** – Reliable difference, p<0,01

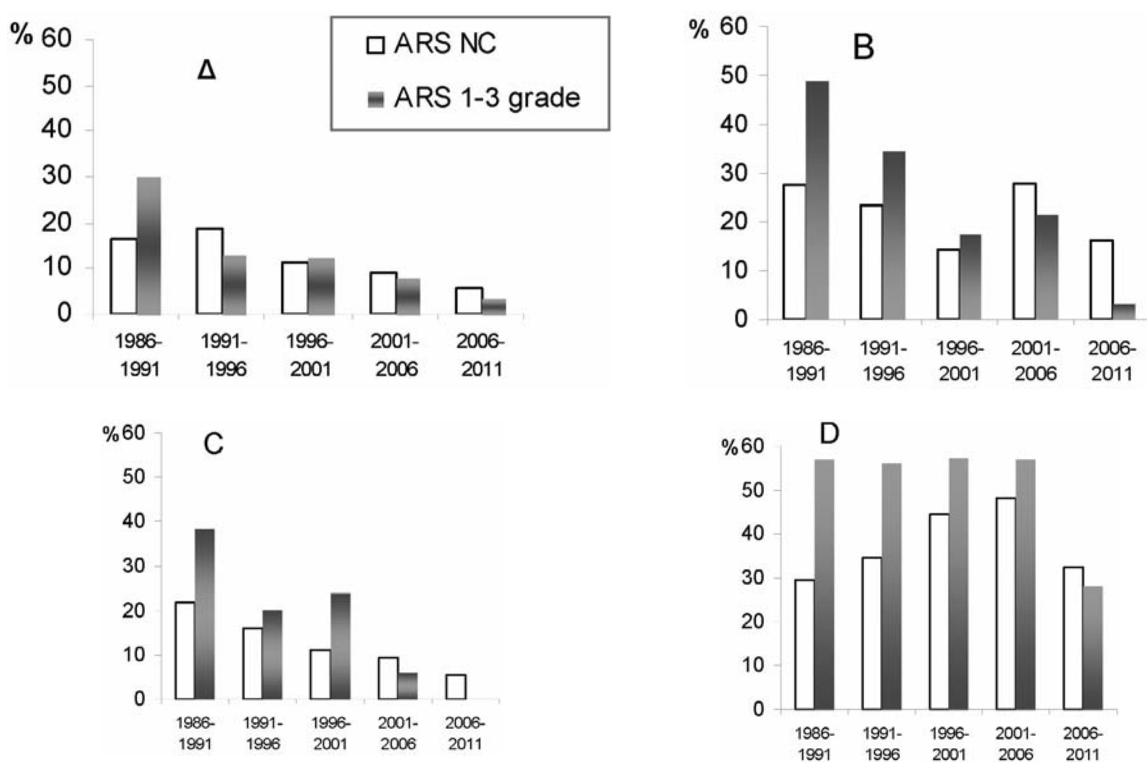


Fig. 3.69. *The frequency of granulocytopenia (A), lymphocytopenia (B), thrombocytopenia (C) and erythrocytopenia (D) at the stages of observation of ARS convalescents and patients with ARS NC (data of SI «RCRM of AMS of Ukraine»).*

High frequencies cytopenia in the first 5 years after exposure changed by the tendency to decrease in subsequent years. Within 25 years the frequency of all hematologic syndromes in ARS convalescents was significantly higher than in the ARS NC (Fig. 3.69).

In collaboration with scientists from Germany an international computer database was created for survey of persons exposed to radiation from the Chernobyl accident, and from other radiological incidents. The database contains 2,390 histories of ARS convalescents and persons with non-confirmed ARS.

3.3.2. Radiation cataracts and other eye pathology

Before the Chernobyl accident radiation cataract was assumed to occur when a dose load was not less than 2 Gy. But in 1990 already there were reports about the appearance of cataracts at lower doses. Forecast of 1992, which predicted specific peak of radiation cataract in 1997, was fully justified in two independent studies of radiation cataract in the sufferers of the Chernobyl disaster – the study based on Clinical-Epidemiological Registry (CER) of RCRM and international research UACOS.

There are currently 223 known cases of radiation cataract with a typical clinical picture. The first results of UACOS study showed the possible existence of threshold, but at much lower levels than 2 Gy, for some age groups of approximately 0.1 Gy. The threshold depends on the form of cataracts and can not be higher than 0.7 Gy.

Analysis of survey results based on the CER showed that the typical radiation cataracts occur at doses less than 0.1 Gy, the absolute risk of radiation cataract dependent on dose after being at risk for 5 years is shown in Fig. 3.70.

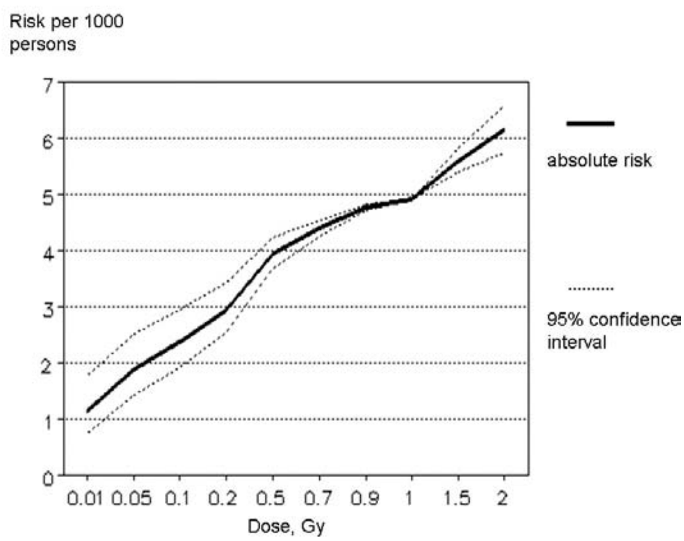


Fig. 3.70. *The absolute risk of radiation cataract depending on dose after being at risk for 5 years.*

Simulation of radiation cataract revealed that radiation caused by additive-relative risk of radiation cataract is 3.451 (1.347, 5.555) per 1 Gy, $p<0.05$. The development of cataract is also influenced by the duration of radiation. The threshold dose for radiation cataract in this study was not fixed; the latent period can exceed 22 years. These studies and mathematical modelling evidence for the view on the radiation cataract as the stochastic effects of radiation exposure.

Results of the international «Pittsburgh Project» and conducted in parallel with it, Ivankiv prolonged study showed that the initial lens changes occur in pediatric population at very low dose levels caused by radiation contamination of soils.

In sufferers of the Chernobyl disaster two new forms of radiation retinopathy were described – «chestnut syndrome» (early and late) and «the syndrome of the radiation grating».

There are also new radiogenic effects, with signs of deterministic:

- The functioning of the eye as a complex of receptors is accompanied by generation of permanent potential of the retina. Radiation exposure violates the generation of this potential; threshold dose is 200 mSv [5].
- Radiation exposure causes dose-related decrease in ability to accommodation. Threshold for this effect is a dose of 150 mSv [6].

3.3.3. Immunological effects

Investigation of the immune system, which began in RCRM in 1987, relied on the existing experience of the world radiobiology. Study of the impact of small doses of ionizing radiation on the human immune system, faces a number of difficulties associated with the need for distinguish radiation effects from the complex of several negative environmental factors, dependence of pathological changes from the ratio of isotopic spectrum, duration of exposure and routes of radionuclides, peculiarities of tissue, organ and individual radiosensitivity.

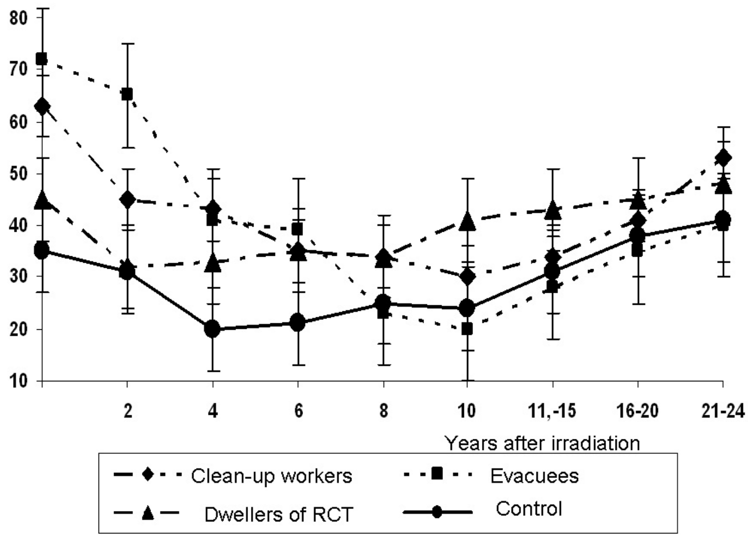


Fig. 3.71. *The frequency of secondary immunologic deficiency in affected by the Chernobyl accident.*

Investigation of frequency of violations of immune function (Fig. 3.71) in more than 165,000 affected of different categories in the remote period after the accident show the significant growth, which was the most pronounced in clean-up workers. Changes in the immune system of ARS convalescents, which were observed 5 years after irradiation, were characterized as a radiation-induced combined immunodeficiency with suppression of functions of T-and B-chains and failure of non-specific resistance mechanisms.

In 10 years in 32 % of patients compensatory changes appeared in the immune system, 37 % ARS patients showed deregulatory changes. Manifestations of deficiency of cellular immunity were found in 31 % of patients. In 15–25 years after exposure a violation of differentiation of primitive progenitor cells was revealed with increased their output in peripheral blood and reduced level of CD123w-antigen (IL-3 receptor) expression (Fig. 3.72).

In patients suffering from acute radiation syndrome in the remote term a recovery of some populations of immune cells was recorded – T lymphocytes, including cytotoxic T cells, B lymphocytes and most phylogenetically older populations – natural killer cells. Dose dependent disturbances of subpopulations and their functional activity retained, indicating the existence of certain exhaustion of the compensatory reserve of cell subpopulations. For the total population of $CD34^{+}$ cells correlation coefficient reaches significant – 0.48. This conclusion is confirmed by the analysis of early progenitor cells, shown in Fig. 3.73.

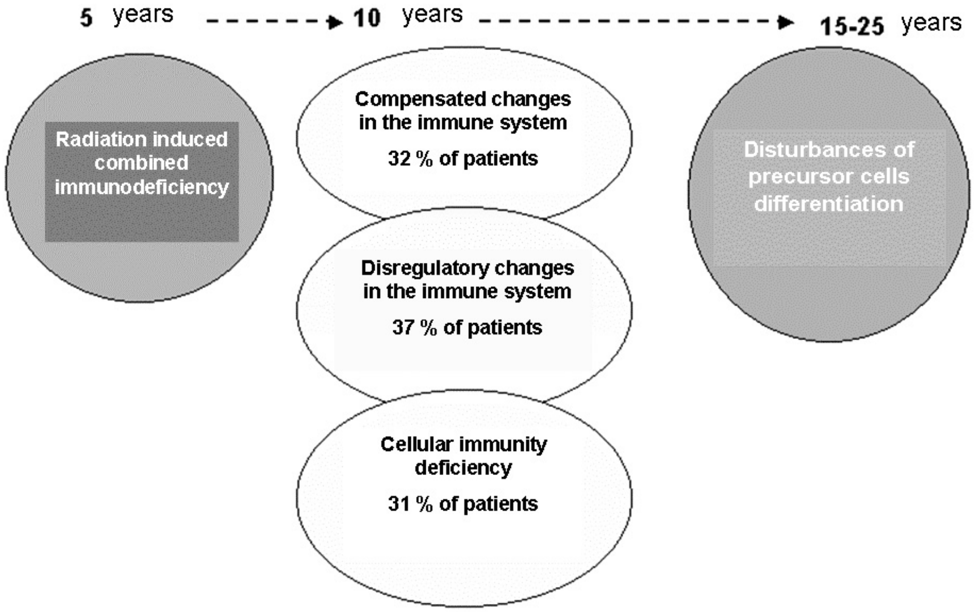


Fig. 3.72. *Changes in the immune system of patients who suffered from acute radiation syndrome during post-accident period.*

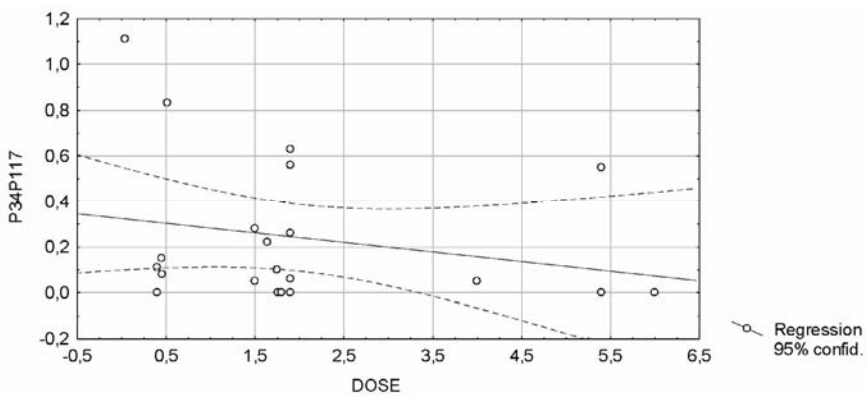


Fig. 3.73. *Histograms of the number of early CD34^{+}117^{+} progenitor cells dependency on radiation dose 20 years after the acute radiation syndrome.*

Study the effects of remote period in the range of low and medium doses faces a number of difficulties associated with the presence of somatic and psychosomatic diseases. Formation of the immunological effects in the range of low doses is affected by the following main factors:

- Non-lethal radiation-induced damage to cells (proliferation of functionally defective offspring;
- Spreading effect due to humoral factors);
- Modification of the immune response (neuro-immune factors, lipid metabolism and concomitant pathology);
- Adaptive system responses (a shift of cell cycle phases to radio-resistant; graded dose-dependent engaging of immature cells production and non-specific activation).

The results show the changes in responses of leukocytes and particularly lymphocytes to non-specific mitogens, tissue and microbial antigens in the Chernobyl clean-up workers with chronic somatic pathology of remote period – chronic obstructive pulmonary disease, chronic hepatitis and discirculatory encephalopathy. In the formation of certain definite effects changes in expression of surface activation antigens of lymphocytes – CD25, CD71, and, to a lesser extent, – HLA-DR were established. Depending on the existing pathology both the decline and increase of responsiveness were being detected. The most probable mechanisms of such changes should include the preservation of non-repaired radiation-caused damages as well as the chain of secondary effects such as activation-induced apoptosis of antigen-reactive cells and non-specific immunosuppression.

Significantly shorter telomeres in groups of clean-up workers and staff of 30-km zone was found as well as the inverse relationship between telomere length, the entry of cells in the early stages of apoptosis, on one hand, and a history of radiation group, on the other hand (Fig. 3.74).

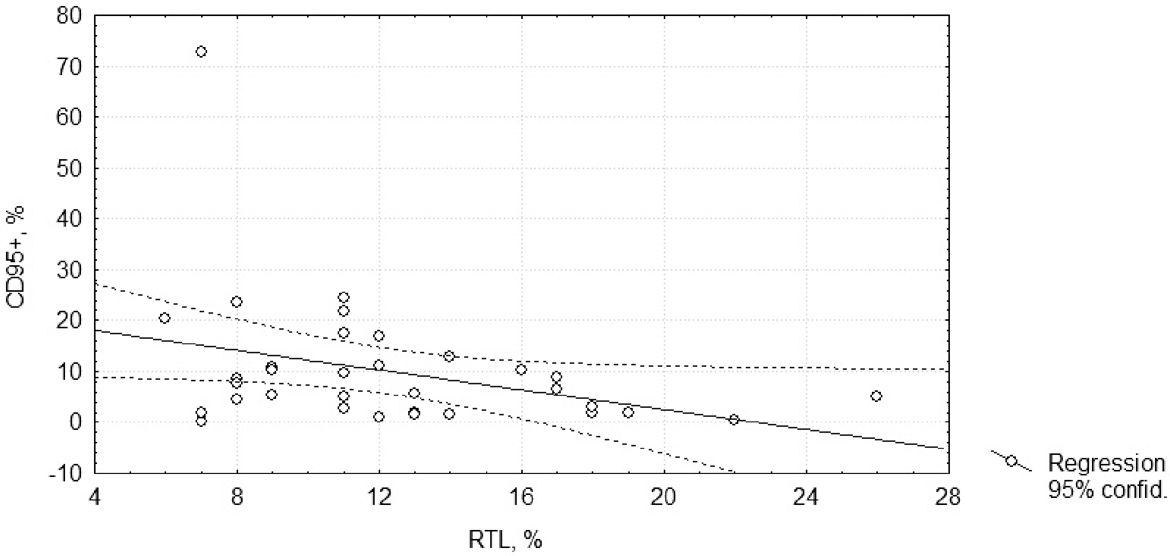


Fig. 3.74. *Scattering diagram with regression direct index of relative telomere length and percentage of CD95^{+} cells On the abscissa axis: RTL – relative telomere length (%), on the axis of ordinate – number of CD95^{+} cells (%).*

At that, a sufficiently high fraction of cells expressing anti-apoptotic protein bcl-2 is conserved, and *in vitro* action of apoptosis inducer verapamil does not significantly change the average indices of this fraction, indicating a possible heterogeneity of cell populations by telomere length and the entrance to apoptosis.

The influence of radiation and oxygen radicals can increase gene expression of cytomegalovirus (CMV), which may be the main cause of increased CMV-seropositivity, CMV reactivation among the Chernobyl clean-up workers and ARS convalescents. Growth of CMV infectivity has also been linked to increased rates of somatic diseases, especially chronic gastritis, bronchitis, and various types of arthritis among CMV-positive patients.

The existence of significant homology between IgHV genes in lymphoid cells of patients with CLL with antimicrobial and antiviral antibodies was found. Viral and bacterial infections in synergy with autoantigens or apoptotic cells can trigger CLL. Findings that in Chernobyl-affected patients with CLL antibodies are homological to antibodies that react with viral and bacterial components, is evidence of possible contribution of infections in CLL pathogenesis even after almost a quarter of century after the nuclear accident.

Research whithin 24 years indicate to the existence of system-defined cellular responses in low-dose irradiation that are defined both in the early period of recovery of the immune system and in remote span of time. The study results of people affected by the Chernobyl disaster enlarge experimental radiobiological data and come to an agreement with them, which proves the leading value of radiation factor in the formation of immunological effects.

3.4. Effect of the complex factors of the Chernobyl disaster on public health

3.4.1. Neuropsychiatric effects

Long-term neuropsychiatric consequences of the Chernobyl disaster are recognized in the world [8], although the causes of their origin continue to be discussed. Recently received numerous new data on the pathogenesis of cerebral effects of even small doses, are schematically shown in Fig. 3.75: violation of neurogenesis in the hippocampus of adults, changes in gene expression profiles, neuroinflammation reactions, alteration of neurosignalling, apoptotic cell death, cell death and injuries due to secondary lesions and others. These disorders, along with long and well-known «vascular-glial union» are likely to explain the mechanisms of radiosensitivity of the brain.

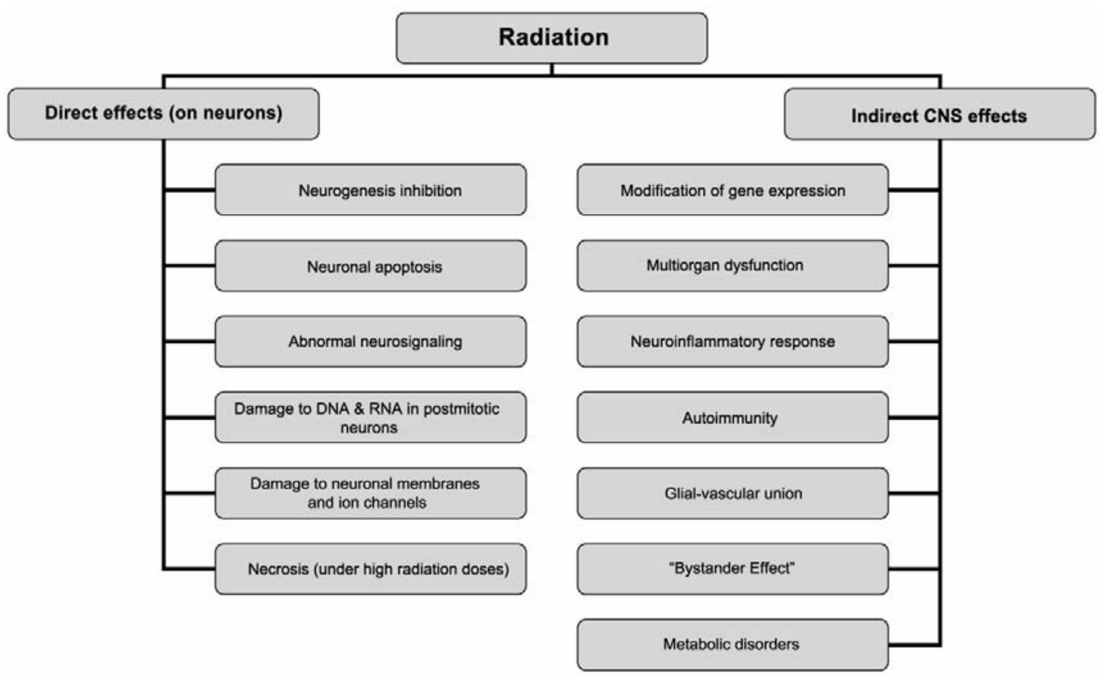


Fig. 3.75. *Pathogenesis of radiation brain damage after irradiation at doses up to 5 Sv.*

Table 3.39.

Dose dependency of radiocerebral effects

Dose	Effect
Adults (whole body irradiation)	
50−100 Gy	Radiation brain damage (orthodox)
>2−4 Sv	Radiation neurological manifestations (A.K. Guskova, I. N. Shakirova, 1989; A.K. Guskova, 2007)
>1 Sv	Neurophysiological and neuroimaging biomarkers of radiation and postradiation encephalopathy *[SI «RCRM of AMS of Ukraine»]*
>0,3 Sv	• Neuropsychiatric, neurophysiology, neyroimmune, neuropsychological and neuroimaging dose-related effects *[SI «RCRM AMS of Ukraine»]* • Postradiation cognitive deficits *[SI «RCRM AMS of Ukraine»]* • Excessive dose-dependent increase in mortality from diseases of the circulatory system (McGeoghegan et al., 2008)
>0,15−0,5 Sv	Epidemiological data on radiation risks of cerebrovascular disease (Ivanov et al., 2006; *SI «SCRM NAMN Ukraine»*; Shimizu et al., 1999, 2010; Preston et al., 2003)
CHILDREN (head exposure)	
>1,3−1,5 Gy	Remote cerebral effects (Ron et al., 1982; Yaar et al., 1982)
>1,3−1,5 Gy	Brain tumors (Sadetzki et al., 2005)
>1,3−1,5 Gy	Schizophrenia (Gross, 2004)
>0,1 Gy	Cognitive deficits (Hall et al., 2004)

IN UTERO	
0,06–0,31 Gy fetal external exposure	At the 8^{th}-15^{th} week of gestation – mental retardation (Otake et al., 1996)
0,28–0,87 Gy fetal external exposure	At the 16^{th}-25^{th} week of gestation – mental retardation (Otake et al., 1996)
The dose to the fetus > 20 mSv and thyroid gland *in utero* > 300 mSv (accident at a nuclear reactor)	At the 8^{th} week of gestation or later – neurophysiological and cognitive dose-related effects *[SI «RCRM of AMS of Ukraine»]*
The dose to the fetus > 10 mSv and thyroid gland in utero > 200 mSv (accident at a nuclear reactor)	At the 16^{th}-25^{th} week of gestation – neurophysiological and cognitive dose-related effects *[SI «RCRM AMS of Ukraine»]*

Modern data on the dose dependency of radiocerebral effects are summarized in Table 3.39.

Dose-related cognitive and neurophysiological disorders were revealed after prenatal exposure from the Chernobyl disaster in terms of more than 8 weeks of gestation at doses above 20 mSv to the fetus and greater than 300 mSv to the thyroid gland *in utero*, and at 16^{th}–25^{th} week – more than 10 mSv and more than 200 mSv, respectively. Radiation exposure in childhood is associated with dose-dependent cognitive decline in adulthood and psychological disorders, including schizophrenia, later in life. Remote cerebral radiation injury was observed after the impact of 0.1–1.3 Gy to the brain in childhood. Exposed *in utero* and in 0-1^{st} year of life require active surveillance in connection with an increased risk of various neuropsychiatric diseases.

Radiation-associated effects in adults were demonstrated at doses greater than 0.15–0.25 Sv. Dose-related neuropsychiatric, neurophysiological, neuropsychological and neuroimaging deviation were found after irradiation at doses greater than 0.3 Sv, and neurophysiological and neuroimaging markers – at doses above 1.0 Sv. Post radiation brain damage was mainly localized in the frontal-temporal regions of the dominant hemisphere and involved both white and gray matter of the brain. After irradiation at doses more than 0.3–1.0 Sv such structural and functional brain damages were characteristic: the atrophy of frontal cortex and temporal lobe, changes in subcortical structures and conductor paths, especially in the dominant hemisphere. Exposure in adulthood is a risk factor for chronic fatigue syndrome as predisposition to neurodegeneration, cognitive deficits and other neuropsychiatric disorders, accelerated aging of CNS, and a new model of schizophrenia.

Official (registry) information on mental disorders underestimate the real picture about one order through passive surveillance and reluctance of mentally ill to address medical help. In the most recently released evidence-based psychiatric epidemiological study of clean-up workers using a structured international psychiatric interview (Composite International Diagnostic Interview, WHO-CIDI) was established that pursuant to «effect a healthy liquidator» (selection of mentally healthy people to clean-up works), clean-up workers before the accident had significantly lower prevalence of anxiety disorders and alcohol abuse (Table 3.40).

Table 3.40.

Mental health before *the Chernobyl accident: «effect of healthy liquidator»*
(adapted from Loganovsky, Havenaar, Tintle, Guey, Kotov, Bromet, 2008)

Disorders	**Clean-up workers n=295**	**Control n=397**
Mood disorders	11 (3,7%)	27 (6,8%)
Anxiety disorders other than posttraumatic stress disorder (PTSD)	5 (1,7%)	23 (5,8%)
PTSD	4 (1,4%)	1 (0,8%)
Alcohol abuse	25 (8,6%)	62 (15,6%)
Periodic explosive disorder	11 (3,8%)	14 (3,5%)
Suicide ideation	5 (1,7%)	8 (2,0%)

After the accident among clean-up workers a significantly increased prevalence of depression (18.0% and 13.1% of control) and suicide ideation (9.2% and 4.1 %) was revealed. However, this did not apply to alcohol abuse and periodic explosive disorder. Within the last year before the interview in clean-up workers prevalence of depression (14.9 % and 7.1 %), PTSD (4.1 % and 1.0 %) and headache (69.2 %, and 12.4 %) was increased (Fig. 3.76, 3.77).

Note. After correcting for age in 1986, liquidators and controls differed only anxiety disorder – adjusted odds ratio (AOR) AOR = 0.3; 95 % CI 0.1, 0.9; p = 0,03) and alcohol abuse (AOR = 0.6; 95 % CI 0.3, 0.9; p = 0,02).

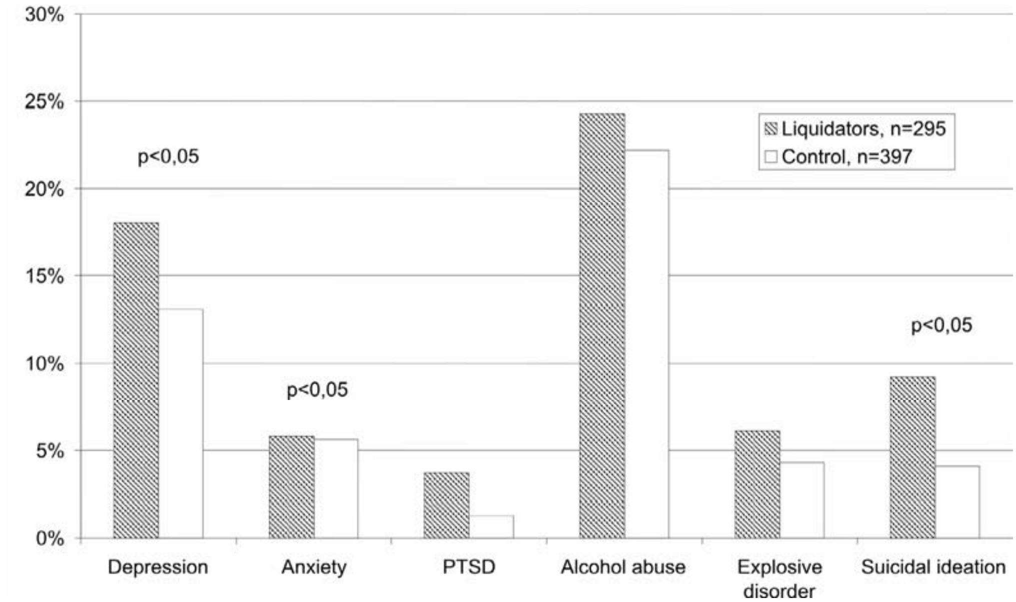


Fig. 3.76. *The prevalence of mental disorders in clean-up workers of the Chernobyl NPP accident (total since 1986)*
(Adapted from Loganovsky, Havenaar, Tintle, Guey, Kotov, Bromet, 2008) [9]
The probability of differences determined based on the adjusted odds ratio according to age in 1986 and the debut of disorder before the Chernobyl disaster.

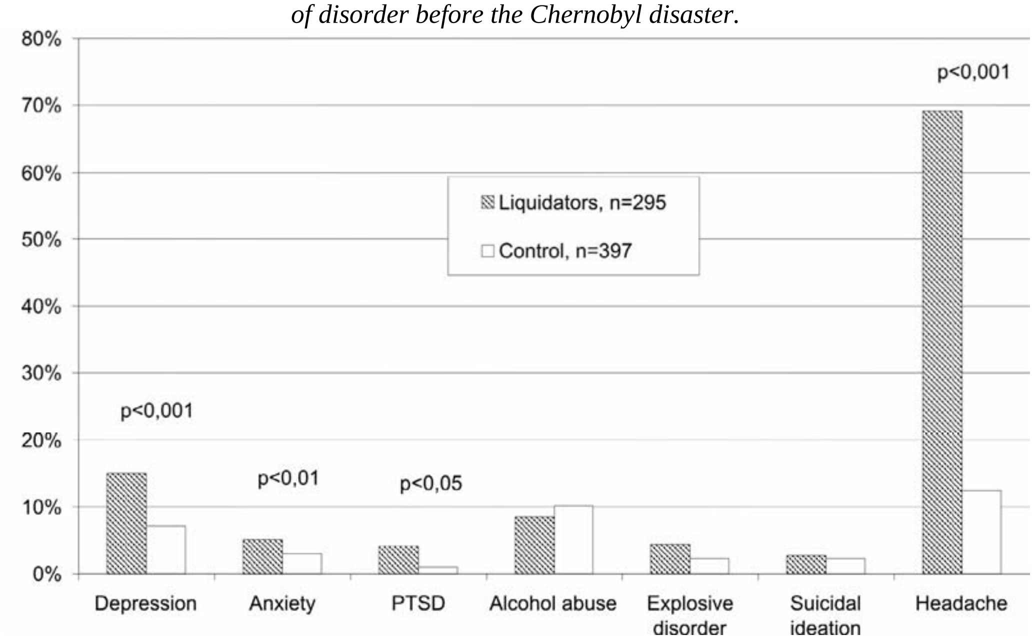


Fig. 3.77. *The prevalence of mental disorders in in clean-up workers of the Chernobyl NPP accident (last 12 months)*
(Adapted from Loganovsky, Havenaar, Tintle, Guey, Kotov, Bromet, 2008) [9].
The probability of differences determined based on the adjusted odds ratio according to age in 1986 and the debut of disorder before the Chernobyl disaster.

Clean-up workers with depression and PTSD lost more days of capacity for work than patients with the same disorder in control group. The degree of the disaster impact was associated with the severity of somatic symptoms and PTSD. Thus, in the liquidators long-term adverse effects of the Chernobyl disaster in relation to mental health were revealed.

Based on analysis of data of CER RCRM clinical and epidemiological evidences were received about the increasing frequency of mental disorders (organic, depression, etc.) and cerebrovascular pathology in clean-up workers with existing radiation risks at doses >0.25–0.5 Sv.

In contrast to widespread erroneous ideas about the excessive use of the diagnosis «vegetative-vascular dystonia» as a «token» of being under the influence of radiation, this diagnosis in the first years after the Chernobyl accident was found only about in a quarter of clean-up workers registered in the system of CER. As it is seen from Fig. 3.78, diagnostics of vegetative-vascular dystonia during post-accident years significantly reduced and at present amounts to only about 5 % of a representative sample of clean-up workers.

Gradually after the crash in clean-up workers the prevalence of cerebrovascular disease – especially chronic cerebral ischemia (I67.8), cerebral atherosclerosis (I67.2) and to a lesser extent, hypertensive encephalopathy (I67.4). significantly increased.

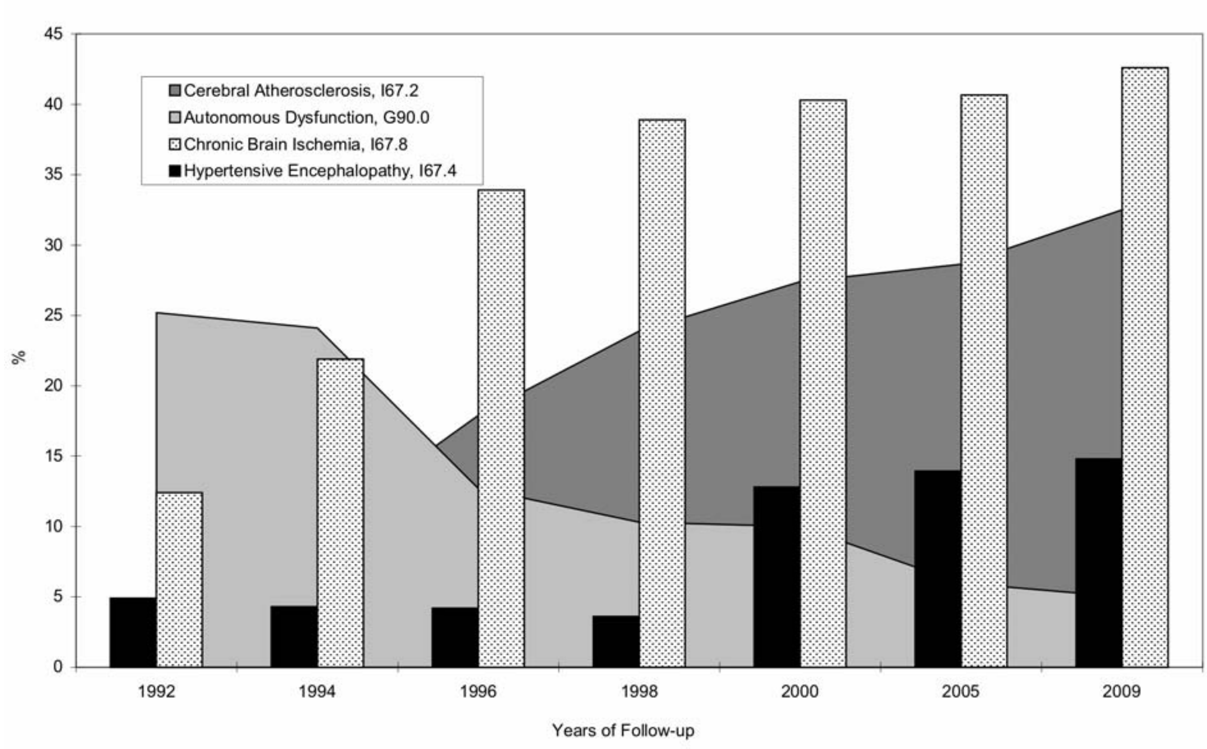


Fig. 3.78. *The dynamics of cerebrovascular disorders in the cohort of clean-up workers registered in the system of Clinical-Epidemiological Registry of SI «RCRM of AMS of Ukraine».*

Current rating (2008–2010) of mental health of randomized sampling from representative cohorts of clean-up workers and evacuees from the exclusion zone, who are registered in the CER, confirmed a long-term psychiatric consequences of the Chernobyl disaster. In the clean-up workers and evacuees there are much more mental and behavioural disorders in general, vascular dementia, mental and behavioural disorders due to alcohol consumption, dysthymia and PTSD. The frequency of organic depressive disorder, organic anxiety disorder, organic emotionally labile (asthenic) disorder and organic personality disorder is increased among clean-up workers.

Neuropsychiatric consequences of the Chernobyl disaster are etiologically heterogeneous as a result of the combined radiation and non-radiation accident factors, especially stress, as well as social change and traditional risk factors. Meanwhile, a dose-related increase in cerebrovascular pathology in clean-up workers of 1986–1987, in particular, cerebral atherosclerosis, especially hypertension encephalopathy was established (Fig. 3.79.).

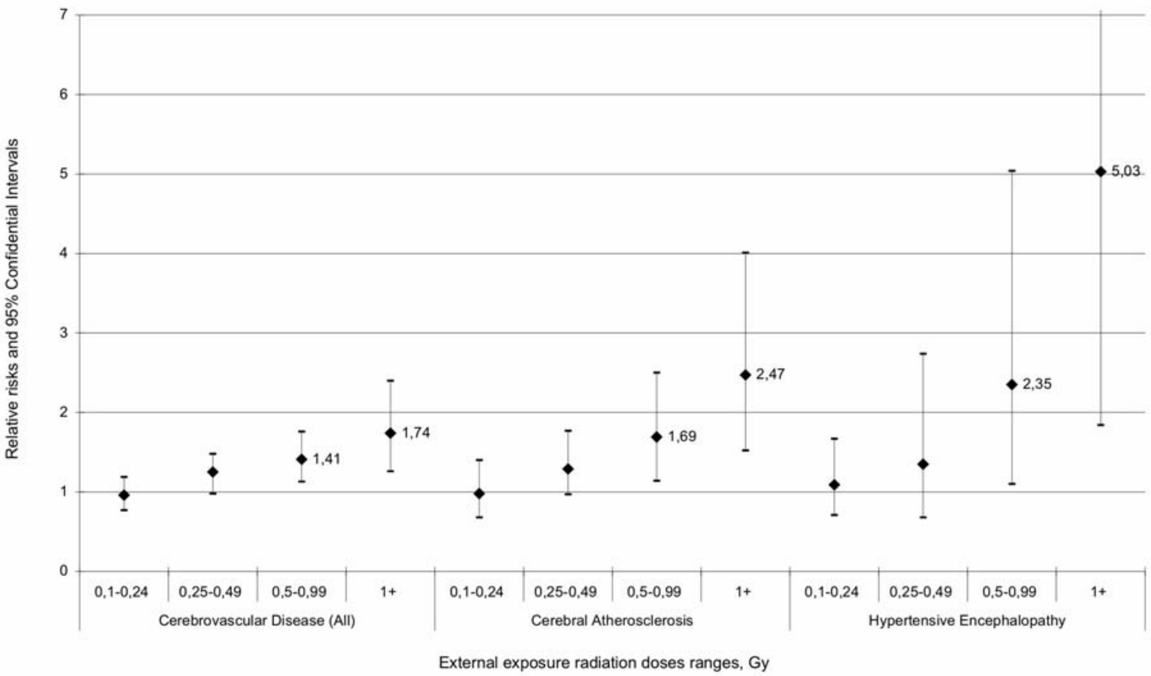


Fig. 3.79. *Relative risk of cerebrovascular disorders in males clean-up workers of 1986–1987 with different doses of irradiation. Control – clean-up workers with doses <0.05 Gy (CER data,1992–2004). (Adapted from L.I. Krasnykova, V.A. Buzunov, 2008) [10]. Indicated the values of the significant relative risks.*

The growth other neuropsychiatric diseases in clean-up workers of 1986–1987 was established, including dose-dependent increase of vertigo and vestibular disorders frequency.

According to SRU, a dose-related increase in diseases of the nervous system and sensory organs, vegetative-vascular dystonia, essential hypertension and cerebrovascular pathology in clean-up workers of 1986–1987 was also found (Fig. 3.80).

Excesses relative risks (ERR) per 1 Gy for neuropsychiatric diseases were established in clean-up workers of 1986–1987 according to SRU and CER data (Fig. 3.81).

Alcohol addiction syndrome is prevalent among 26.8 % of clean-up workers of 1986–1987 (in population 15.6 %, $p < 0.001$), and another 17.2 % of clean-up workers abuse alcohol. In other words, mental and behavioral disorders due to alcohol use were found in 44 % of liquidators. The link was revealed between exposure to the complex factors of the Chernobyl disaster and the development of alcohol dependency syndrome, which occurs secondary, due to existing mental disorders in clean-up workers.

In the prenatally exposed children more nervous system diseases and mental disorders were found. They had a lower overall rate of intellectuality (IQ) due to lower verbal IQ and increased frequency of disharmonious intelligence compared with the unexposed group of peers. When this disharmony exceeded 25 points, it correlated with radiation dose of fetus. No differences in verbal intelligence were in both groups of mothers, but evacuated experienced significantly more stress events and had more depressive disorders, PTSD, somatoform disorders, anxiety and insomnia, social dysfunction than mothers from Kyiv.

Despite the relatively low fetal doses of irradiation during the radiation accident at a nuclear reactor with the release of iodine radionuclides into the environment brain damage is possible not only at the most critical period of cerebrogenesis (8^{th} and 15^{th} weeks of gestation) but in later pregnancy, when thyroid doses in utero are the highest (Fig. 3.82).

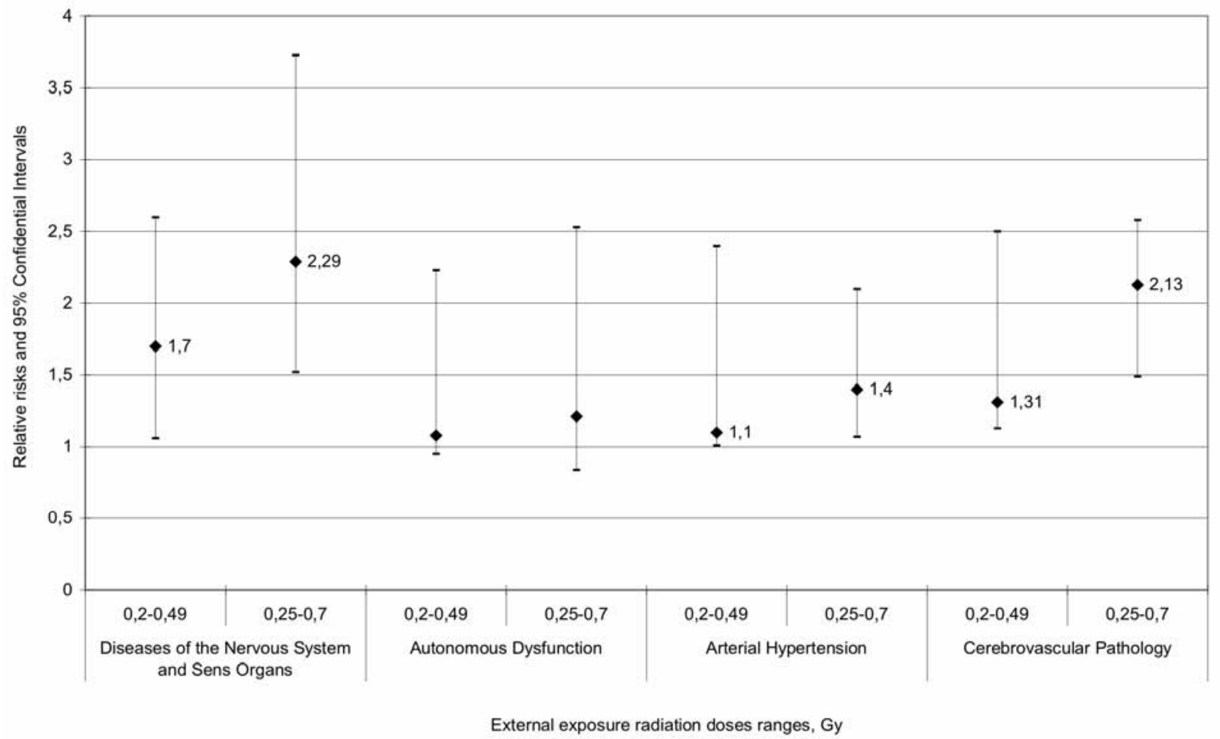


Fig. 3.80. *Relative risk of neuropsychiatric diseases in males clean-up workers of 1986–1987 with different doses of irradiation. Control – clean-up workers with doses <0.05 Gy (data of SRU, 1986–2001).(Adapted from V.A.Buzunov, L.I. Krasnykova, E.A. Pirogova, etc.) [11]. Indicated the values of the significant relative risks.*

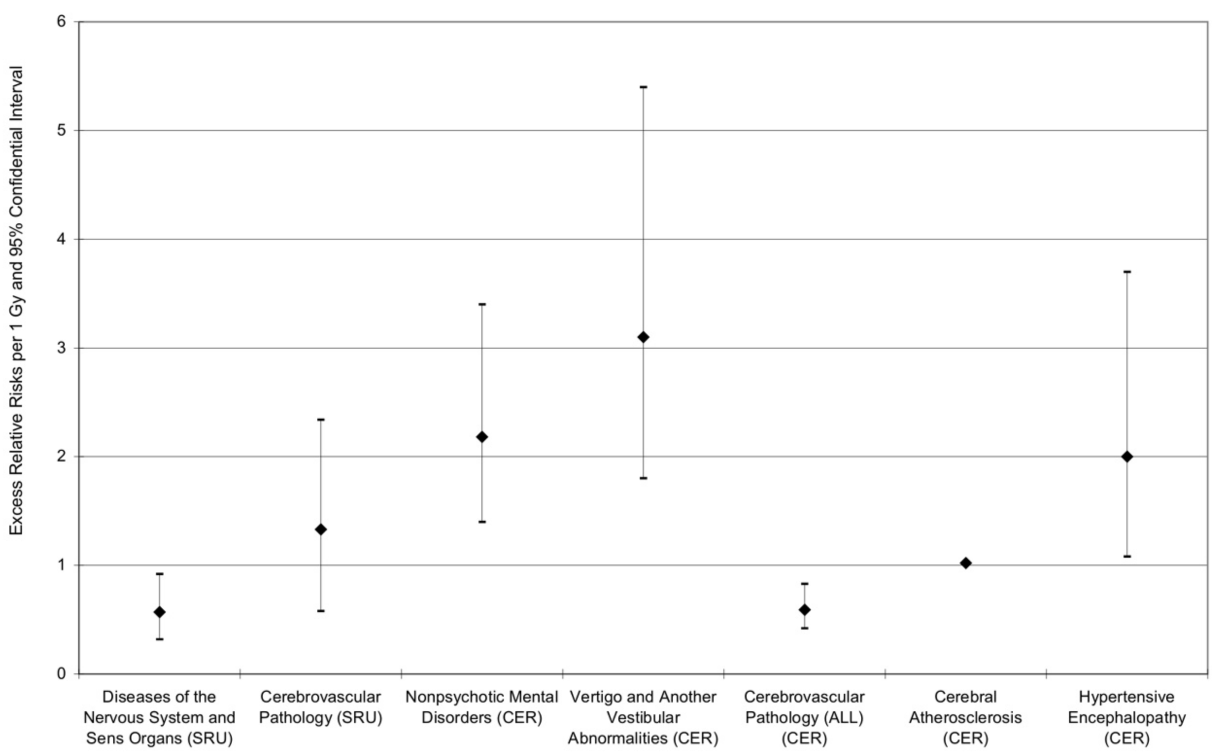


Fig. 3.81. *Excess relative risk of neuropsychiatric pathology per 1 Gy in males clean-up workers of 1986–1987 with different doses of irradiation (data of SRU, 1986–2001 and CER, 1992–2004). (Adapted from V.A.Buzunov, L.I. Krasnykova, E.A. Pirogova, etc.) [11].*

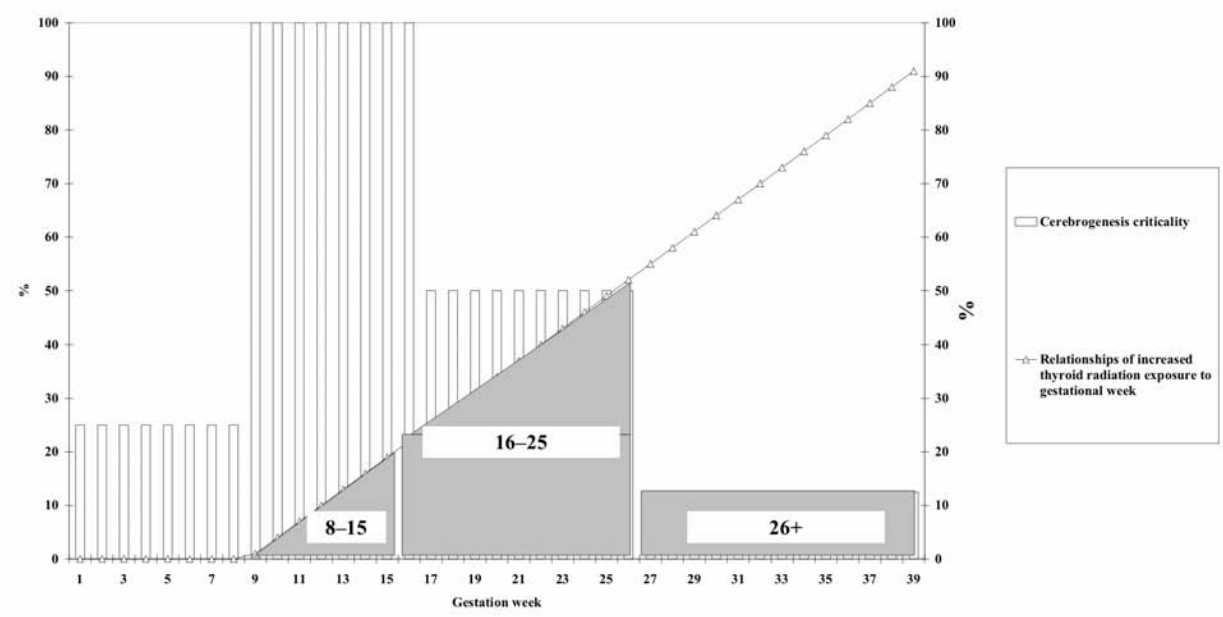


Fig. 3.82. *Conditional image of relationship between critical periods of cerebrogenesis and growth in thyroid doses in utero by a model of ICRP-88 in in utero exposed children from the Chernobyl disaster area (gray shapes correspond to the degree of vulnerability of brain irradiation by radioiodine) (adapted from Loganovsky et al., 2008 [12]).*

Based on extensive neuropsychiatric research with reliable personal dosimetry guidance, the findings regarding damages of the dominant (left) hemisphere of the brain after intrauterine exposure from the Chernobyl disaster were revealed.

Though, no excess of severe mental retardation, persons exposed *in utero* had more neuropsychiatric disorders, neurological signs of destruction of the brain left hemisphere, lower rates of general and verbal IQ, disharmonic development of intellect through lower verbal IQ, disorganized EEG patterns, excess lateralized to the left frontal-temporal area of delta- and beta-spectral power bioelectric activity of brain with depression of theta- and alpha-power, and interhemispheric inversion of processing visual information. Mothers' mental health disorders, stress, and prenatal exposure led to contribute to these effects, along with traditional risk factors.

The main neuropsychiatric lessons of the Chernobyl disaster defined in the framework of the NATO Science for Peace and Security: negative psychological effects (radiation anxiety and panic reaction) and psychosomatic disorders, «victimization» with «panic escape to the disease», disability and social inactivity, inadequate social protection; socio-psychological and radiological problematic of resettlement; peculiarities of the «postradiation PTSD» with hypochondriac fixation of the future (anxiety about possible oncopathology, congenital abnormalities in children and others); effects on the developing brain, long-term mental health disturbances in adults; potential radiocerebral effects; suicides.

3.4.2. Cardiovascular disease

At the global level is recognized that in most large-scale nuclear accident at Chernobyl NPP priority impact on the health of all categories sufferers belongs to cardiovascular diseases. The relationship between radiation dose and pathogenic, clinical features, morbidity and mortality from cardiovascular diseases remain one of the main research areas. According to the Scientific Registry of Cardiology among cardiovascular diseases of 18,669 clean-up workers prevail hypertensive and coronary heart disease. Their share in the structure of hospitalization increased 4 times (Fig. 3.83). The most critical category consists of clean-up workers 1986.

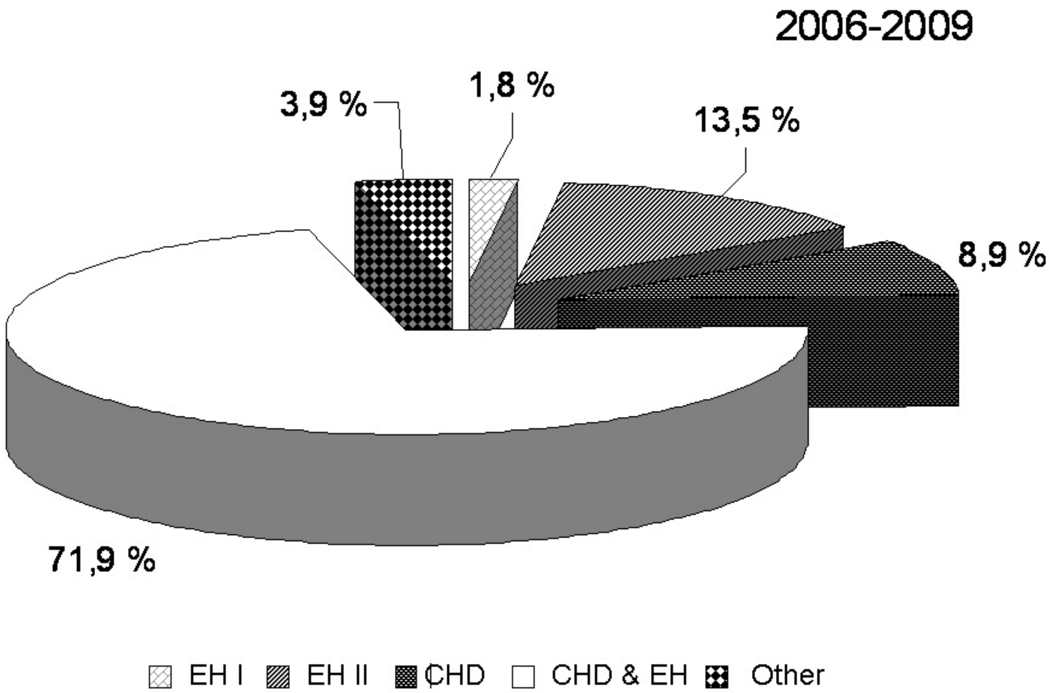


Fig. 3.83. *Shares of coronary heart disease (CHD) and essential hypertension (EH) in the structure of causes of clean-up workers hospitalization at 2009.*

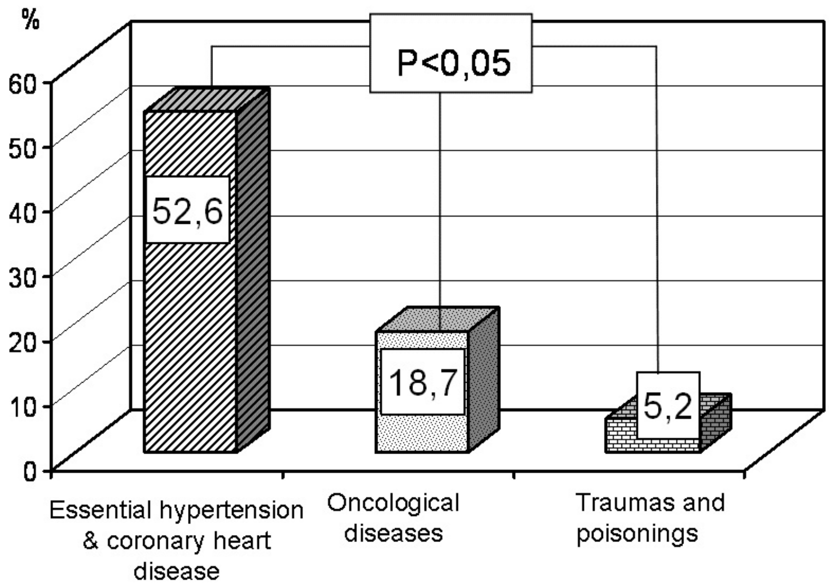


Fig. 3.84. *Structure of clean-up workers mortality.*

According to the analysis of pathologoanatomic investigations of 988 deceased clean-up workers, essential hypertension (EH) with coronary heart disease (CHD) cause more deaths than all cancer diseases in total (Fig.3.84).

3.4.3. Bronchopulmonary pathology

Results of long-term (1996–2009) pulmonological investigations of 16,133 clean-up workers of 1986–1987 in the Outpatient Clinic of Radiation Register of RCRM of AMS of Ukraine testify to significant steady increase in cases of respiratory diseases.

Among 7,665 male clean-up workers of 1986–1987 with chronic obstructive pulmonary disease (COPD) and radiation dose above 250 mSv relationship between probable relative risk of COPD, chronic bronchitis and exposure was dose-dependent (Fig. 3.85).

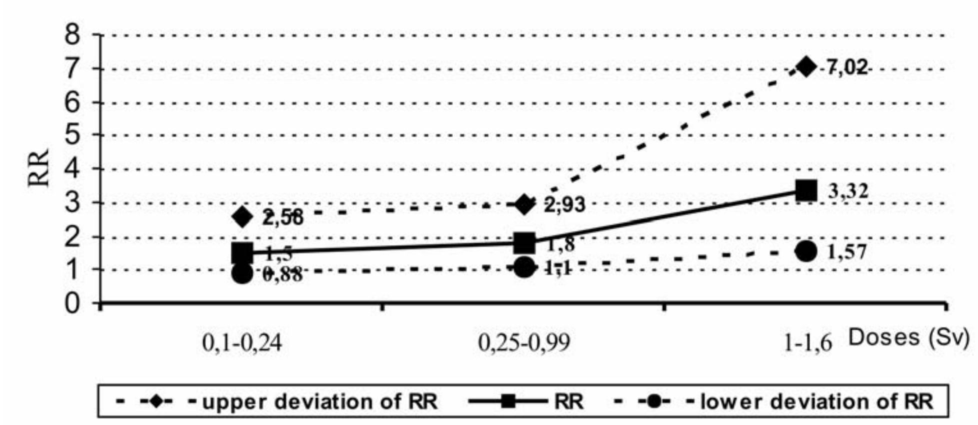


Fig. 3.85. *Relative risks (RR) and 95 % confidence interval of COPD morbidity of Chernobyl clean-up workers of 1986-1987.*

The course of COPD in clean-up workers is characterized by fast development fibroplastic changes in the lungs and bronchial mucosa with progressive deformation of the latter, hyporeaktivity of exacerbations and disorders of bronchial secretion, accompanied by a lack of inflammatory response in bronchial mucosa with redistribution of cells in T-lymphocyte system. COPD in clean-up workers is a component of multiple organ pathology, which is essentially caused by disturbances in the integrative systems of homeostasis.

Character of disregenerative changes in bronchial epithelium of clean-up workers, particularly expressive pathology of cambial cells and the presence of cells with changed phenotype, suggests to consider outlined contingents a high risk group to develop endobronchial neoplasms. In cases of COPD the patterns of normal expression of EGFR, HER2 and the tendency to higher expression of Ki-67 and the low level of Ctk^+, Vim^+, and BER-$EP4^+$ cells. Lung cancer is characterized by high expression of Ki-67^+ and $HER2^+$ epithelial cells in combination with the low number of $EGFR^+$, Ctk^+Vim^+BER-$EP4^+$, $CD25^+$ and HLA-DR^+ cells.

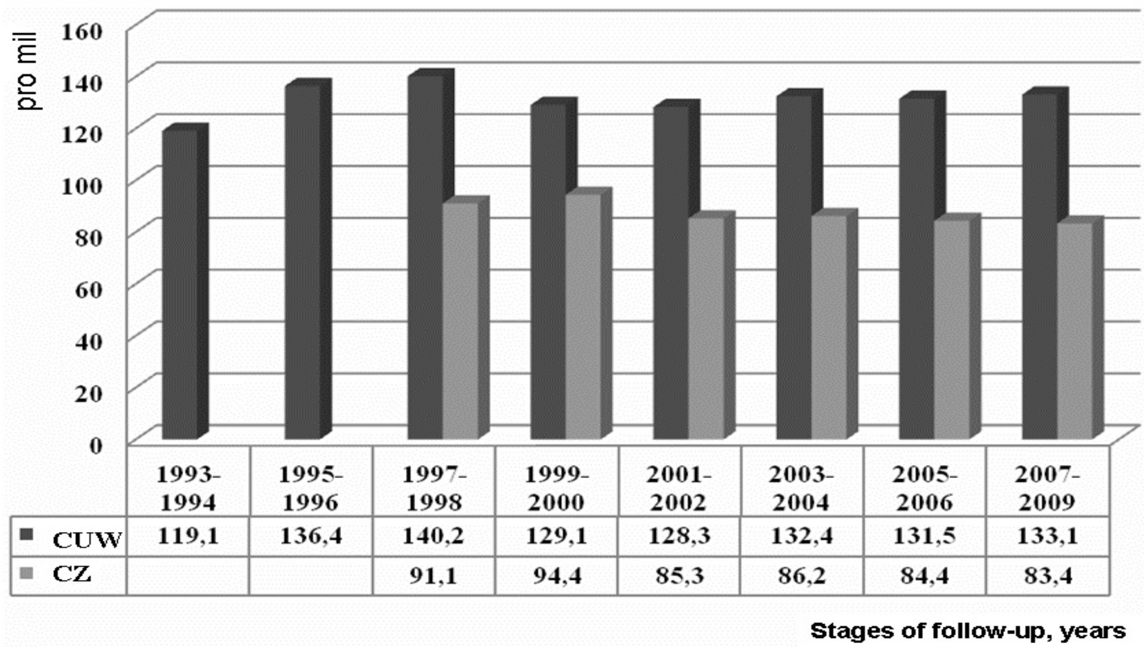
3.4.4. Pathology of the digestive tract

Diseases of the digestive system takes 2–3 rank place among non-tumorous diseases in individuals affected by the Chernobyl disaster. Cohort study of morbidity, disability and mortality of Chernobyl clean-up workers show persistent negative changes in health – after 24 years diseases of digestive system took top spot (31.1 %) in the structure of non-cancer disease, and the third place in the performance of disability indices (10.3%).

Gastrointestinal system in the conditions of Chernobyl accident is the main target-tissue for damaging factors of radiation and non-radiation nature. Monitoring of the digestive system in clean-up workers showed that erosive-ulcerative pathology of the stomach and duodenum and liver disease are the most common.

According to CER data, erosive-ulcerative pathology of the stomach and duodenum in clean-up workers in the post-accident years increased from 119.1 ‰ in 1993–1994 to 133.1 ‰ in 2007–2009 and was higher than the official statistics (68.3 ‰ – 96.6 ‰) (Fig. 3.86).

Epidemiological «case-control» study showed higher risk of erosive-ulcerative pathology in the Chernobyl clean-up workers with absorbed dose >25 cGy (OR = 4.67 with CI 2.84–7.71) in a broad age range (20–59 years).



	1993-1994	1995-1996	1997-1998	1999-2000	2001-2002	2003-2004	2005-2006	2007-2009
CUW	119,1	136,4	140,2	129,1	128,3	132,4	131,5	133,1
CZ			91,1	94,4	85,3	86,2	84,4	83,4

Fig. 3.86. *The incidence of erosive-ulcerative pathologies of stomach and duodenum in the Chernobyl clean-up workers (CUW) and residents of 4th contaminated zone (CZ) during the observation periods.*

Ionizing radiation and other negative factors of the Chernobyl accident influence on the organization of all structural components of the gastric mucosa in clean-up workers of all ages. These changes can be characterized as induced pathomorphosis characterized by atypical clinical course with dominated astheno-vegetative syndrome, association with Helicobacter pylori, altered secretion and autonomic regulation, combinaton with concurrent disease. Indices of basal concentrations of cortisol, adrenocorticotropic hormone and gastrin were in direct relationship with the level of absorbed doses above 25 cGy, which indicates a damage of local self-regulation of gastroduodenal area with domination of gastrin mechanism acid-formation.

In the remote period after the accident (2004–2009) in clean-up workers with erosive-ulcerous pathology of the stomach and duodenum marked atrophic changes of the stomach were revealed that causes a high percentage of hypo- and anacide states. Reduction of gastrin and gastric acidity was growing since the dose increased starting with 25 cGy, the lowest value of these parameters were recorded in irradiated in the range of 50.0–99.9 cGy. Changes of personality revealed, characterized by high levels of anxiety, presence of mental and emotional stress and lack of neuro-psychological mechanisms that relieve anxiety.

From the second decade after the accident a marked increase in the number of detected cases of chronic hepatitis and cirrhosis was noticed. Between 1992–2009 among the 2,881 CER patients suffering from chronic hepatitis, 70 cases of liver cirrhosis were found. The most numerous group in the nosological structure of chronic diffuse liver diseases were non-alcoholic steatohepatosis (50.0 %) and steatohepatitis (36.6 %). Changes in functional state of the liver were more prominent in clean-up workers with large doses of radiation. A direct correlation was found between the level of absorbed radiation dose and the activity of gamma-glutamiltranspeptidase ($r = 0.6$, $p<0,02$), alaninaminotransferase ($r = 0.39$, $p<0,02$), glucose concentration ($r = 0.5$, $p<0,03$) in serum (Fig. 3.87).

Analysis of liver functional state biochemical parameters of clean-up workers in accordance with the dose of irradiation showed significantly increased activity of aspartataminotransferase ($p<0.001$) alaninaminotransferase ($p<0.05$), decrease of bilirubin ($p<0.05$) and beta-lipoprotein ($p<0.001$) in clean-up workers with absorbed doses >50 cGy in comparison with the liquidators who received doses <5 cGy.

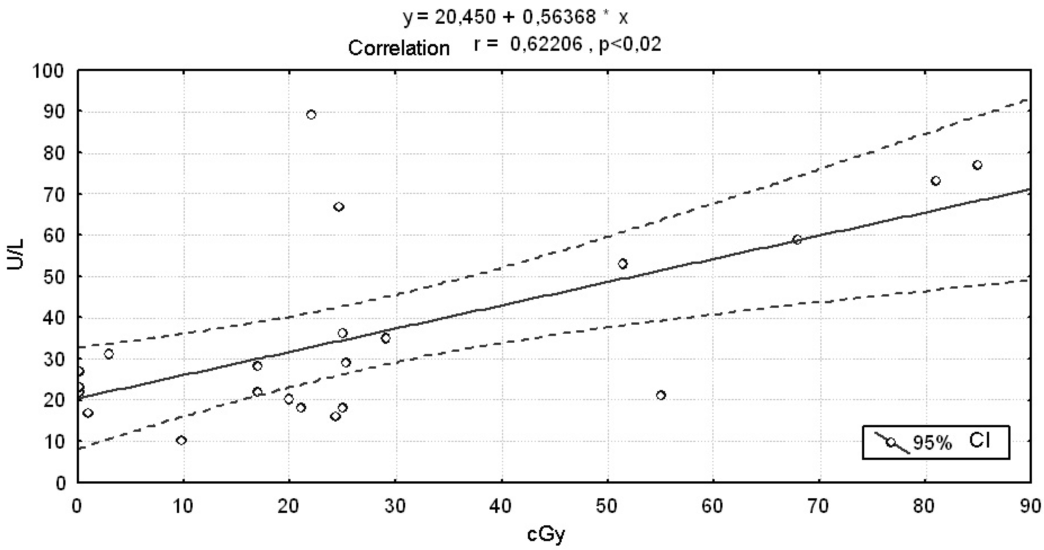


Fig. 3.87. *Regression-correlation analysis between the level of absorbed radiation dose and the activity of serum gamma-glutamiltranspeptidase in clean-up workers with non-alcoholic steatohepatitis and steatohepatosis.*

Contrary to the notion of sustainable benign course of non-alcoholic steatohepatitis the development of this pathology in clean-up workers is progressive. Long persistent course increases the likelihood of liver fibrosis and its final stage – cirrhosis in the remote period after the accident.

Taking into account the pathogenic features of digestive system diseases approaches to the treatment of this pathology in Chernobyl clean-up workers were developed.

3.4.5. Hematological effects

Results of hematopoietic system monitoring of clean-up workers have shown that at the early post-accidental period (1986–1990) in 25 % examined in peripheral blood reduction in the number of leukocytes (leukopenia) and in 12 % – leukocytosis were recorded, the 9.5 % had higher content of erythrocytes and hemoglobin level, 9 % – thrombocytosis, 14.5 % – lymphocytosis and 10.5 % – monocytosis. At the more remote observation periods after the accident (1991–2000) were determined: leukocytosis and leukopenia in 24 % and 19.7 % of examined, in 7.6 % – thrombocytopenia, in 2.4 % – thrombocytosis. In 15 % of cases bi- and pancytopenia were found. In 2009 remains stable percentage of patients with leucopenia, thrombocytopenia and anemia and slightly increased number of people with lymphocytosis (Fig. 3.88).

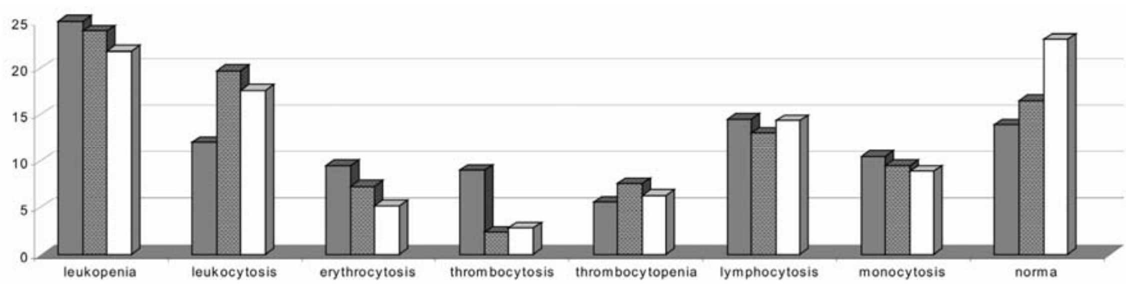


Fig. 3.88. *Structure of hematological disorders in clean-up workers in dynamic observation.*

For the whole period of observation at a relative normalization of quantitative indices qualitative damages were characterized by irregularities in the nucleus and cytoplasm of the cell elements of hematopoiesis as hyposegmented neutrophils, vacuolization of the cytoplasm of granulocytes and lymphocytes, cytoplasmic outgrowths, toxogenic granularity.

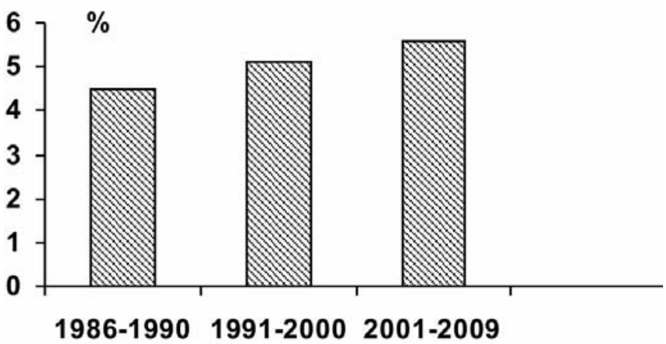


Fig. 3.89. *Ratio of qualitative disorders in hematopoietic cells among clean-up workers by observation periods.*

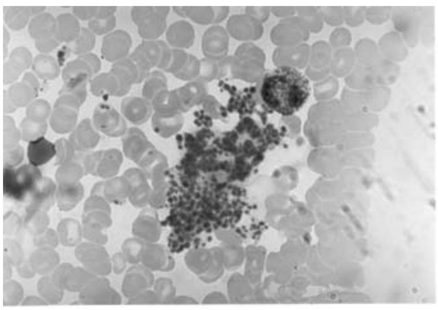


Fig. 3.90. *Accumulation of platelets.*

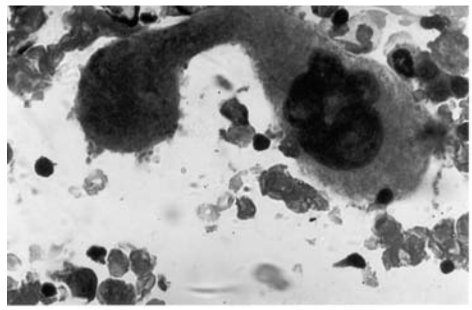


Fig. 3.91. *Abnormal megakaryocytes with partial platelet constriction.*

Among megakaryocytes the number of «old» cells increased, the presence of giant platelets, cells with polymorphic granularity, and in part of examined – aggregates of platelet, and accumulation of micro-makroform were found (Fig. 3.89–3.91).

Thus, not only exposure, but the whole complex of factors associated with the Chernobyl disaster affected the health of the population, needing additional health measures to counteract that impact.

4. SOCIOECONOMIC AND SOCIOPSYCHOLOGICAL CONSEQUENCES OF THE CHERNOBYL DISASTER: MAJOR PROBLEMS AND PRESENT ASSESSMENTS OF POSSIBLE OPTIONS FOR THE AFFECTED AREAS DEVELOPMENT

4.1. Evaluation of economic expenses and losses related to the Chernobyl disaster

The Chernobyl disaster brought about considerable losses to the economy and social sphere not only in the former USSR but also beyond its boundaries. The accident has caused extremely large-scale destructions to the everyday life, environment, and industry in the numerous regions of the former Ukrainian SSR, Belarus SSR, and Russian SFSR. The accident consequences are still producing destructive impact onto all aspects of life in Ukraine, Belarus, and in Russian Federation:

- decreased production of the electricity consumed by economy and public;
- heavy losses suffered by agricultural and industrial facilities;
- damaged forest areas and water industry (a limited use of 5120 km^2 of farmlands and 4920 km^2 of forests);
- significant expenses for evacuation of 116 thousand people and construction of residential space for the people evacuated in 1986; also in 1986–1987 the following were made available: almost 15 thousand apartments, hostels for over a thousand affected people, 23 thousand buildings, 800 sociocultural institutions;
- right after the accident, substantial funds were targeted to ensure protection of population from radiation impact and minimize the threat to human life and health;
- huge amounts of financial aid and technical resources in the former USSR were directed to the affected areas in order to renew life activities and industry, decontaminate the environment, ensure social support to the people who still have lived within the contaminated areas, provide them with clean food and medical services;
- the affected people have got partial compensation for the evacuation-caused material losses, including losses of personal property, grain crops, residential space, etc.; and
- all types of industrial facilities and collective farms have got compensations for the lost financial, material, and technical resources with the objective to renew their activity and ensure employment of the evacuated people.

Overcoming the Chernobyl disaster consequences is on-going, still diverting great resources from the state budget, generally decelerating economic development of Ukraine, and worsening standard and quality of the entire country population’s life.

4.1.1. Evaluation of loss to the USSR economy related to the Chernobyl disaster

As per the data provided by the Ministry of Finance of the USSR the total amount of direct losses and expenses from all sources of financial support was 9 200 million roubles (approximately USD 12.6 billion) over the period of 1986–1989.

In 1990, the expenses from the USSR state budget spent for the activities dealing with elimination of the Chernobyl disaster consequences amounted to 3324 million roubles. Moreover, one billion roubles were consumed from republican budgets of the Russian SFSR, Ukrainian SSR, and Belarus SSR.

As is well known, the following year of 1991 was a peculiar one. This was the year of the USSR collapse. Though the USSR allocated 10300 million roubles for the liquidation activities, only a part of them was used; and at the end of the year it was exclusively from the state budgets of Ukraine, Belarus, and Russian Federation.

The costs out of the 'Assistance Fund for the Chernobyl Accident Consequences Elimination' (account No. 904920) in the amount of 544 million roubles were spent on elimination of the Chernobyl disaster aftermath. The costs of the fund were accumulated from budget sources of the USSR, Ukrainian SSR, and Belarus SSR, State Insurance funds, as well as voluntary contributions from natural persons and legal entities. In 1988–1989, receipts in foreign currencies amounted to 2970 thousand roubles, including 2200 thousand roubles in freely convertible currencies.

4.1.2. Evaluation of total economic loss to Ukraine

Total economic loss includes of several components.

The direct loss includes a loss caused by a damaged to the infrastructure located within the Chernobyl NPP-adjacent area and within the 30-km Exclusion Zone, including the cities of Pripyat and Chernobyl. Hence, valuation of the direct loss caused by outage of the national economy's tangible objects (objects of economy) located within the Exclusion Zone that has resulted out of the Chernobyl accident amounts to 1010.6 million roubles (Table 4.1.).

Table 4.1.

The loss caused by outage of the national economy's tangible objects (objects of economy) located within the Exclusion Zone in Ukraine and taken out of use as a result of the 1986 Chernobyl NPP accident

Description of tangible object lost as a result of the Chernobyl disaster		**Fixed production assets and tangible floating assets**		
		Year of evaluation	**Value, thousand**	
			Roubles	**USD**
Objects and expenses for principal construction of the Chernobyl NPP (Level III)		1986*	99.0	136.1
Chernobyl NPP Unit 4		1964**	201.0	223.3
'Chernobyl-2' facility		1984***	97.7	137.0
Enterprises of various industries (11)		1986	149.0	205.1
Hard surface motorways (353 km)		1986	60.6	83.3
Collective and state farms (16)		1986	98.4	135.2
Inter-farm enterprises (3)		1986	18.7	25.7
Facilities and networks of water supply systems, sewerage systems, heat and power supply systems		1986	12.0	16.5
Housing facilities	State (402)	1986	209.8	288.3
	Private (2 278)	1986	7.1	9.8
	Rural houses (9 050)	1986	28.2	38.8
Facilities of social infrastructure (150)		1986	29.1	40.0
Total		-	1010.6	1339.0

* In April 1986 one USD had been costing 72.75 kopecks.
** In 1964 one USD had been costing 90 kopecks.
*** In October 1984 one USD had been costing 71.3 kopecks.

In addition to the substantial loss caused by outage of the tangible objects within the Exclusion Zone, the following types of losses were inflicted:

– losses and damages of the technical and mechanical vehicles that were used and contaminated during the accident consequences elimination and then disposed at 'Rossokha' retention site and at 'Buriakivka' radwaste disposal site – 33.5 thousand roubles or USD 46.0 thousand;
– losses caused by resettlement of the affected people and outage of capital assets during the period that followed 1986;

– value of wasted housing facilities and private property located out of the Exclusion Zone – 0.2 billion roubles (as per 1984 prices) or USD 2.8 billion;
– value of wasted fixed production assets located out of the Exclusion Zone – approximately 0.4 billion roubles (as per 1984 prices) or USD 5.6 billion.

So, the total direct loss amounts to USD 1 billion and 385 thousand (Table 4.2):

Table 4. 2.

The total loss within the Exclusion Zone

Type of loss	Roubles, thousand	USD, thousand
Loss of tangible objects	1010.6	1339.0
Disposed vehicles and equipment, activities	33.5	46.0
Total	1044.1	1385.0

The total direct loss of tangible objects and objects of economy located out of the Exclusion Zone amounted to 0.6 billion roubles or USD 0.84 billion.

Totally, 0.601 billion roubles or USD 0.841 billion.

The total direct loss amounts (1,385+0,84)= USD 2.225 billion.

Evaluation of direct expenses. The cost of accidental and post-accidental measures was calculated based on the total amount of finance allocated for the following types of activities: social protection of affected people, specific medical aid, research and development, radiation monitoring, ecological remediation of the environment; rehabilitation and RAW disposal, capital investments, works within the Exclusion Zone, and other expenses.

According to the calculation of expenses basing on the abovementioned pattern, the total sum of direct expenses in 1986–2010 amounts to USD 30500 million.

Furthermore, the Comprehensive State Program for the Chernobyl NPP Decommissioning and the Shelter Object Transformation into An Ecologically Safe System for 2006–2010 determined the implementation period to be approximately one hundred years. Financial support to all the required activities shall be provided from the State Budget of Ukraine. The cost of activities amounts to approximately UAH 3.5 billion or USD 470 million (USD 1 = UAH 7.5 at average during these years).

Analysis of the indirect loss.

Economic activity has been completely stopped within the areas with contamination density exceeding 555 kBq/m^2 (15 Ci/km^2) and partially stopped in the sectors with contamination density amounting to 185–555 kBq/m^2 (5–15 Ci/km^2). Recovery of these lands will take no less than dozens of years. Moreover, use of about 5000 km^2 forest areas is limited. Over 1986–1991, the total loss in forest management and wood processing industry amounted to 1.8–2.0 billion roubles (as per 1984 prices). The reduction in coniferous powder harvesting inflicted the damage amounting to 15 million roubles. Economic loss of the waterworks system and fishing industry in Ukraine was 2.3–3.1 billion roubles.

Hence, the annual losses caused by a disuse of the contaminated agricultural lands, forest areas, and water resources in 1986–1991 amounted to 1.625 billion roubles (total loss is 9.75 divided by 6 years = 1.625).

Thus, in 30 yeas after the accident (till 2015) the indirect loss to the mentioned field shall amount to 1.625 x 30 = 48.75 billion roubles.

Over this period, reduction in electric energy generation shall inflict damage in the amount of 20.0 billion roubles, and the loss caused by the moratorium on operating NPPs power development shall make up 48.0 billion roubles.

Till 2015, the total amount of indirect losses shall amount to 116.75 billion roubles In 1984, at the time of calculating the indirect loss, one USD had been costing 0.713 roubles. Therefore, total amount of the indirect loss is USD 163.74 billion. (Table 4.3).

Table 4.3

Breakdown of the indirect loss inflicted by Ukraine as a result of the Chernobyl accident till 2015

Description of loss	Billion roubles
Caused by disused agricultural lands, forest areas, and water resources	68,37
Cost of non-generated electric energy	28.05
The loss caused by the moratorium on operating NPPs power development	67,32
Total (USD 1 = 0.713 roubles)	163,74

In late 2001, the Chernobyl NPP operation was stopped. The nuclear power plant was finally shutdown subject to the Memorandum between the Government of Ukraine, the Governments of the G7 Countries, and the Commission of the European Communities (Canada, Ottawa, 20 December 1995) and as specified in the appropriate decisions taken by the Cabinet of Ministers of Ukraine. The following is the shutdown order for the Chernobyl NPP Units: Unit 1 on 30 November 1996; Unit 2 on 11 October 1991; Unit 3 on 15 December 2000.

As a result of Chernobyl NPP presheduled shutdown, it’s service life hasn’t been reached, and hence 197181600,0 MWt/hr of electric energy was non-generated. Whereas 1 KWt|hr be costing 0,03 € total costs of electric energy realization had to be amounted 5,92 billion €.

According to the world-wide experience (Leningrad, Kursk, Smolensk NPP in Russian Federation) service life of 1, 2, 3, ChNPP units (RBMK-1000) can be prolonged for 15 years over designed term. In addition it would permit to generate about 275940000,0 MWt/hr of electric energy and earn about 8,28 billion € whereas 1 KWt|hr be costing 0,03 €.

Therefore total costs of electric energy realization had to be amounted 5,92+8,28=14,2 billion €.

Costs for electric energy generation (prime cost of production), costs for recovery works on unit N2 after the fire in machinery hall, costs for change of TC have to be accounted. These costs would amount 1,3 billion € at the designed term of service life, and 1,59 billion € at the extended one, that is amounted in total 1,3+2,09=3,39 billion €.

Thereby, losses because of non-generated electric energy due to presheduled shutdown of ChNPP amounted to 14,2-3,39=10,81 billion €, or USD 14,51 billion (rate 1 € ≈ USD 1,34 дол.США).

Evaluation of Ukraine’s total economic loss. In accordance with the presented calculation pattern (Table 4.4.), the total economic loss of Ukraine caused by the Chernobyl NPP accident amounts to USD million. 198 млрд. 402.

Table 4.4

Breakdown of the final amount of the total loss inflicted by Ukraine as a result of the Chernobyl accident, as of 2010

No.	Expense items	USD, million
1	Direct losses of tangible objects and objects of economy	
1.1	– within the Exclusion Zone	1 385
1.2	– out of the Exclusion Zone	840
2	Direct expenses to financing the activities and works aimed at elimination of the accident consequences:	
2.1	– share of Ukraine in the USSR State Budget of expenditure (1986 – 1991)	5 732,5
2.2	– expenses of independent Ukraine (1992 – 2010) including expenses to decommissioning the Chernobyl NPP and transformation of the Shelter Object into ecologically safe system	12194,94
2.3	Indirect loss (with an allowance for a 30-year period after the accident – till 2015) and losses due to presheduled shutdown of ChNPP	178250
Total		198402,44

The abovementioned losses are not comprehensive, as it is extremely difficult to take into account all the indirect losses inflicted by the economy of Ukraine, for example: (a) health breakdown, incapacity for work, loss of income by the present and future generations of affected people; (b) future expenses for the contaminated lands and water bodies remediation; (c) future expenses incurred due to decommissioning the Chernobyl NPP, transformation of the Shelter object into an ecologically safe system, and radioactive waste disposal from the Shelter Object.

Conclusions and proposals

1. The Chernobyl accident demonstrated that the expenses for assuring safety at nuclear facilities are significantly lower than those for elimination of potential accidents' consequences.
2. The Chernobyl disaster caused enormous losses, first of all, to the three affected countries, i.e. Ukraine, Belarus Republic, and Russian Federation. For instance, the total economic loss of Ukraine amounts to approximately USD 232 billion. Among them, heavy indirect losses were inflicted (non-production in power engineering, manufacturing, agricultural, forest, water, and fishing industries, etc.).
3. The scope of Ukraine's social and economic losses to be eliminated during the forthcoming decades is incomparable with an actual economic potential of the country, and thus preconditions a pressing necessity for international assistance.
4. The burden imposed on the Ukrainian economy by the Chernobyl accident and large scales of the elimination activities is still among the most severe and major consequences of the disaster. For many decades, the expenses for the Chernobyl disaster aftermath minimization shall complicate economic development of the country and deteriorate the population's life quality and standard.

4.2. Current major socioeconomic, social, and psychological problems within the radioactively contaminated areas

Chernobyl is a social tragedy. The social and psychological impact upon the public was an immense suddenness of Chernobyl. The ecological, economic, and medical consequences were potentially predictable. Hiroshima, Cheliabinsk, nuclear polygons in Kazakhstan have provided an ever-more convincing doubtful experience. Chernobyl has demonstrated an enormous devastating effect onto the social and psychological sphere of a great number of people (up to six million people, if to include Kyiv residents, who were actually affected, though were not officially declared as victims).

The Institute of Sociology was involved into research too late; as late as in 1992, when Ukraine was already overwhelmed by a wave of political and socioeconomic crisis that has 'mixed' with the Chernobyl factor.

In 1992, the first-phase opinion polls covered ten thousand victims of all categories, including liquidators. Over next several years, the sampling included 100 individuals residing within the 'exclusion zone', 300 individuals out of zone II and 300 ones out zone III, 300 liquidators, and 300 individuals from the 'clean' zone for comparison. Unfortunately, the social monitoring indicates that social consequences of the Chernobyl disaster are still large-scaled and their comprehensive addressing leaves much to be desired.

4.2.1. Fears and level of health

Fear is gradually vanishing. 47% of the whole host of the Ukrainian population were afraid of the Chernobyl consequences in 1992. However, a level of fear reduced annually, and became a third, having dropped down to 16% (Table 4.5). Also, a share of citizens, who believe 'the Chernobyl factor' to be the major driver in their health deterioration, reduced from 41% to 15%. A level of fear related to the Chernobyl accident aftermath is too closely related to a level of health effects produced by the

Chernobyl consequences, the correlation coefficient is R = 0.90. It appeared that affected individuals from zones II and III evaluated a status of their psychological health twice as good (60 and 62 scores, respectively) as their physical health status (33 and 36 scores, respectively). The scale was from 0 scores (critical) up to 100 scores (very good). The resettled victims assessed both their health statuses as being on equally low levels (37 and 32 scores). The same refers to 'clean' area residents. Levels of both their health types are equal – 45 scores (the data are as of 1997).

Table 4.5.

Comparison of population shares in Ukraine that have evaluated a level of their own health status and an extent of the Chernobyl disaster impact onto their health. Ukraine. N = 1880. Years 1992 and 2010, %

		1992	2010	Changes
Health status	Very poor or poor	17	22	+5
	Satisfactory	53	58	+5
	Good or very good	30	20	-10
	Total	100	100	-
Health impact of the Chernobyl disaster	Is the major factor contributing to health deterioration	41	15	-26
	Is deteriorating health equally to other factors	27	36	+9
	Other factors have greater impact than the 'Chernobyl' one	10	22	+12
	It's difficult to say	22	27	+5
	Total	100	100	–
Scared of the Chernobyl disaster aftermath		47	16	-31

Source: Sociological survey of IS NASU: Ukrainian society. – Kyiv: Institute of Sociology, 2010. – pp. 45, 55.

The main criteria, and hence the main goal, of overcoming the Chernobyl disaster aftermath should become such a rehabilitation of the affected people that is able to maximize their social life standard, i.e. to recover an individual's pro-active attitude towards addressing vital problems, most of which look to the future.

4.2.2. State of the affected people, as per 1992 polls

60% of the respondents had fear related to food quality; also their general helplessness level, insomnia, and irritation have increased. About a third (30%) had lost interest in life and 20% had lost appetite (Table 4.6). One in two suffered from bad mood, loss of activity; the accident left its stamp on entire life of 40% of people. The affected community is deeper and deeper immersing in a state of social infantilism. A 'community of the doomed' is being formed. They rely mainly upon God, themselves, immediate relatives, and life-long support from the state. Ninety percent of the affected people are concentrated on their own health, health of their children and family. Sociocultural and landscape space of the resettled people is in disorder, they badly adapt themselves to new conditions. Most of them wish to come back to native though dangerous land.

The highest ratings go to the most critical life factors: 'future of children' – 73%; 'price rises' – 69%; and 'health status' – 56%. These are related to a family and an individual. 'Fate of Ukraine' as the fourth factor has got a rating of 51% having confirmed that even in the post-catastrophic situation the Ukrainians have not lost their progressive citizenship. Generally, pessimists dominate among the affected people (60% in zones II and III; 41% among the migrants). Instead, there are 45% of optimists and only 27% of pessimists within 'clean' areas.

Actually, the affected people and the entire population of Ukraine have suffered from a double stress. There were 'two Chernobyls'. The first one was objectively evident, as some people witnessed the accident and others got to know about it due to rumours and the 'hostile' media. The 'second

Chernobyl' was informational, when domestic media was permitted to openly put the disaster's history into the public domain. The affected people started to independently seek for adequate post-accidental survival patterns.

Table 4.6.

Consequences of the Chernobyl disaster as percepted by the affected people during the first years after the accident, 1992, %

		Residents of the contaminated areas	**Resettled people**	**Residents of 'clean' areas**
The following deteriorated after the accident:	Health	81	85	20
	Financial condition	45	65	35
	Attitude towards authorities	43	45	32
	Situation at work	38	40	6
	Family relations (climate)	42	30	6
	Attitude towards religion	4	3	1
Future forecast with reference of the accident:	Things will come right, I'm not scared	5	9	17
	It is necessary to seek for a way out	11	20	28
	It's no need to cry over spilt milk	18	28	18
	The worst is in the future	38	26	21
	We are doomed	22	15	6
Completely satisfied with:	Medial check-up	1	5	5
	Medial treatment and recreation	8	2	12
	Supply of medicines	5	3	6
	Supply of clean food	2	9	16
Whom do you rely upon?	Myself	38	45	57
	God	56	22	34
	Authorities	10	13	5
	Science	6	4	10
	Foreign assistance	2	1	4
Where costs are to be allocated first of all?	Resettlement	43	27	12
	Medical care	11	31	41
	All costs are to be distributed among the affected people	19	25	19

4.2.3. Eight and a half years after the accident

The second sociological survey took place in 1994 and generally demonstrated stabilization of people's passive socio-psychological orientations within the affected zones.

Migration. A share of potential migrants amounts to 52% within the affected zones in contrast to 27% in 'clean' areas.

Expectations. Surprisingly, the affected people have become a little more active (Table 4.7). A number of those wishing to run a business, take land on lease or buy it, re-educate is almost twice as large as the same quantity among 'clean' individuals. It's noteworthy that both within 'clean' areas and among the affected people, there was a quarter of passive individuals 'living to survive', 28% and 24% respectively.

Mitigation of the Chernobyl disaster consequences. All self-evaluations of the situation made by the affected individuals are directly related to the issue of overcoming the Chernobyl consequences. Only 1% of the affected are sure that 'everything that is required is being done'. However, 40% believe that 'something is being done'. 39% gave a peremptory answer: 'nothing is being done'. Surprising were 20% of undecided. After all, the full picture of overcoming the aftermath is affecting their fate and is taking place in front of their very eyes. It is notably that a third of the affected people, whatever area they live in, point out that they 'overcome all hardships'.

Table 4.7.

Expectations of the affected individuals and population of 'clean' areas, 1994, %

Expectations	Affected areas	'Clean' areas
Seek for additional income	42	55
Do not have any plans, just want to survive	28	24
Run a business	21	11
Take a land on lease or buy it	14	8
Re-educate	11	6

Note: the percentage total in the columns exceed 100, as respondents have selected up to three answers.

Urgent types of social aid. The lead is assumed by the types of aid that are absolutely predictable in a state of social exclusion: monetary aid – 66%; medicines – 64%; food – 51%; clothes – 47%; medical treatment – 40–47% (Table 4.8). Among 10 most urgent types of assistance, the 9th position is taken by a purely psychological aid: 16% of the affected need 'improvement of family relations', and for some reason this indicator was significantly higher for the 'clean' amounting to 23%. Wellbeing of a family is often narrowed down to its material prosperity. However, it proves to be far from it.

Table 4.8.

Criticality of social aid types, 1994, %

Rank	Types of social aid	Affected areas	'Clean' areas
1	Monetary aid	66	63
2	Medicines	64	62
3	Food	51	39
4	Clothes	47	56
5	Medical treatment of children	47	32
6	Medical treatment of relatives	46	38
7	Personal treatment	40	38
8	Organization of leisure, rest	26	24
9	Improvement of family relations	16	23
10	Changing a place of residence	14	5

Attitude towards food. Few, if any, affected people eat only 'clean' food. There are 10–18 % of foolhardy: a quality of food does not matter for them. Besides, the affected people and 'clean' individuals have almost identical structure of food positioning.

Conclusions

1. Notwithstanding their place of residence and extent of its radiation contamination, the affected people are almost completely concentrated on the problems of just survival.
2. When solving the problems of survival, the affected people first and foremost rely upon themselves, their family and relatives, i.e. isolate in a small family circle. They have trust neither to community-based organizations, nor to authorities. The Ministry of Chernobyl (presently the Ministry for Emergencies of Ukraine) is an exception.
3. More than a third of the affected individuals know nothing about or hit the high spots in the Law 'On Status and Social Protection of the Citizens Affected by the Chernobyl Disaster'. Only 1% of the affected people believe its provisions are fair.

4.2.4. Ten years after the Chernobyl accident

During 1992–1997, a share of the affected individuals (approximately 20%), who were still in a state of social and psychological maladjustment, remained almost constant – 'Chernobyl has broken my entire life'. This proportion was less among the youth, only 10%. Women and residents of rural areas were particularly vulnerable to the 'syndrome of an accident victim'. As of March 1997, acuteness of resettlement from zones II and III, as percepted by the affected individuals, reduced down to the level of nationwide migration trends.

With regard to the renewed industry, the affected individuals consider the following directions to be the most prospective: processing of agricultural products – 70%; production of consumer goods – 68%; traditional national business – 52%, etc. Therewith, the young are notable for higher optimism, economic confidence, and initiative.

Chernobyl raised *an issue of comparing man-caused, biogeneous, and sociogenic risks*. From the one hand, there are objective risks governed by technical and technological characteristics and natural factors. From the other one, there are subjective risks that are formed in people's consciousness and subconsciousness[8-10].. In case there is a lack of well-functioning system of information, training, and education that covers standards of daily living activities and there are discrepancies between the objective and subjective (sociological) assessments, then a situation may turn into a catastrophic one. Governmental decisions become inadequate.

4.2.5. Twenty years after the Chernobyl disaster

A range of the Chernobyl disaster social consequences is too wide and deep (Figure 4.1). With the objective to avoid sociocultural degradation, each component of the problem requires much attention, great amounts of expenses, and relevant reaction of government and community. A technological disaster happens in a clap. However, the induced sociocultural disaster is expanding slowly, since a community of affected people degrade into radiation-isolated reservations gradually, almost imperceptibly in the first instance. More than that, the environment becomes clearer and safer, though a community of victims, who are left to themselves, is further degrading.

So far, treatment of the following variety of social syndromes that have been imposed on the affected community by the disaster and its aftermath was a failure[12–13], whether it was done by medical means, or at the expense of material compensations, or by environmental rehabilitation: (a) *'syndrome of a victim'* – a large part of the affected individuals refer themselves to a community of victims during their entire life; (b) '*syndrome of social exclusion'* – absence of initiative, paternalism, demands for 'eternal rent from the government' dominate in the collective consciousness of affected individuals; (c) *'syndrome of evacuation and resettlement'* is driven by a disturbed picture of the world and weak adaptation to new conditions that are typical for the affected people; (d) '*syndrome of lost health'* is a combination of adults' and children's health deterioration and a fact of the disaster and its overpowering consequences; (e) *'syndrome of uncertainty and confusion'* is a paradox reliance of the affected individuals upon the government in terms of solving their problems combined with simultaneous almost complete distrust to authorities and recognition of a real support from a family; (f) '*syndrome of ignorance'* is the affected individuals' unfamiliarity with laws and rules of activities for daily living in the post-accident environment, thus guidance by subjective risks and not by actual situation in a daily life. Instead, affected people choose the following vital targets for their future: promote health of children – 80%; establish own business – 55%; indulge in spiritual development – 54%; strengthen a family – 52%; promote personal health – 50%.

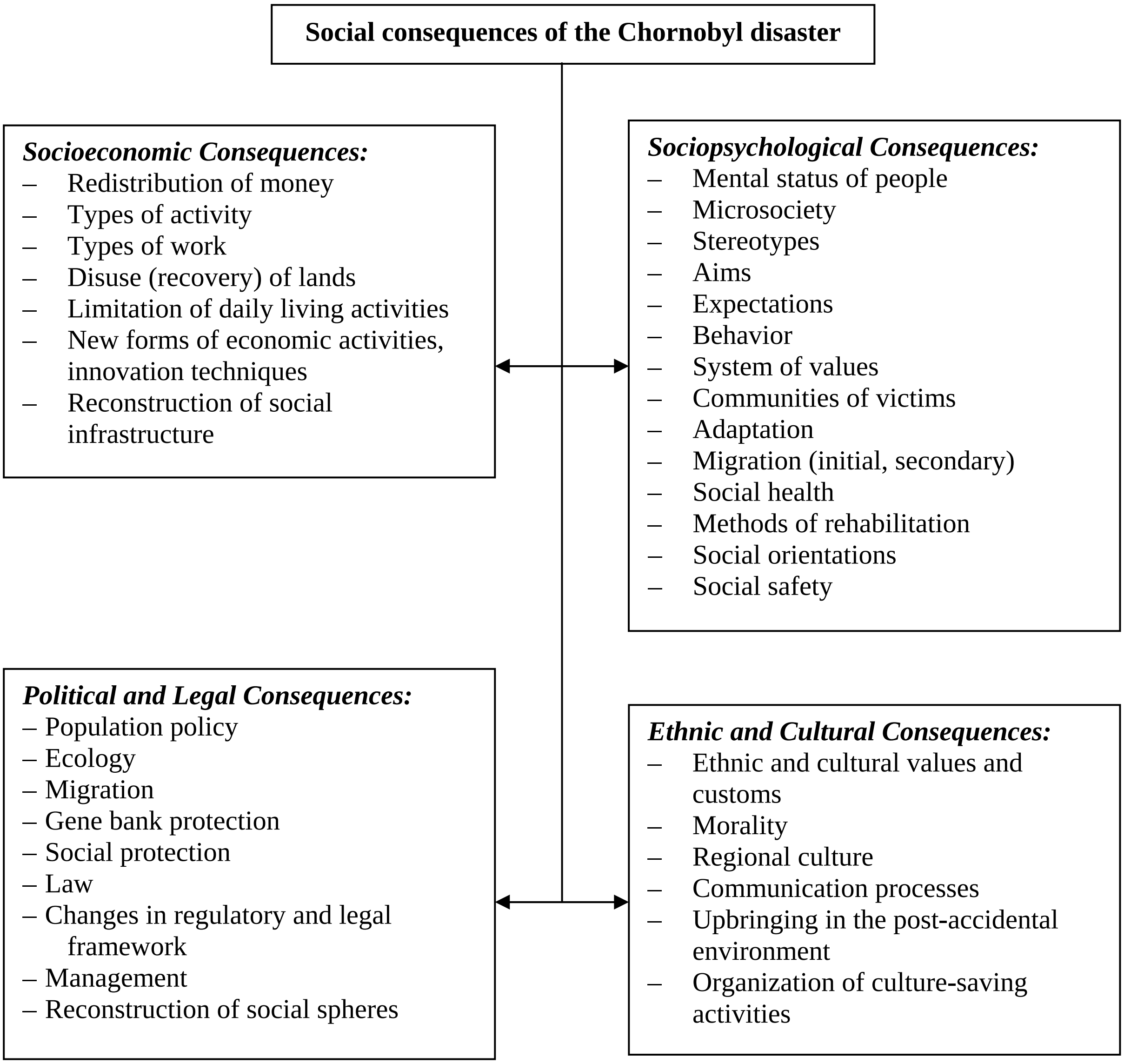


Fig. 4.1. *Structure of the Chernobyl disaster social consequences.*

As early as in 1998, a research group from the Centre of Social Expertise under the NASU's Institute of Sociology submitted the following proposals:

1. Review the concept for the affected people resettlement, since a share of volunteers has sharply decreased and the state funds were severely scarce.
2. Develop a specific program for a 'recovery of life' within the gradually decontaminated areas.
3. Conceptually and functionally redirect social policies towards the affected individuals and comprehend it from the following aspects: (a) *self-sustainability*, i.e. establish a system of socioeconomic conditions providing an active individual with an opportunity to earn money for a completely independent support of his/her family and pay taxes; (b) *rehabilitation*, i.e. renew an adequate status of the affected people's social health and turn some of them into active citizens; (c) it is certainly necessary to consider *social criteria* while evaluating effectiveness and efficiency of any activity for eliminating consequences of the accident or disasters; (d) it is necessary to transfer *social policy* from a social aid concept to a concept of

social recovery of active individuals and communities, the following structure of the victims is to be a benchmark: (a) *the self-sufficient individuals* able to secure all personal needs and needs of their family after the recovery; (b) *the demi self-sufficient individuals*, who require some social aid to become self-sufficient; (c) *the dependants*, who can exist only at the expense of social assistance.

4.2.6. Results of 1997 social survey

The respondents included 1200 affected individuals and liquidators. Also, 121 experts have provided their assessments of the situation and the proposals regarding its improvement.

Among other factors, results of the survey demonstrated that almost no conditions have been established for: (a) providing jobs to the affected people; (b) rehabilitation of safe environment; (c) robust social infrastructure (education, medicine, post, transport, etc.); (d) efficient management instruments; (e) family business, as only 8% of the affected people thought the above conditions were available. Social capital (potential for mutual aid and interaction) is quite scanty and has certain particularities regarding each category of the affected individuals. The level of community control over the authorities' decisions is low. Very few affected individuals the same as before refer to social bodies (mostly local authorities) for assistance.

Conservatively negative remains the self-esteem of the Chernobyl disaster's health effects made by the affected individuals: liquidators – 86%; zone II – 77%; zone III – 74%. Satisfaction by the level and quality of medical services in all groups of the affected individuals is still quite low. Compared to previous years (2001 in particular), the awareness about rules of living activities among the population of the radioactively contaminated areas has increased to some extent. Specifically, 7–10% of residents from the involuntary resettlement areas assert that they have thoroughly studied such rules, another 12–14% note they use the rules (follow them) in their daily life. Large majority of the affected people (almost 90%) need special-target educational programs covering the safety of living within radioactively contaminated areas. Environmental activity of the public has risen considerably. In 2007 almost 70% of the affected individuals participated in the environmental activities, compared to 45% in 2001. The most pressing problems of the victims are as follows: 71% need extra jobs; 64% – recovery of safe environment; 62% – a full-fledged servicing system; 61% – efficient management instruments; 33% – conditions for small and family business.

Experts state that there are no structures of civil society able to ensure control over the authorities and address pressing problems jointly with the power within the contaminated areas. Interface of various bodies within RCA is coordinated mainly by the command and administrative methods, i.e. top-down.

Assessment of the activities for the Chernobyl accident consequences elimination as made by the affected people point out the following:

1. It is necessary to thoroughly revise the social policy with the objective to revive life within RCA and involve national, non-governmental, business, and public effort into the process of recovery, i.e. it is necessary to join administrative and self-government controls in an integral system;
2. It is necessary to re-orient the program of life recovery within RCA from contamination hazards, i.e. radiation risks, towards activation of people and communities, search for innovative chances of life-sustaining activity and behaviour within RCA.
3. It is necessary to develop an evolutionary way for transformation of people from the 'affected' status to a status of a full-fledged citizen of Ukraine.

Proposals: 1. Adopt new legislative instruments. 2. Develop all forms of social partnership and promulgate positive experience through involvement of mass media and efficient dissemination of information.

4.2.7. Activities of the Socio-psychological rehabilitation centres and distribution of information to the affected individuals

The negative impact of the Chernobyl disaster long-term effects produced on population is first of all manifested in social and psychological domain, since traditional ways of people’s daily living activities have undergone deformations and socioeconomic activities within the areas contaminated with radionuclides has been falling into a decay. Against the background of the above problems, more than 20 years these people are living in a situation of an aggravated though uncertain health risk. Therefore, a steady anxiety about adults’ and children’s health status has formed in the affected people. Generally, the situation may be characterized as a poly-modal life crisis of the affected individuals that intensifies a number of social risks, generates a confrontation in interpersonal relations and intergroup attitudes, and evokes prolongation of the crisis.

It is necessary to consider sociological and psychological impact of the Chernobyl aftermath as seriously as the effects of dose absorbed by people, since a psychological stress contributes not only to an increased incidence rate among population, especially with regard to psychosomatic diseases, but also to an increased level of morbidity. Moreover, psychological effects are the most widespread and long-term.

The Centres for socio-psychological rehabilitation and distribution of information among the affected people that were established in 1994–2000 by the Ministry of Ukraine for Emergencies and Affairs in Protection of Population from the Consequences of the Chernobyl Disaster under the support of UNDP programs (Borodianka, Boyarka, Ivankiv, Korosten, Slavutych) were involved into task-oriented elimination of the social and psychological consequences of Chernobyl.

The following were the field of concerns covered by the Centres for socio-psychological rehabilitation and distribution of information among people: social and psychological support to people; development of personal responsibility for one’s own life; orientation towards affirmative addressing of existing problems; development of communities and interpersonal relations; formation of efficient behavioural models in line with new living conditions. While ensuring continuous interface with the communities in terms of developing their self-government and local upgrowth potential, the Centres warrant projects’ outcomes stability and ensure dissemination and acquisition of positive experience.

Social and psychological problems of the affected people to date are still urgent, as well as overcoming the ‘syndrome of a victim’ and negative perception of radioactively contaminated areas as far as a living possibility is concerned. Hence, experts of the Centres for people’s socio-psychological rehabilitation endeavour to find new approaches to addressing the problems above.

Also, the Centres’ important work area is developing civic engagement among youth. The objective is to involve the oncoming generation into social and political life of a native habitat, foster leadership skills in youth as well as interest in decisions taken to make effect onto life of the communities, form environmental outlook and healthy lifestyle.

Dissemination of information on the Chernobyl disaster consequences to public is still the most efficient method for overcoming social and psychological problems. Informational, analytical, and educational activities of the Centres are aimed at identifying the key issues regarding general environmental situation in the region, socioeconomic processes, as well as public needs for the information about safe living within the radioactively contaminated areas. A top-priority of the Centres’ research activity are the following issues of ‘Chernobyl’: public attitudes towards various problems; level of awareness; psychological, social, and ecological aspects of life in the regions.

In order for the Centres to efficiently implement initiatives and programs, introduce advanced international techniques into the recovery processes and sustainable development of a strong psychological and social immunity among the affected population, the institutions collaborate with international organizations and programs, promote attraction of charitable funds to implementation of the projects targeted at socioeconomic recovery of the affected regions and improvement of the local life standard.

The Centres for rehabilitation demonstrated their highly efficient activity while helping all age brackets of people; disseminating information about opportunities for social risks mitigation among all interested groups; extending their activity to entire districts (rayons); facilitating formation of active communities in population centres that are targeted at overcoming their most pressing problems.

4.2.8. Social lessons learned from Chernobyl

Lesson 1. It is necessary to lay an anthropological concept for both prevention and overcoming of the disaster's consequences at the centre, i.e. an individual and a social community, being the absolute values of society and mankind in general, apply to the centre. Everything produced by mankind, starting with ideas, techniques, engineering, wars, services, etc., produces social impact, improvement and deterioration of people's life.

Lesson 2. It is necessary to give consideration to substantial differences, gaps, and discrepancies between subjective and objective assessments of risks. A provision for the following levels is to be made: academic (expert assessments), legal (regulations, standards), managerial (resources, capacities, staff), informational (completeness and topicality of information); everyday consciousness (the affected people's understanding and assessing their own status and the world around). Nothing but minimization of gaps between the levels produces the most efficient outcomes in terms of adequate actions aimed at surmounting the consequences.

Lesson 3. An almost complete oblivion of the destiny of hundreds of thousands of 'liquidators' is unacceptable, as they localized the accident and its consequences at the expense of their health, if not life. A recourse to the methods of overcoming a disaster using a tremendous number of people is unacceptable. It is necessary to train professional cohorts of liquidators in advance and move to an 'unmanned' surmount of accidents' consequences and reduce involvement of volunteers to a reasonable minimum.

Lesson 4. The society of 'Chernobyl' victims (2.6 million people) is in a state of social depression and social exclusion. Paternalistic orientations towards a governmental rent for the lost health and broken lives are increasing. It is a mistake to limit the social policy for eliminating the consequences exclusively to social assistance. Large-scale recovery activities are needed in order to return the affected individuals to active life.

Lesson 5. Long-term keeping of the affected communities in a state of information vacuum is unacceptable. It is necessary to continuously disseminate information about environmental conditions and ways of adequate behaviour and living; the information is to be recipient-oriented and specific.

Lesson 6. In contrast to the risk concept that causes fear, stress, and various 'social syndromes' in the affected people, it is necessary to increase productivity of a chance concept, i.e. focus on search for and implementation of efficient behavioural models and life activities in post-accidental situations.

Lesson 7. A leading role in the chance concept is to be given to the idea of social health and turn of consciousness towards the future.

Lesson 8. Regard is to be had to the fact that during a disaster and after it especially significant role is gained by subjective risks of a situation assessment, they are caused by a number of reasons, and lack of information especially. Exactly the subjective risks followed by affected individuals usually differ greatly from objective assessments. Distribution of complete, timely, and targeted information about the risks and chances usually helps affected people to return to an actual situation spacing and real behaviour.

Lesson 9. Keeping the Chernobyl-affected people in a 'stopped life' atmosphere for such a long time is unacceptable. It is necessary for a large-scale recovery and development program for the affected individuals and communities to become (although with a great delay) a 'roadmap' in overcoming social, sociocultural, and socioeconomic impact of the disaster.

Lesson 10. For all the activities aimed at recovery and development of the affected communities and areas an allowance is to be made for the nationwide trends of retargeting onto active models of behaviour and living activity.

Lesson 11. To overcome social consequences, it is necessary to consolidate all types of gnoseological potential (skills of innovative thinking and appropriate chance models finding): (a) *local*, i.e. leaders and volunteers in local communities; (b) *national*, i.e. multidisciplinary expert groups; (c) *international*, i.e. academic, governmental, and public.

Lesson 12. The international community has no right to forget the not yet surmounted social consequences of Chernobyl, fate of 2.6 million victims. The same as we remember fascism and the Holocaust. Ukraine is not able to solve social problems of Chernobyl independently.

Lesson 13. The monitoring that has been accomplished by the Institute of Sociology under NASU is unique, since unlike traditional techno-economic and ecological approach towards analysis of man-made accidents or disasters, the focus was put onto an individual and social community that are the main values of nation and mankind in general.

Lesson 14. Both for Ukraine and for the whole humanity, the Chernobyl has laid the foundation of a search for new post-accidental models of survival, i.e. a revolutionary change of axiological and normative system became archi-urgent.

Lesson 15. An exceptional priority of the anthropological concept is underpinned by recent events in the world. The U.S. officials were sure that the 'Iraqi problem' would be instantly solved by technics and tactics of the military industrial sector. Actually, the U.S. and their allies are subject to unpredictable social and sociocultural consequences and have no clear and constructive idea about their overcoming. The military doctrine has steeped in a multidimensional social space.

Therefore, the post-Chernobyl situation should be evaluated basing first of all on an extent of addressing social problems, on condition they are not merely narrowed down to social assistance (benefits, special payments, retired pays, etc.).

4.2.9. Nuclear power in Ukraine: attitude of Ukrainian people

The Chernobyl NPP has been shut down. Instead, the topicality of nuclear power development in Ukraine (NPU) is continuously present on the government task list. In spring 2009, a package of NPU issues was included into the Social Monitoring of the Institute of Sociology under NASU. Despite a residual fear of the Chernobyl accident consequences, the Ukrainian community votes affirmatively and in the main says 'yes' to NPU (the rating is 41%), including even radical approvals, i.e. 13% vote for NPU development and believe the Chernobyl NPP closure was a mistake. NPU is disapproved by the minority (33%). About half of the citizens (46%) think it is safe to live at a distance not less than 50 km from an operating NPP. Almost a third failed to give a definite answer. This was due to the lack of public awareness, which is confirmed by the fact that only 7% have enough or profound knowledge about safety of operating NPPs; 29% believe their knowledge is satisfactory, a quarter has only heard something in gossips and talks, and a third are unaware. Hence, knowing a level of people's trust to sources of information is important (Table 4.9). The most confidence regarding safety of operating NPPs people instil in radiology experts (43%), ecological organizations (39%), mass media (36%) and international monitoring agencies (31%); the less authority belongs to the management of NPPs and RAW storage facilities (14%).

While doubting safe living within an NPP area, people wish the following compensations for a risk of potential accidents: regular medical and preventive examinations – 64%; free health improvement and treatment at health resorts – 59%; monthly monetary payments – 48%; access to the information on a radiation situation – 22%; establishment of civilian control over the safety rules adherence – 18%. The majority of citizens (65%) would like none of their relatives to work at NPP; 12% of the respondents personally agree to work there; 21% of the population failed to give a definite answer.

Table 4.9.

Level of trust to the sources of information about operating NPPs' and RAW storage facilities' safety levels. Ukraine. 2009. 1800 questionnaires, %

Sources sought	%
Radiology experts	43
Ecological organizations	39
Mass media	36
International monitoring agencies	31
National monitoring agencies	21
Management of operating NPPs and RAW storage facilities	14
It's difficult to say	10

Note: the respondents have chosen up to three sources.

The conclusions. A somewhat unsure attitude of Ukrainian people towards nuclear power is driven by the stereotypical state of mind that has formed after the Chernobyl disaster, as well as untimely and occasional provision of information.

Consequently, further development of nuclear power in Ukraine may encounter a significant resistance in the society. The branch is still informationally closed, seems dangerous, and Ukrainians are still not prepared to active civilian control over its activities. Large-scale PR-campaigns are required to change a subjective perception of Ukrainian nuclear power facilities network's safety into the realistic one.

4.3. Dynamics analysis of the demographic, social, and psychological changes in society caused by the Chernobyl disaster aftermath and ways to overcome their negative development

Unfortunately, after 2007 the system for governmental accounting of the individuals affected by the Chernobyl disaster and provision of information on implementation of relevant programs was destroyed. The State Statistics Service has suspended publication of statistical data books on implementing the programs for elimination of the Chernobyl accident consequences. The authors had to make a considerable effort in order to gather the information required to develop this Section of the National Report.

The data summarized by us in Table 4.10 bear evidence of the fact that over the course of the past 25 years the Chernobyl disaster and its consequences have become a tragedy for Ukraine and many millions of its residents. Not all from among the affected people have got a medical servicing at medical and preventive treatment facilities under the MH of Ukraine.

Table 4.10.

Dynamics of a number of people exposed (affected) as a result of the Chernobyl disaster in Ukraine in 1987–2009, at the close of a reported year, individuals

Year	Quantity of the affected people (were under medical supervision*)	Quantity of citizens, who have obtained the status of 'affected' **
1	2	3
1987	264587	Recording was started in 1994
1988	256849	
1989	320459	
1990	347252	
1995	2744226	3092958
2000	2608354	3278521
2005	2342207	2526216
2009	2238334	2254471

* – as per the data from the state statistical reports, forms 2-TsDN, 15, 16,
** – as per the data from the state statistical reports, form 7 (Chernobyl).

As of 01 January 2010, a quantity of the affected people in Ukraine amounts to 2254471 individuals. Over 2.15 million of the victims, i.e. 95.4% of the total amount, still have to live within a radioactively contaminated area (Table 4.11). More than 164 thousand people left RCA over a whole post-disaster period.

Table 4.11.

Quantity of affected people living within RCA, individuals, as of 01 January 2009

Category of the affected people		**Of which children aged 0-14**	**Including children under 1 year**
All victims	2151811	373846	27541
Of which in the zones: exclusion zone	117	-	-
absolute (mandatory) resettlement	4548	1026	78
guaranteed voluntary resettlement	612080	131358	9611
Enhanced radioecology monitoring	1535066	241462	17852

Source: data from the State Statistics Service of Ukraine.

Table 4.12.

Distribution of population residing within the radioactively contaminated areas and subject to an extra irradiation dose exceeding 0.5 mSv/year, as of 2009

Average annual dose, mSv	**Total number, individuals**	**Children under 18, individuals**
≥ 5	986	319
1 – < 5	135621	32758
0.5 – < 1	179874	54909
Total	317467	87986

In consequence of socioeconomic changes and crises, all conditions of life, labour, nutrition, and medical services in the population centres within RCA do not fully correspond to the modern standards. As of 2009 (as demonstrated by the data in Table 4.12), 317 467 individuals, including 87 986 children under 18, are still exposed to the doses exceeding 0.5 mSv/year.

4.3.1. Demographic changes in Ukraine and within the radioactively contaminated areas

During the period of 1991–2009, Ukraine lost almost 6.5 million people as a result of the nationwide demographic crisis. Over the last years, the demographic situation in the worst affected regions (the Zhytomyr Oblast and the Kyiv Oblast) has not differed markedly from the national markers. For instance, in 2000–2009 the birth rate was even slightly higher there (Figure 4.2 4.1). However, the mortality rate was also higher: whereas its average level in Ukraine in 2000–2009 amounted to 15.9 ‰, in the Zhytomyr Oblast it was 17.7 ‰ and in the Kyiv Oblast it amounted to 17.4 ‰. The differences between the markers of 2004–2009 is statistically valid (Ukraine – 16.13±0.19, the Zhytomyr Oblast – 18.17±0.24, t=6.72, the Kyiv Oblast – 17.73±0.23, t=5.47).

An increased birth rate was registered in zones II and III in 1992–1999. It was at the time when the affected people have been most actively resettling to clean areas. We believe, the increase was related to their wish of having benefits when getting residential space and jobs at the places of immigration. Analysis of the population death rate outside the radioactive contamination zones revealed (Figure 4.4.) that mortality levels depend on a category of radioactive contamination zone and a level of legally regulated average individual exposure dose.

During the post-disaster years, the demographic crisis within RCA has worsened significantly. In early 90^{th}, reproductivity of population within RCA was negative low (zone II – 5.6 ‰, zone III – 6.0 ‰, zone IV – 9.1 ‰); and since 2006 it became catastrophic negative (zone II – 20.6 ‰, zone III – 14.0 ‰, zone IV – 21.5 ‰). Over 18 years (1986-2003), the total demographic loss within the radioactively contaminated areas amounted to 48.8 thousand people. The net population loss was formed due to 25.2 thousand of unborn and excess (6.9 thousand) of died people. Level of loss in unborn children per 1000 women of childbearing age increased from 8 people in 1986 up to 76 in 2001, i.e. 9.5 fold, and in a whole post-accident period this level amounts to 41,1 ‰. The rate of loss in children unborn by women aged 15-49 in the monitored region was equal to the national level, and in 1986-2003 its value was 14.2 ‰, which is three-fold lower than within RCT.

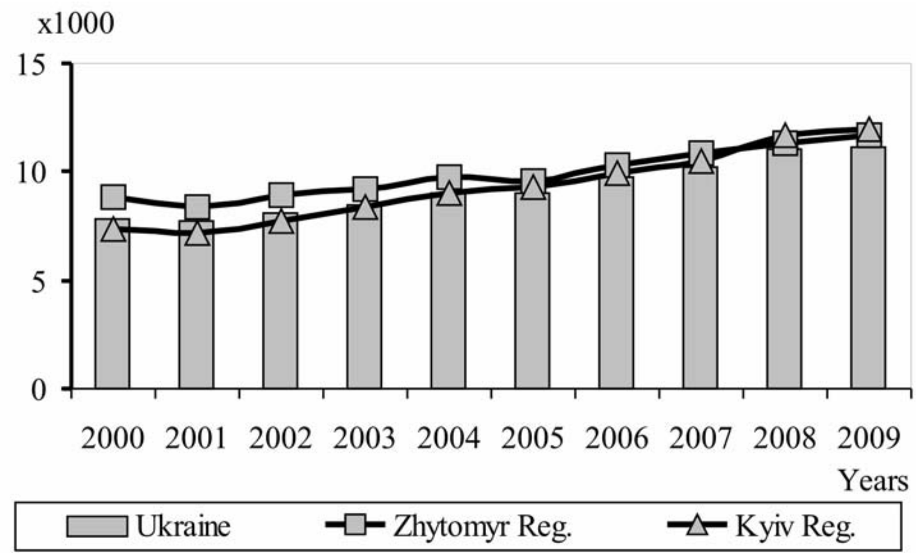


Fig. 4.2. *Birth rate in Ukraine, in the Zhytomyr and Kyiv Oblasts in 2000-2009, per 1 000 people.*

In 1991–2005, the loss of population within the contaminated areas was greater than in their location regions. In accordance with our calculations, in 1991–2000 52–98 % of the civilian loss within zones II and III was caused by migration outflow of people (a regulated and voluntary resettlement). And in subsequent years, the main factor was the predominance of deaths over births (Figure 4.3).

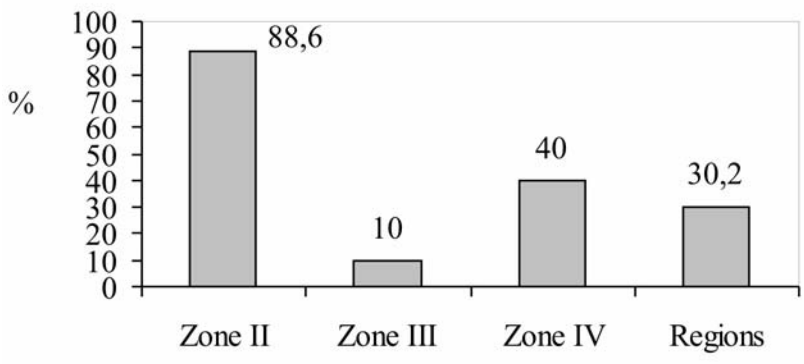


Fig. 4.3. *Loss of population in 1991-2005 in relation to a radioactive contamination zone category, %*

The demographic loss in population within the worst radioactively contaminated regions is also formed because childbearing is usually put off by fertile women. The most significant contribution to the total loss of unborn children was made by the children not born by women aged 20–29.

In 1986–2003 as compared to 1979, the population loss linked to supermortality increased everywhere through all main types of death causes. The biggest waste of population was formed out of the losses caused by non-neoplastic somatic pathology that preconditioned about 40.0% of female and almost 24.0% of male deaths. The next (in order of relevance) death type belongs to neoformations; it has caused 35.1 % of the losses as compared to only 15.9 % of such losses nationwide. A considerable part of the human loss caused by neoformations is formed out of 45–75 year old age groups, which contributes to ageing of population. External death causes form 20% of the affected individuals. Especially in the employable age and in 60–64 year old age group.

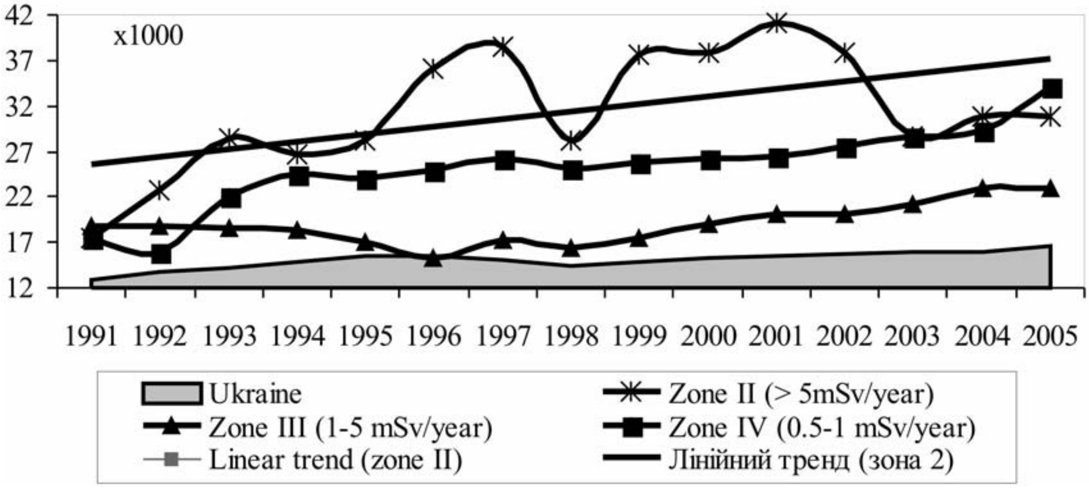


Fig. 4.4. *Population death rate depending on a category of a radioactive contamination zone and a level of legally regulated average individual exposure dose in 1991-2006, per 1000 people.*

In accordance with the component analysis data, the contribution of non-neoplastic pathology to RALE (reduction in anticipated life expectancy) changes formation was ranging between 45 and 65 %, the input of neoformations was 10–25 %, external causes – 10–45 %, depending on sex, area, and period of survey. During 1996–2000, the contribution of neoformations to RALE change reduced almost twice as compared to 1991–1995. However, the contribution of somatic pathology increased 1.2–1.3 times. The sharpest (over 85 %) reduction in life expectancy was due to deaths of people aged 15–59. The disorders in organs and systems, which have formed in the previous years, later, since 1991, started to demonstrate themselves by an increased general mortality of population and child morbidity within the worst affected areas (Figure 4.5).

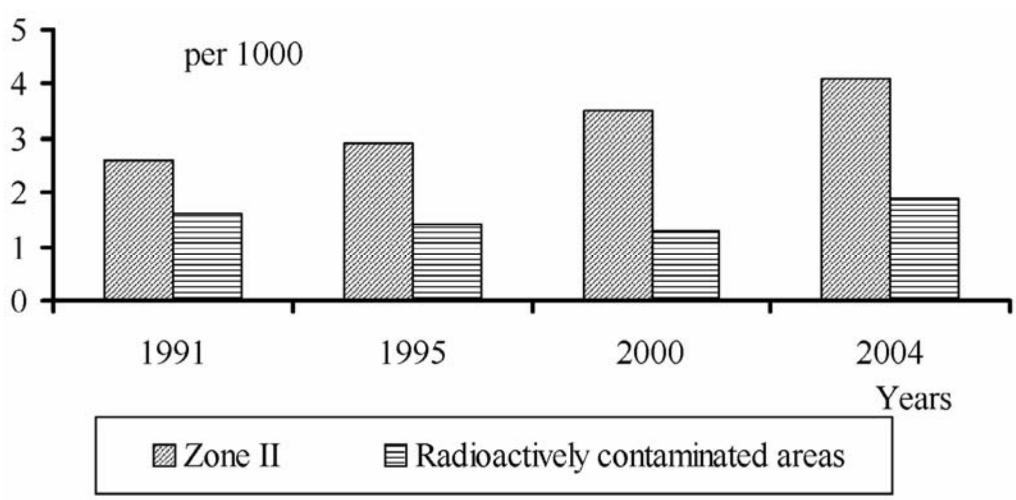


Fig. 4.5. *Morbidity of children aged 0-14 and residing within zone II and radioactively contaminated areas, per 1000 children.*

An increased infant morbidity rate is still present within the contaminated areas, and first of all it is stipulated by respiratory system diseases, conditions emerging during prenatal life, and congenital abnormalities. Thus, the data obtained afford grounds to believe that the exposure preconditions not only an increased rate of infant morbidity, but also a change in the structure of its causes.

4.3.2. Ways to overcome negative developments of demographic, social and psychological changes in the society caused by the Chernobyl disaster aftermath

The areas of radiation hazard (zones I and II) has formed within a radius of 100 km around ChNPP and still exist in Ukraine, in 25 years after the Chernobyl accident. Inhabitation of people as well as getting of agricultural and other products and foodstuffs, which meet nationally accepted standards, are impossible there. Due to the disaster and its consequences, the so-called ecological migration has emerged. Complete abandonment of the two cities and over a hundred villages; irreversible degradation of at least 67 villages, one city, and three towns; accelerated degradation of about a thousand villages located in the northern part of the Zhytomyr and Kyiv Oblasts and in the western part of the Chernihiv Oblast form a significant negative impact of the catastrophe. Moreover, as far as radiation factor is concerned, in 25 years the pre-accident conditions of life were renewed in none of 2 293 centres of population that were approved as ‘radioactively contaminated’ in 1991. During the post-accident years, a typical feature of the worst affected areas has become the increased morbidity rate resulting from chronic radiation effects and basically caused by somatic pathology depending on the levels of contamination and exposure. This regularity is distinctive both at the oblast (province) level and at the rayon (district) one. Taken together, these factors have resulted in heavier demographic loss, reduced vitality and life expectancy of RCA inhabitants, if compared to the entire country.

In order to improve demographic situation within RCA as far as radioactive contamination and public exposure doses are concerned, it is necessary to create the radiation conditions that would meet national safety criteria. Recovery of radioactively contaminated population centres has been envisaged by the activities for the catastrophe consequences elimination in Ukraine for many years already. However, this activity was implemented in none of them.

The main effort is to be targeted at preventing morbidity of people of employable age and older, inclusive of males. While developing the migration policy, it is also necessary to take account of the existing radiation conditions and levels of anticipated exposure doses.

Under the existing socioeconomic conditions and as a result of ionizing radiation effects, health of ACE (accident consequences elimination) participants is being deteriorated. As far as death rate is concerned, they rank next to RCA residents. Common for both groups of the affected individuals are the excess mortality and increased death rate caused by the diseases of blood circulatory system and digestive apparatus. Therefore, an improved medical support to the affected people, that is treatment and diagnostic work to prevent chronic illnesses and reduce morbidity, is to become the next crucial trend in time-distant activities for eliminating the disaster consequences.

4.4. Nuclear and radiation risks as percepted by Ukrainian people and implementation of the risk reduction methods into everyday life of Ukrainians

The reality situation of the affected individuals was characterized by an increased radioecology risk, which overall effect on people is still to be determined. Going through situations of an elevated risk evokes anxiety, uncertainty of the future, fear for one’s own health and health of children. Most everyone among the affected individuals has a low level of tolerance for enduring uncertainty, the latter causes their disadaptation, i.e. reduced ability to independently renew normal daily living activities. Therefore, the affected people have fewer chances to withstand risks, no matter what risks lie at the root of assessing a situation, whether objective or subjective ones. A risk level depends on the awareness about actual everyday conditions and ways of their improvement, which is connected with an opportunity to find contextual and future-oriented chances for constructing current and future life.

Improving a standard of knowledge about actual nuclear and radioecology risks is still an urgent problem for the affected individuals, since they need to be guided by objective versus subjective assessments of the post-Chernobyl conditions. Nowadays, the instruments to define objective nuclear and radiation risks have been developed and clearly formulated in science and practice; i.e. a hazard level for both the environment at large and public health in particular is estimated depending on actual data on environmental conditions. However, apart from objective assessments, people are also prone to have a purely subjective perception of a situation, which forms the subjective risk.

Usually, an individual feels socially and psychologically uncomfortable in a radiation hazard environment. The malaise is due to the post-accidental emotional shock, as any negative impact of external factors 'spoils' the well-being of subjects. However, effects of radiation exposure particularly differ from other negative impacts. Until a certain edge, an individual does not physically and mentally feel radiation effects in such a way as he feels, for instance, cold or heat, light or noise. Then why the fact that the Chernobyl disaster has produced extremely severe negative consequences in terms of deteriorating social and psychological well-being of the affected people and doing general harm to social health is given such a great importance? Firstly, an accident-caused trauma; secondly, a long-term stay of a large number of people in the post-accident reservation; thirdly, the long-term effects of low-dose radiation.

Most people's assessments of the world around are based not on scientific knowledge, but on instinctive and subjective judgments about what is safe and acceptable and what is dangerous and should be better avoided. These very subjective judgments form social and psychological feeling of people. And if a life goes wrong, then depression and dejection are formed even though a physical health is good.

The social subjective risks are caused primarily by an extent of affected individuals' capability to cope with the problems of everyday life (Table 4.13). Significant is the fact that 97% of the affected people in 30-km zone have coped with their everyday problems in the best way, while 78% was the value for zone II and 85% were among the 'clean' ones. A tenth (11%) of self-settlers within 30-km zone live a full life and overcome all their problems. Instead, the relative values are: 7% for zone II and 5% for 'clean' areas. However, there are a lot more people, who are 'just surviving' or are 'driven to despair'; 62% within 30-km zone, 43% in zone II, and 50% among the 'clean' ones. Thus, the country is totally impoverished and hapless. The share of those completely or partially coping with their problems is equal in all the three groups, i.e. 35% in each.

Table 4.13.

Breakdown of answers to the question: 'Characterize your present life'. Victims of the Chernobyl catastrophe. 2001. 1200 questionnaires, %

Characteristics of life	Affected zone		'Clean' areas
	Zone I	Zone II	
Live a full life, cope with all problems	11	7	5
Not always cope with hardships and difficulties	24	28	30
Not live, but survive	57	40	46
Driven to despair	5	3	4
It is difficult to say	3	22	15
Total	100	100	100

Fear-risks (Table 4.14). The fear of a recurrent accident at the ChNPP has been discarded by history, since the NPP is not in operation for a long time already. Surprising is the fact that 'Chernobyl' people are less afraid of an incurable severe disease (48%) than the 'clean' ones (54%), and significantly less is the fear of people living in Zakarpattia, the value is only 31%. Naturally, the fear of a natural disaster worries residents of Zakarpattia 1.5-fold more than others; 34 versus 2–22%. Within 'clean' areas the level of anxiety to impoverish down to a beggar is significantly higher (26%), if compared to the affected zones (12–18%). Just the same refers to a loss of job, 28% versus 6–12%. Anxiety causes risks, which have the following probability (according to self-evaluations of people affected by the Chernobyl disaster): (a) related to a threatening environment – 0.81; (b) related to health of children – 0.70; (c) related to social life – 0.68; (d) related to industrial activity – 0.57; (e) related to family environment – 0.44.

Table 4.14.

Breakdown of answers to the question: 'What are you most afraid to suffer from?' Victims of the Chernobyl catastrophe and victims of disasters in Zakarpattia (Transcarpathian region). 2001. 1200 questionnaires, %

		Zones I and II Victims of the accident	**Victims of ecological disasters in Zakarpattia**	**Residents of 'clean' areas**
1.	Repeated accident at the Chernobyl NPP	59	14	19
2.	Incurable severe disease	48	31	54
3.	Accident at a Ukrainian NPP	24	18	19
4.	Natural disaster	22	34	20
5.	Accident at the Shelter of Chernobyl NPP Unit 4	18	6	5
6.	Impoverishment down to a beggar	12	18	26
7.	Loss of job	12	6	28
8.	Crime and hooliganism	10	5	15
9.	Transport accident	7	9	11
10.	Employment injury	5	8	7
11.	Mushroom, etc. poisoning	2	1	1

The so-called 'syndrome of a victim' is among the most considerable factors that form subjective risks of the affected individuals. Its significance was intensified by speculations of politicians, as well as by mass media that could sometimes have presented information that was not verified or not confirmed by expert conclusions against the background of the state's poor economic development, unstable political environment, and deterioration of public health caused by the Chernobyl accident consequences, crises, changes of power, and other factors.

In 2007, the affected individuals identified the negative factors that, in their eyes, produced the most considerable health effects: consequences of the Chernobyl accident gained 58%; impoverishment of a family – 38%; ecological situation – 30%. Therewith, it is remarkable that the affected people attribute very low rates to the factors that really produce a significant negative impact on human health: quality of food – 22%; unhealthy lifestyle – 16%, smoking – 14%, harmful work environment – 13%, and drinking alcohol – 8%. Thus, while analyzing a social impact produced by the Chernobyl disaster aftermath, it is necessary to juxtapose objective and subjective risks and clear out which ones take priority in addressing specific problems of the post-Chernobyl situation.

Exposure of the affected people's consciousness, as well as the consciousness of the entire Ukrainian nation, to risks depends on formation and further enhancement of radiological safety culture in administrative, industrial, technical or nationwide context, i.e. generally, in a broad social sense. Everyday, routine ability to resist negatives stipulates efficiency of the safety culture. It is facilitation of access to professional services and resources (medical, educational, informational, industrial, economic, administrative) as well as individual learning of safety rules that considerably reduce a level of subjective risks.

As per medical expert assessments, a reduction in illness risk is possible due to the following: (a) early diagnostics and timely treatment; health improvement and psychological adjustment; (b) full value nutrition; (c) mastering of methods for health self-improvement, disease prevention, adherence to a healthy lifestyle.

Economic, material, and professional risk factors are to be reduced by way of consolidating power, local self-government, and business structures; implementation of efficient radiology-safe practices and management techniques; improvement of dosimetry and radioecology monitoring; development of radiology-safe production methods; training in safe conduct and operations within radioactively contaminated areas, etc.

As far as education is concerned, it is proposed to introduce training in radiological risk prevention, methods for health improvement and disease prevention, safe conduct within contaminated areas, psychological adjustment, self-maintenance, etc. into pre-school and school educational programs, as well as into the trainings for future mothers, families with infants.

Crucially important are the methods of day-to-day, particularly symbolic, ‘transformation’ of the disaster’s negatives into human potential positives based on scope of knowledge, skills, feelings, and experience. Extremely efficient is increasing a capacity for recovering competence in and culture of everyday radiological safety and transmitting them to others.

Current tasks of the policy for *shaping and improvement of radiological safety culture* are within the following directions:

- Review of legal basis towards activation of social position in the affected individuals, rendering professional and vocational assistance, while increasing the chances for rehabilitation and recovery.
- Enhancement of educational and informational activity with all with all strata of the affected people, while providing personnel and resources.

For a successful implementation of these tasks, the great experience and colossal scope of knowledge accumulated by the experts in ‘Chernobyl’ issues are to be applied.

4.5. Implementing recommendations of UN Chernobyl Forum in Ukraine: accomplishment of the projects for recovery and development of the affected areas and communities

Promotion of sociocultural and socioeconomic activity was determined as a priority in overcoming the Chernobyl disaster consequences both on the international level in the United Nations Resolution on sustainable development in the report ‘The Human Consequences of the Chernobyl Nuclear Accident. A Strategy for Recovery’ and in the national policy of Ukraine, particularly in the National Program for Minimization of the Chernobyl Disaster Consequences during 2006–2010 and in the Chernobyl Forum’s profound scientific report, titled ‘Chernobyl’s Legacy: Health, Environmental, and Socioeconomic Impacts’.

The Chernobyl accident caused a number of factors that had a negative impact onto socioeconomic activity, including family and medium business development. The following are among them: (a) *Radioactive contamination,* rural areas were mostly affected, as small and medium business is based on agriculture there, and most part of farm units ceased to exist as a result of the Chernobyl disaster; (b) *Demographic structure of population,* large-scale migration of people, low birth and high death rates, ageing in the affected areas, and consequent reduction in potential staffing for small and medium business; (c) Inactivity related to the so-called ‘syndrome of a victim’; (d) Limited access to information, rights, and opportunities with regard to running a private business, etc.

According to recommendations of the UN Chernobyl Forum, the following is to be done to address the above problems:

1. Facilitate recovery of social units that have been ruined or lost as a result of the evacuation, resettlement, and collapse of the Soviet Union by way of social interaction improvement and development of community initiatives and economic projects in cities and villages;
2. Promote establishment and advanced development of small and medium enterprises, particularly agricultural and food ones, notwithstanding their ownership pattern, with the objective to recover an estimable management and surmount poverty;
3. In every possible way contribute to the development of specific eco-tourism and conservation of biodiversity in the Polissia region.

In late 2002, a joint project of UNDP and the Ministry for Emergencies of Ukraine, titled ‘Chernobyl Recovery and Development Program (CRDP)’, was launched to provide assistance to the government of Ukraine in implementing innovative and efficient approaches to comprehensive overcoming of the socio-psychological and economic problems. The CRDP objective is to involve people into independent solving of problems of their habitats by recovering social units in the affected centres of population, forming people's skills in independent identification and addressing of a problem, gaining self-government experience; all the abovementioned activities would promote advanced life standard of the affected people.

During 2002–2009, 279 community organizations were setup and are operating in 192 villages of the affected areas through implementation of the principle 'Community and Power: Recovery and Development Partners'. The community includes over 20 thousand individuals, who have implemented 190 socioeconomic initiatives under the CRDP support (reconstruction of water piping, schools, washhouses, first-aid and ambulance stations; ensuring gas supply; establishment of youth, civil, household, and service centres), etc.

To implement a project, the community had to establish partnership relations with local governance, representatives of rayon and oblast (province and district) administrations, and local businessmen. It is noteworthy that exactly private entrepreneurs and businessmen play an important role in community projects implementation. The CRDP experience demonstrated high activity of businessmen in accomplishing community initiatives. In particular, with total cost of the community projects exceeding UAH 18 million, over UAH 2 million, or approximately 9%, were contributed by local sponsors. On average, financial support of the projects consists of the following: up to 17% were contributed by a community independently, ~ 40% by local authorities, ~ 30% by CRDP. The community projects had a great effect in getting access to improved servicing and life standard; consequently, about 200 thousand people have got benefits from the accomplished community projects.

Some initiatives of the community were targeted at small servicing businesses establishment. For instance, in 2006 the Prometheus Community setup a service and household centre offering a wide range of services in the village of Cherepyn in Ovruch Rayon. Six people found their jobs in the centre, some of them were previously unemployed. After the success, in 2008the Prometheus Community decided to implement another economic project, i.e. start of the Cattle Insemination Centre.

Within the framework of the SRDP project, during 2002–2009 the communities established 3 service centres and 40 youth and public centres, which are operating as social enterprises. The community development initiatives not only produce economic effects but also surmount poverty. Built on trust, critical thinking, and joint activities, the community development process ensures exerting control over personal life, ability to overcome personal fears and surmount everyday problems. Moreover, it is the control over your own life that is an essential precondition for a private business establishment.

With the objective to address the problem, CRDP facilitated setup of a network that includes 7 economic development agencies in the four worst affected oblasts (provinces): three in the Zhytomyr Oblast (Brusyliv, Korosten, Ovruch); two in the Kyiv Oblast (Borodyanka and Ivankiv); one in the Rivne Oblast (Dubrovytsia) and one in the Chernihiv Oblast (Ripky). The agency is an institution for competitive advantages build-up, investment attraction, and rendering other informational and methodical assistance to regional businessmen. To undertake their mission, the agencies have qualified personnel and up-to-date technical facilities; on a daily basis they provide consultations to private entrepreneurs and individuals, who plan to establish their own business. Unfortunately, as of 2010, a large part of the affected areas did not have access to the Internet, which is constraining their search initiatives.

The Chernobyl Forum also recommends another prospective direction of small and medium business, i.e. green tourism development. Traditionally, Polissia was a recreation and relaxation area. In 2009 and 2010, a review of green tourism initiatives was accomplished within the affected localities of the Rivne and Chernihiv Oblasts, it revealed that many owners of green tourism homesteads have purposely created them to improve an economic climate in the family, with no view of business development prospective. In addition, there is a need in initial capital.

Establishment and running of a family business are also complicated by a lack of the legal basis that deprives entrepreneurs of economic and social protection and notwithstanding a high unemployment level greatly limits a scope of volunteers. In particular, a poll in the three worst affected districts (rayons) of the Rivne Oblast demonstrated that 36% of respondents consider it necessary to create jobs in the nearest future; at the same time, only 4–5% wish to establish their own business under the existing complicated and uncertain conditions. This factor is twice as low as the national one amounting to 8%.

Small and medium business development shall facilitate improvement of the economic situation within the affected areas and will be able to partially address the problem of employment. Presently business initiatives however are rather pilot projects than a systematic approach to addressing the problem. To fully use a business development potential, it is necessary to update a legislative basis for small and family business, improve dissemination of information about business development opportunities among people, and enhance the procedure for a private business establishment, render consultation services to the individuals, who have already started or plan to start their own business.

By its resolution of 20 November 2007, the United Nations General Assembly has again confirmed that the Chernobyl disaster has caused significant social, psychological, and economic consequences.

5. SHELTER OBJECT CONVERSION INTO AN ECOLOGICALLY SAFE SYSTEM AND DECOMMISSIONING OF THE CHERNOBYL NPP

5.1. Shelter Object conversion strategy

Major principles, purpose and strategic areas of activities related to the Shelter Object (SO) conversion into an ecologically safe system for the first time were established in the ‘Strategy of the Shelter Object Conversion’ developed in 1997.

In view of the main results of the first stage of the Shelter Implementation Plan (SIP) the ‘Strategy of the Shelter Object Conversion’ was refined and approved by decision of the Inter-Agency Committee for Comprehensive Resolution of Chernobyl NPP Problems dated 12 March 2001.

Universally recognized basic principles and objective concepts of safety reflected in the requirements of the effective safety norms, regulations and standards were taken as a basis for the subject Strategy.

The Strategy established the following three basic stages of the Shelter Object conversion into an ecologically safe system:

- **Stage 1** – stabilization of the state of the existing facility, enhancement of operation reliability and durability of the structures and systems ensuring stabilization and monitoring of the Shelter’s safety performance.
- **Stage 2** – construction of additional protective barriers, primarily the confinement, that provide conditions required for technical efforts of Stage 3 and ensure safety of personnel, public and environment, preparatory engineering and technical activities aimed at developing process of fuel containing materials removal from the SO during stage 3, arrangement of the infrastructure for Shelter Object radwaste management.
- **Stage 3** – removal of fuel containing materials and long-lived RAW from the SO, their conditioning and further storage and disposal in radwaste storage facilities in accordance with the effective standards, decommissioning of the Shelter Object.

Major part of the works planned for Stage 1 and 2 is being performed under the SIP. Furthermore, part of the efforts planned for Stage 1 has been already completed. In particular, the above is related to modernization of the dust suppression system and engineering structures stabilization. The work on creation of the Integrated Automated Monitoring System is nearing completion. The New Safe Confinement (NSC) is being designed, and when constructed it will create preconditions for implementation of further plans related to SO conversion into an ecologically safe system.

5.1.1. Current status of Shelter Object nuclear and radiation safety

Radiation and nuclear hazardous materials inside the Shelter Object

Varieties of nuclear fuel formed during the active stage of the accident are currently in the Shelter Object.

There are three varieties of fuel containing materials (FCM), containing the bulk of irradiated nuclear fuel (INF): fragments of the reactor core (FRC), fuel particles (fuel dust) and lava-like fuel containing materials (LFCM).

Most of them are found in the central hall and premise 305/2 under the reactor (fig. 5.1 look the coloured inset).

Significant part of SNF got into the reactor vessel and premise 305/2 under the reactor, where conditions for fuel heating up to high temperatures were created. Fuel fragments entered into reaction with structural materials: zirconium, metalwork, serpentinite filling of biological protection, sand, concrete and formed high-level lava-like fuel containing materials (LFCM).

LFCM spread over the premises, corridors, cable passages and other free channels and, when hardened, formed accumulations of their varieties (fig. 5.2 look the coloured inset) at different elevations of the destroyed ChNPP Unit 4.

LFCM may contain up to 130t of uranium INF [1], and significant part of radionuclides generated in the reactor. Therefore, LFCM still present the main source of nuclear, radiation and radio-ecological hazard.

Assessment of the overall nuclear fuel amount that remained in destroyed Unit 4 was based on studies on radiation fall-out [2], and now it gives grounds to consider the matter that about 95% of nuclear fuel of the initial reactor loading are in the Shelter Object.

Table 5.1.

Specific activity ratings for generated radionuclides located in Shelter Object premises as of the end of 2010, Bq/g of uranium

Alpha-emitters	Beta-emitters	Beta-gamma-emitters
$^{238}Pu – 6.41 • 10^6$	$^{90}Sr – 6.63 • 10^8$	$^{106}Rh – 2.86 • 10^4$
$^{239}Pu – 5.0 • 10^6$	$^{90}Y – 6.63 • 10^8$	$^{125}Sb – 1.75 • 10^5$
$^{240}Pu – 8.18 • 10^6$	$^{106}Ru – 2.86 • 10^2$	$^{134}Cs – 2.43 • 10^5$
$^{241}Pu – 2.30 • 10^4$	$^{147}Pm – 6.00 • 10^6$	$^{137}Cs – 7.98 • 10^8$
$^{242}Pu – 1.30 • 10^4$	$^{241}Pu – 2.97 • 10^8$	$^{144}Ce – 8.15$
$^{241}Am – 2.24 • 10^7$		$^{154}Eu – 1.05 • 10^7$
$^{243}Am – 5.15 • 10^3$		$^{155}Eu – 2.04 • 10^6$
$^{244}Cm – 8.65 • 10^5$		
Total ~ $2.5 • 10^{12}$ Bq/g of uranium		

Consequently, total activity of the radionuclides in the Shelter Object currently makes up approximately $4.8 • 10^{17}$ Bq.

Recent investigations on refinement of LFCM accumulations geometry and spatial arrangement [3] have shown that there are two areas at top elevations of ChNPP Unit 4 in the vicinity of biological protection system ‘E’, where LFCM accumulation can be found (fig. 5.3 look the coloured inset).

Calculation results analysis have shown that minimal amount of LFCM (1 t of UO_2) at the top elevations of the destroyed Unit 4 is no less than 15t. This fact must be considered while developing strategies of INF removal from the Central Hall, and in construction of the New Safe Confinement and in the course of further activities on the Shelter Object conversion into an ecologically safe system.

The experimental data analysis [4] suggests that high-uranium FCM accumulations are located in the south-east part of premise 305/2 (near the gap opening into premise 304/3), as well as in the vicinity of the burn-through towards premise 307/2 (fig. 5.4 look the coloured inset) [5].

Detailed investigations allowed considering LFCM generation scenario from a new angle. Fuel channels failure, fuel meltdown and dispersion in the south-east quarter of the reactor core resulted in depressurization of the reactor space. Pressure pulse lowered the reactor support (Scheme ‘OP’) by 3.85 m, blew off and raised the biological protection system (Scheme ‘E’) weighting more that 3000 tons.

The process had the nature of a powerful dynamic pulse. The reactor support sank. The fuel melt thereafter flew in the open space towards the south-east part of the wall of premise 305/2 and the gap between the reactor support and biological protection tank (Scheme ‘Л’).

Detonation of steam-hydrogen mixture resulted in the south-east quadrant of premise 305/2 filled with fragments of the destroyed reactor core. Consequently, reactor core fragments formed the ‘furnace’ configuration. Its burden was presented by the following constituents: 'sinter' (zirconium, zirconium dioxide, uranium dioxide, metal); 'coke' (graphite blocks, rings, plugs); 'cindery fluxes' (serpentinite, filling of expansion joints and installed clearances) [6]. First, all the 'burden' components were heated to a high temperature, and from below were heated by its melt, which gradually melted through the sub-reactor plate's concrete.

The 'burden' subsided gradually with materials consumption, and the 'sinter' ran out through the opening in the wall between premises 305/2 and 304/3, and formed horizontal stream of the black LFCM. Furthermore, fuel concentration grew gradually due to the settlement of fuel inclusions of the 'burden' and formed the three-layer composition: 'sinter' (LFCM), fuel and metal (fig. 5.5).

The top layer down to elevation 9.7 m is presented by uranium-poor black LFCM (congealed solution of light oxides). The bottom layer is formed by high-ruthenium metal. The intermediate layer (congealed solution of heavy oxides) with uranium concentration exceeding 50 % forms accumulations of fuel containing materials, composition and structure of it is unknown due to absence of access to them.

Table 5.2.

Expert assessments of LFCM distribution in build-up of premise 305/2

Premise	FCM accumulation, elevations	Properties of FCM in accumulation	FCM amount m^3	Uranium fuel amount, t
305/2	No.1 – elevation +8.400 – +11.000	Black LFCM, FRC	150 – 180	36 ± 12
	No.2 – elevation +9.000 – +11.000	Brown and black LFCM, FRC are possible	80 – 100	25 ± 6
	No.3 – elevation +11.000 – +13.500	LFCM, burden, FRC	5 – 10	3 ± 2
305/2 and 504/2	No.4 – elevation +11.000 – +16.500	Loose FCM	40 – 60	3.5 ± 2
	No.5 – eevation +11.000 – +24.000	LFCM, burden, FRC, loose FCM	70 – 100	12 ± 7
	No. 6 – elevation +16.000 – +24.000	Stalactite- LFCM	0.7 – 1.4	0.2 ± 0.1
305/2	No.7 – elevation +9.700	LFCM	Up to 20	Up to 1.5

The meltdown zone is currently filled with water, the level of which is at elevation 9.1 m. The location of meltdown resultant from interaction of fuel with concrete was proven by results of experiments carried out under the international project CORPHAD.2 [7]. Such scenario may help to explain growth of intensity of fission products release into the atmosphere in 1986 on the sixth day of the accident. This could be related to thinning and subsequent disappearance of the so called 'burden' layer. Fission products release reduced drastically on the tenth day, when meltdown surface congealed and precluded further release of fission products from the melting zone into the atmosphere.

In 2010 based on new design data and analyses of the processes that took place in premise 305/2 at the stage of Chernobyl lavas formation and spreading, expert assessment of nuclear fuel distribution in this premise was done.

The assessment was done for 7 separate representative zones [5]. Overall amount of the irradiated nuclear fuel located in premise 305/2, according to the completed assessment, is 80 ± 30t (uranium). The expert assessments of LFCM distribution in build-up of premise 305/2 are presented in Table 5.2.

The information on condition, behaviour forecast and location of radiation and nuclear hazardous materials within the Shelter Object enables to assess nuclear, radiation and radioecological hazard of the Shelter Object and develop optimal solutions while converting the Shelter Object into an ecologically safe system.

Shelter Object nuclear safety

On 19 June 1990 neutron activity growth was registered in SO premise 304/3 [8]. Drastic growth began on 29 June and reached 60-times increase as against the background.

Detailed investigation of incident triggers and development factors showed that the neutron anomaly concurred with the period, when precipitations water was intensively penetrating into the hot (over 100^{o}C) porous structure of this accumulation (fig. 5.6.) [9].

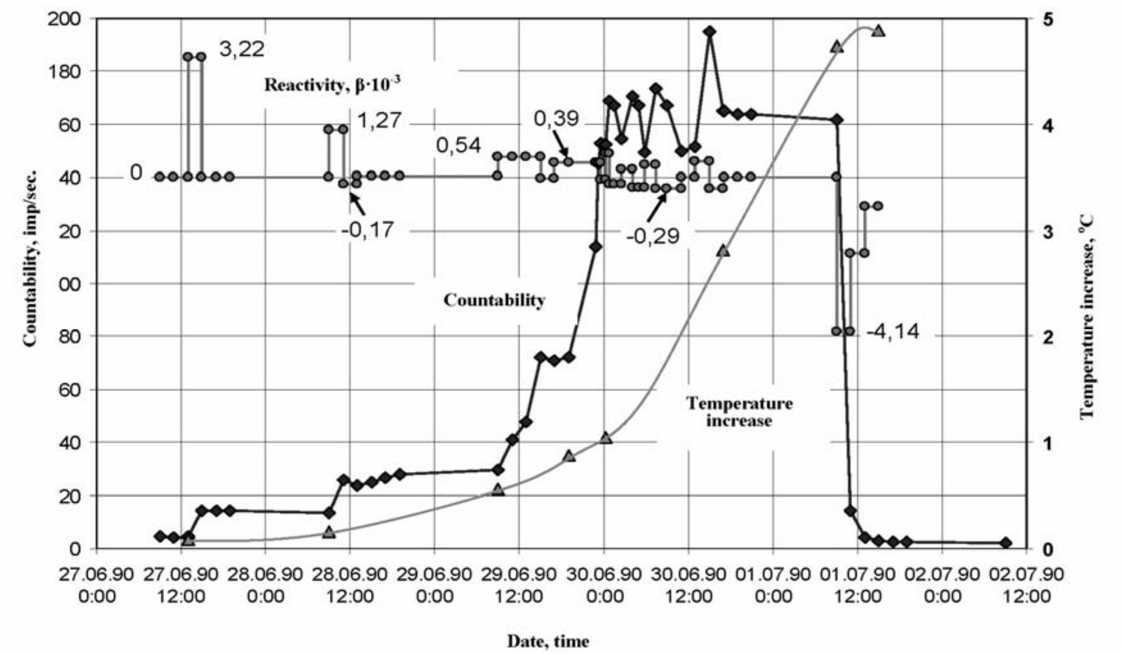


Fig. 5.6. *Critical incident in 1990.*
Diagram of neutron activity in SO premise 304/3.

At the power acceleration stages, during each power leap the accumulation reached supercriticality at positive reactivity the value of which depended on current fuel temperature. The power excursion stopped when amount of water in the accumulation exceeded the amount of optimal damping. Rise of the water front resulted in negative reactivity, and further water ingress lead to accumulation return to the subcriticality.

Long-term monitoring of temperature and neutron activity dynamics has demonstrated high probability of presence of FCM accumulation with high (over 40%) concentration of nuclear fuel in premise 305/2.

Systematisation of temperature measurements data enabled building of isothermal cartogram for foundation slab of this premise and obvious demonstration of presence of 2 zones of intensive heat release in premise 305/2 (fig.5.7.) [5].

Water of temperature exceeding the one of surrounding concrete is permanently observed in wells in the vicinity of zone 1. High temperature gradient between zone 1 and sub-reactor plate remains to date (1988-1989 – > 100 °C, 2010 ~ 20 °C).

Neutron and physical characteristics of the FCM accumulation located in the south-east quadrant of premise 305/2 were assessed based on design modelling of critical assemblies fitting actual footprint of the meltdown area.

Figure 5.8 presents design of such assembly reactivity change due to humidity at a temperature of 27 and 80°C.

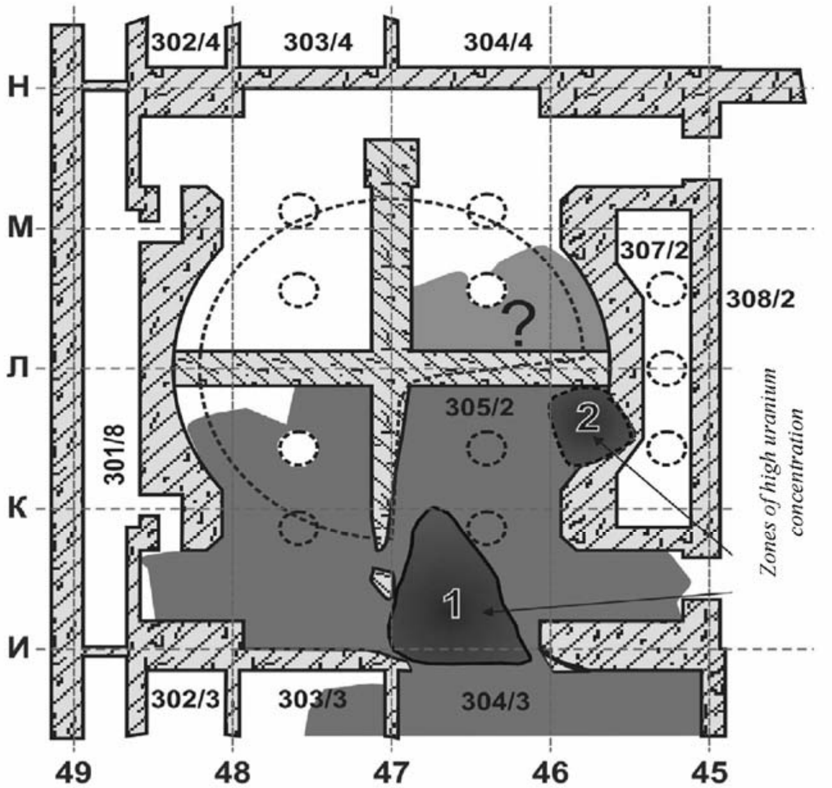


Fig. 5.7. *LFCM massif in premise 305/2. Location of high uranium concentration zones.*

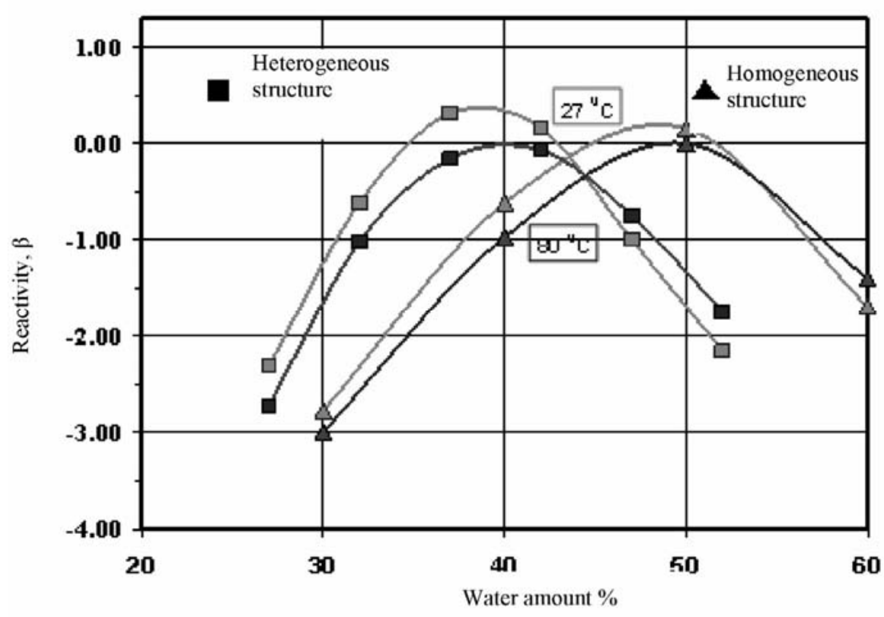


Fig. 5.8. *Reactivity graph for critical FCM accumulation in premise 305/2 south-east quadrant at different temperature and humidity.*

In 1988 temperature of the FCM accumulation was 200°C. The FCM accumulation was dry and subcritical. In June 1990 temperature of FCM accumulation surface was lower, i.e. 100°C. It was damped and critical incident occurred. Then, due to ingress of excessive moisture the accumulation became subcritical. In 2010 and later temperature of the FCM accumulation was 40–50°C. The accumulation is flooded and subcritical. Should the moisture level decrease, the accumulation will pass to supercritical state.

Contemporary notion of neutron and physical, physical and chemical characteristics of FCM accumulations hidden in meltdown zones inside the slab under the destroyed ChNPP Unit 4 reactor has been stated until now, but the issue of nuclear hazard of these accumulations needs to be subject to further studies.

Today, when the New Safe Confinement facility may dramatically impact temperature and humidity conditions of the fuel containing materials, nuclear protection requirements will require permanent attention both during routine operation and at each stage of the Shelter Object conversion into a durable ecologically safe system.

In order to timely preclude potential critical incident the nuclear safety control system needs to be improved by facilitating reliable monitoring of neutron flux density for this critical mass zone and develop preventive measures and means.

In future, the Shelter Object nuclear safety concept, which is based on 'detection and immediate elimination of supercriticality in FCM accumulations' must be revised based on the principal of 'elimination of possibility of a self-sustained chain reaction.'

Shelter Object radiation safety

Shelter Object radioactive airborne particulates

Radiological hazard of airborne particulates of Chernobyl genesis lies in highly toxic transuranium and long-lived isotopes they contain, in particular plutonium and americium isotopes.

Air masses contamination inside and outside the Shelter Object may occur due to the following set of processes:

– dust raised from facility premises surface;
– dust generation in the course of construction and installation works;
– dust generation and dust raise caused by collapse of facility structural members;
– fuel containing materials degradation due to radioactive process and aging of materials;
– leaching of radioactive substances, solutions drying, salt deposits formation and their dust raise.

There are the following two paths of airborne particulate matters transport from the Shelter Object: 'controlled' airborne particulates release occurs through the Bypass system and VS-2 ventilation stack, and uncontrolled' release – through leakages (cracks, openings, maintenance manholes) in the external engineering structures.

Regular monitoring of radionuclides amount (top assessment) and composition in uncontrolled airborne particulates matter release has been done since 1992 by means of accumulative plates installed above light roofing maintenance manholes [10]. Figure 5.9 presents the dynamics of the uncontrolled airborne particulates matter release from the Shelter Object.

An increase in activity releases was registered in 1998 caused by the ventilation stack reinforcement works.

A certain activity increase in 2001 was caused by unfavourable weather conditions, light roofing maintenance works.

In 2002 the monitoring of airborne particulates matter concentrations and particle size in the 'controlled' release through the Bypass system and ventilation stack VS-2 began. Chernobyl accident beta-emitting nuclide products concentration ($\Sigma\beta$) ranged from 0.07 to 23 Bq/m^3 in 2009. The most frequently occurring $\Sigma\beta$ value range was 1–10 Bq/m^3. Furthermore, ^{137}Cs contributed to about 30 % of activity. Particles size as a rule is 1–10 micron.

Radon and thoron progeny have a special place among the Shelter Object radioactive airborne particulates matter. They primarily affect radiation environment in the Shelter Object premises and detection of airborne particles of the Chernobyl genesis.

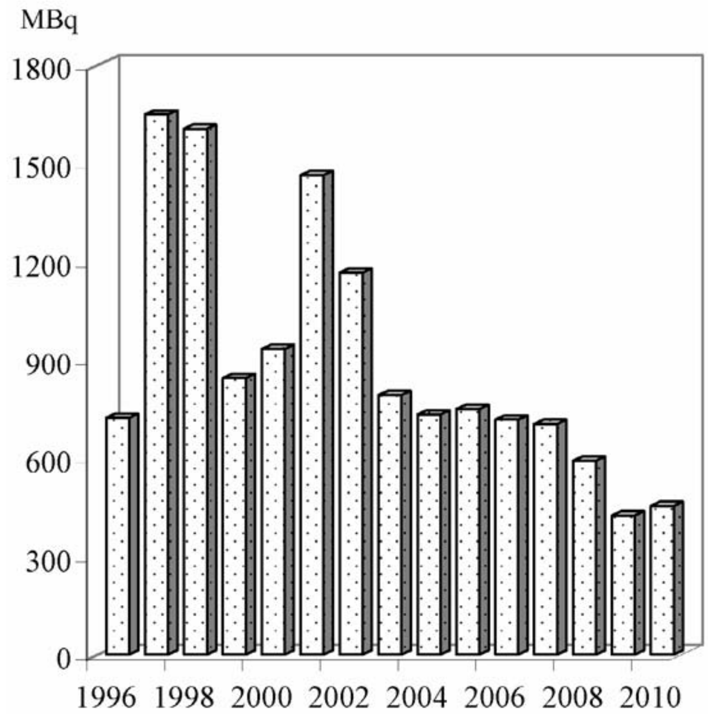


Fig. 5.9. *The dynamics of uncontrolled airborne particulates matter release from the Shelter Object.*

At inhalation of air containing radon and thoron, their progeny are of the greatest hazard, since almost half of them are alpha-emitting. Moreover, they are on submicron airborne particles of 0.05–0.3 micron and can reach lower lung fields.

A concentration of radon and thoron progeny in the Shelter Object is, as a rule, higher, than of airborne particulate products resultant from the Chernobyl accident, which presents a negative factor for the Shelter Object personnel, and has not been counted in internal exposure doses to date. Additional inhalation doses may reach dozens of percents from the dose constrain.

Reduction of uncontrolled releases from the SO has been observed over the recent years. Commissioning of the Modernized Dust Suppression System (MDSS) in 2004–2006 played a significant role in this process, since it expanded the zone of radioactive dust control to the entire area under the SO roof (fig. 5.10 look the coloured inset and 5.11 look the coloured inset).

220 tones of dust suppression solution (48.8 t of dry residue) were supplied to the SO inner space over the period 2006–2009.

MDSS commissioning has more than twice reduced radioactive airborne particles release from the SO, and removable surface contamination in the SO inner space reduced by more than four orders of magnitude. The protective polymer coat covers almost the entire area inside the SO and functions as a containment – precludes transport of radioactive substances into the environment [11].

Today, level of Shelter Object Local Zone near surface air layer contamination with radioactive particles is also measured on a regular basis. It is carried out by means of aspiration units installed along its perimeter.

Figure 5.12 presents the dynamics of average annual concentrations ($\Sigma\beta$: ^{90}Sr + ^{90}Y, ^{137}Cs and ^{241}Pu) of radioactive postulates matter during 1993–2010. Orderly reduction of average annual concentrations ($\Sigma\beta$: ^{90}Sr + ^{90}Y, ^{137}Cs and ^{241}Pu) of radioactive postulates matter began from 1996. It resulted from accident products settling down into the ground, decontamination of the Industrial Site, its verdurization, dust suppression during construction works, and so on. Reduction of ^{137}Cs concentration in the near surface air layer demonstrates insignificant contribution of the Shelter Object releases.

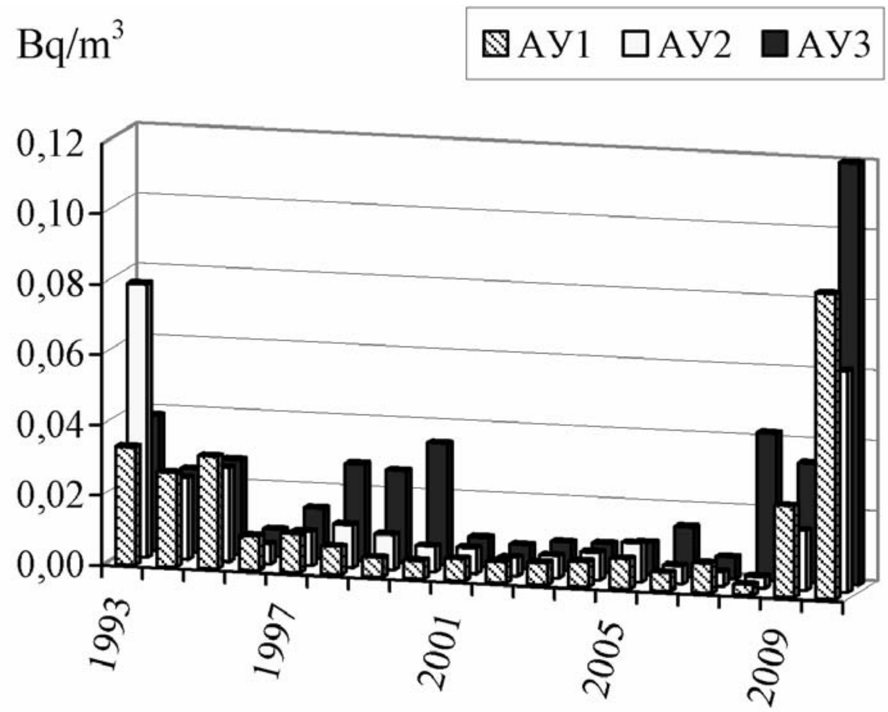


Fig. 5.12. *Average annual concentrations of radioactive airborne particulates (Σβ: ^{90}Sr + ^{90}Y, ^{137}Cs and ^{241}Pu) in the north, north-west and south areas of the SO Industrial Site in 1993 – 2010.*

Increased concentration of airborne particulates in 2009 in the south of the Local Zone resulted from dust generation and dust raise during excavation on the Turbine Hall side.

During 2009–2010 as a result of the intensive excavation on construction of the NSC north and south foundation strips, the concentration of airborne particulates carrying products of the Chernobyl accident increased considerably practically within the entire territory of the Shelter Object Local Zone.

Evaluation of the Shelter Object impact on the environment presents a complex and multi-factor issue. Radioactive airborne particles that are being currently transported from the facility have been generated during the accident and located in the form of dust inside the Shelter Object, and the new ones generated in the course of physical and chemical degradation of fuel containing masses under natural and technogenic factors. Air contamination monitoring may serve as a peculiar kind of indicator of FCM destruction, including the accumulations that are beyond the direct control. Such information would be useful during the NSC construction and commissioning. Furthermore, it is important to know radionuclide composition of airborne particulates matter, their concentration, particles size, locations and reasons for airborne particulates generation, paths of radioactivity transport and settlement, as well as type of dissolution in human respiratory system for determination of individual and collective protection means efficiency. Consequently, monitoring of radioactive airborne particles both in the environment and inside the destroyed unit remains valid in terms of radiation protection and understanding of the processes ongoing in the Shelter Object, in particular assessment of the status of nuclear fuel remains and lava-like fuel containing materials.

Liquid radioactive waste in the Shelter Object

The process of moisture ingress into the facility and accumulation at the bottom levels of the unit in the form of liquid radioactive waste (LRAW) present another factor capable of destabilisation of the current state of nuclear, radiation and ecological safety of the Shelter Object. Moisture penetrates into the SO as a result of precipitations, condensate and man-made solutions. Precipitations get to the SO through cracks and leakages in the light roofing and facility walls. The operating dust suppression system presents the source of man-made solutions.

Having got into SO premises and along its way from top elevations to bottom ones moisture interacts with structural and fuel containing materials, which leads to fission products and produced isotopes transition to water solutions.

Such uncontrolled leakages result in medium-level liquid radwaste accumulated at the bottom levels, which uninterruptedly escape from the SO in the following two directions – to the north and north-east [12–13]. The north stream is accumulated in SO premise 001/3. Up to 300 m^3 of LRAW, which is from 60 % to 70 % of the total amount of water in the Shelter Object is permanently found in this premise. Leakages from the north zone of the pressure-suppression pool, central and south-east premises of the Shelter Object, as well as from the Cascade Wall flow together here. The stream of 700–900 m^3 annually leaks further through the dividing wall to Unit 3 premises and is pumped to the ChNPP Chemical Shop for temporary storage and treatment.

Radionuclide concentration in LRAW from premise 001/3, including transuraniun elements (TUE) tends to increase (fig. 5.13.). Major contributor (up to 80 %) to total alpha-activity of LRAW is americium-241. Contribution of plutonium is less than 30 %.

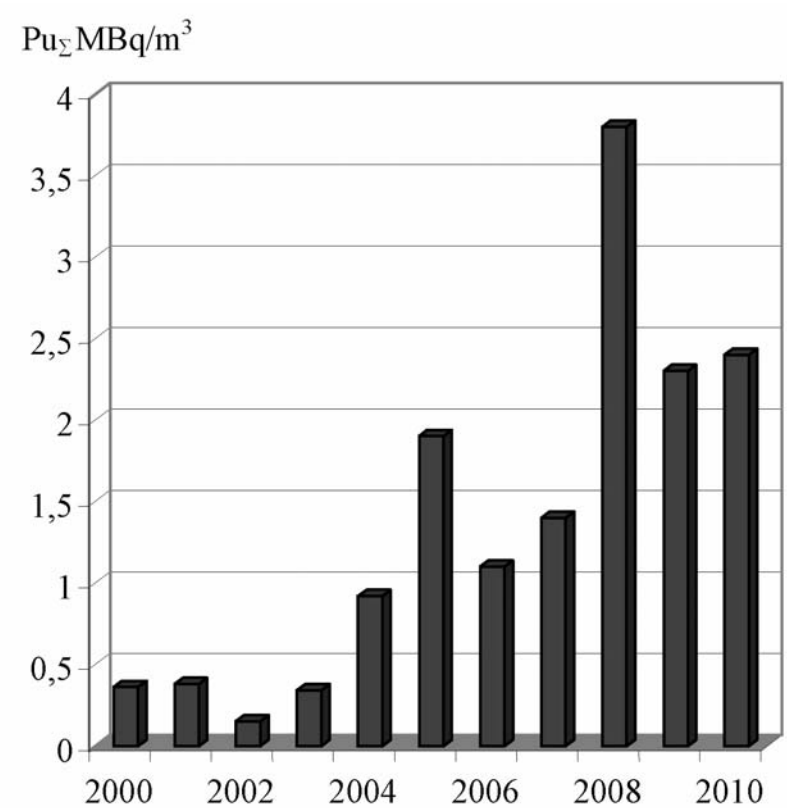


Fig. 5.13. *The dynamics of average annual concentration of $^{238+239+240}Pu$ in LRAW accumulation in premise 001/3.*

The south-east LRAW stream of 300 m^3 gets into premises 017/2 and 018/2 and leaks to ChNPP Unit 3 premises. The dynamics of average annual radionuclide concentration, including TUE, in LRAW of this stream in similar to the one observed in the north stream (fig. 5.14.) [14].

Part of the activity transported with water leakages is concentrated in the form of bottom settlings. Their amount, for instance, in premise 001/3 is estimated as 100 m^3 at total weight of about 150 t [15]. Radionuclide concentration in bottom settlings is by two–three orders of magnitude higher than concentration in the 'unit water'. Bottom settlings drying in the event of cease of leakages and LRAW pumping from premise 001/3 may result in significant exceed of permissible radioactive airborne particles concentration in these and other SO premises.

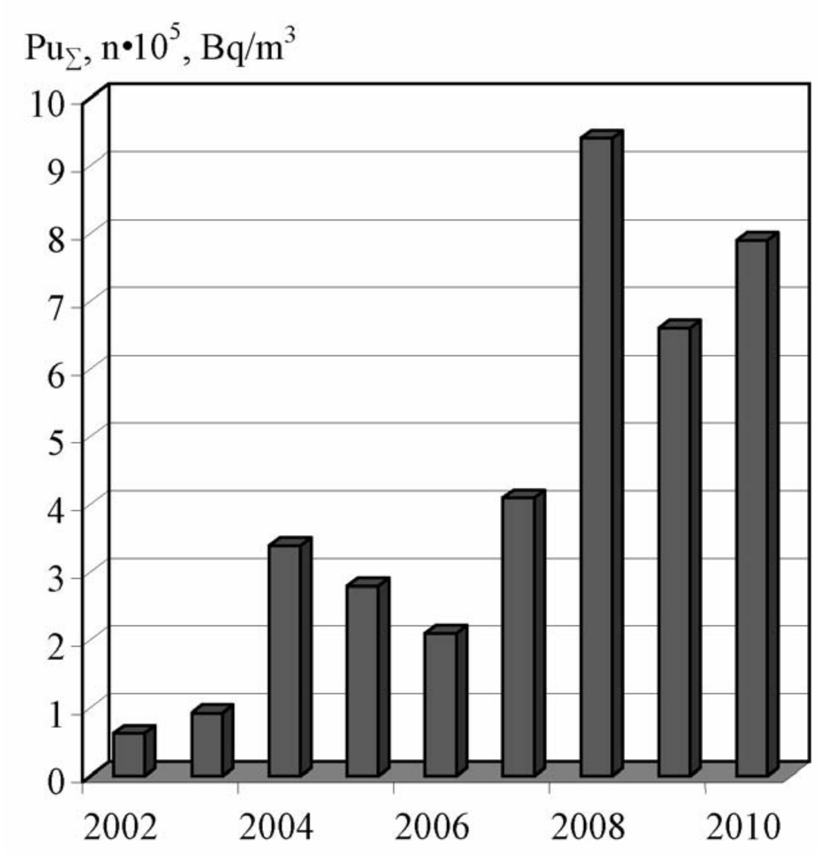


Fig. 5.14. *The dynamics of $^{238+239+240}$Pu concentration in LRAW accumulation in premise 017/2.*

Shelter Object LRAW are characterised by high concentration of organic compounds, including oil products, surfactants and film-forming compounds, as well as TUE activity that does not allow of their reprocessing using the existing Chemical Shop facilities avoiding additional purification [16]. Absence of the latter leads to growth of organic compounds and TUE concentration in the ChNPP LRAW storage facilities. At particular TUE and organic compounds concentration reached, it will not be possible to process such waste at the Liquid Radwaste Treatment Plant which is under commissioning.

Radiation conditions in the Shelter Object premises

Radiation conditions in the Shelter Object premises are caused by their surfaces contamination and radioactive materials they accommodate.

An average exposure dose rate (EDR) value does not exceed 1 R/h (table 5.3) in the most of the reactor unit premises to date. Reactor vessel, premises at elevation +9.00m, steam corridor, premises of the pressure-suppression pool and other, where most of FCM are located present the exception. EDR close to FCM accumulation surface reaches several thousands of roentgens per hour in some places and gradually decreases due to fission of the major dose generating nuclides, first of all, caesium-137 [17].

Table 5.3.

Ranging of surveyed SO premises based on EDR levels

	EDR, R/h						
	< 0.05	**0.05 – 0.1**	**0.1 – 1**	**1 – 10**	**10 – 100**	**100 – 1000**	**> 1000**
Number of premises	27	11	35	54	19	8	2

Deaerator Stack premises are significantly less contaminated than ones of the reactor unit. There are only several premises, where EDR exceeds 1 R/h. These premises are located at top elevations where engineering structures were almost completely destroyed.

EDR is in the range between 0.1 – 2000 mR/h in the Turbine Hall. EDR does not exceed 0.8 mR/h in the normally occupied premises of the SO.

EDR at the SO roof is characterised by the following values:

– over the pipe roof (above the Central Hall) – from 0.5 to 8 R/h, the highest values were observed above the east part of the Central Hall;
– the highest values reach 5 R/h over the ruined premises of separating drums;
– on the Turbine Hall roof – from 0.2 to 4 R/h;
– on the Deaerator Stack roof – from 0.2 to 1 R/h.

Shelter Object premises contamination. SO premise surfaces were contaminated as a result of radioactive particles settlement and their water flooding during the accident of 1986 and during its elimination. Consequently, rather deep penetration of radionuclides into structural materials occurred.

Radionuclide composition of the contamination corresponds to the composition of power unit 4 fuel and includes ^{137}Cs, ^{90}Sr, $^{239\text{-}241}$Pu, ^{241}Am.

Surface contamination levels inside the SO vary within a rather wide range, in particular:

– from 0 to 3000 particles/(cm^2·min.) – for α- particles;
– from 30 to 1000000 particles/(cm^2·min.) – for β- particles.

The removable part of surface contamination is estimated to be 6% of the total amount, as for the individual radionuclides: ^{137}Cs – 4%, ^{241}Am – 10%, ^{239,240}Pu – 2%, ^{90}Sr – 8% i U – 5%.

It should be noted that the radiation conditions at the SO uninterruptedly change both due to natural processes (radioactive fission, FCM degradation, leaching of radionuclides, so on), and human activities (SO operation and conversion).

In assessment of the SO nuclear and radiation safety status in 25 years after the accident it is possible to state that the considerable amount of investigations that took place over this period allowed to obtain results, which enabled arrangement of safe works on SO structural stabilisation and preparatory works for the New Safe Confinement construction.

5.1.2. Stabilisation of engineering structures

In respect that engineering structures function as physical barriers on paths of radioactive substances and ionizing radiation release into the environment, the problem of their reliability and durability is of utmost importance in terms of ensuring nuclear and radiation safety of the Shelter Object.

The completed surveys demonstrated insufficiency of the existing structural system stability when under extreme loads (earthquake, tornado, etc.), and in some critical areas even under limited loads mostly due to local damages, overloading, considerable displacements and corrosion. The overriding negative factor lies in impossibility to ensure compliance with normative requirements to supporting fixing of structures and installation quality control in the course of SO construction in extremely severe radiation environment.

Over 1988-1989 structures of the following three critical zones were subject to strengthening:

– upper tier of Deaerator Stack framework;
– ceiling over the south premise of main circulating pumps;
– ceiling over the south premise of exhaust ventilation air ducts.

Certain defects were later found within the area where southern B1 and B2 beams are supported by the west wall. Reinforcement of the above support area was performed in 1994 by installing steel stanchions under the bottom chords of B1 and B2 beam block. However this measure solved the problem of increase of the support reliability only partly.

Elimination of the hazard related to VS-2 ventilation stack state of failure was the next important step in solving the problem of increasing reliability of the structures affecting the Shelter Object safety. Repair of the ventilation stack load-bearing framework was made in 1998 under the international project with the assistance of experts from Ukraine, USA and Canada.

Since 1998, further surveys of engineering structures state and their stabilization are performed in line with the Shelter Implementation Plan.

The completed analysis of the engineering structures status over their entire life time and assessment of efficiency of the previous measures on failed units and elements strengthening allowed determination of critical zones of the SO structure requiring additional stabilization.

Aa already noted, reinforcement of the supporting joints of southern B1 and B2 beam block completed in 1994 did not provide for acceptable level of this structural component reliability. Besides, defects were found in the area of northern B1 and B2 beam support. Therefore, considering importance of these units reliability for overall SO safety southern and northern B1 and B2 beam supports were additionally reinforced in 1999 (fig. 5.15).

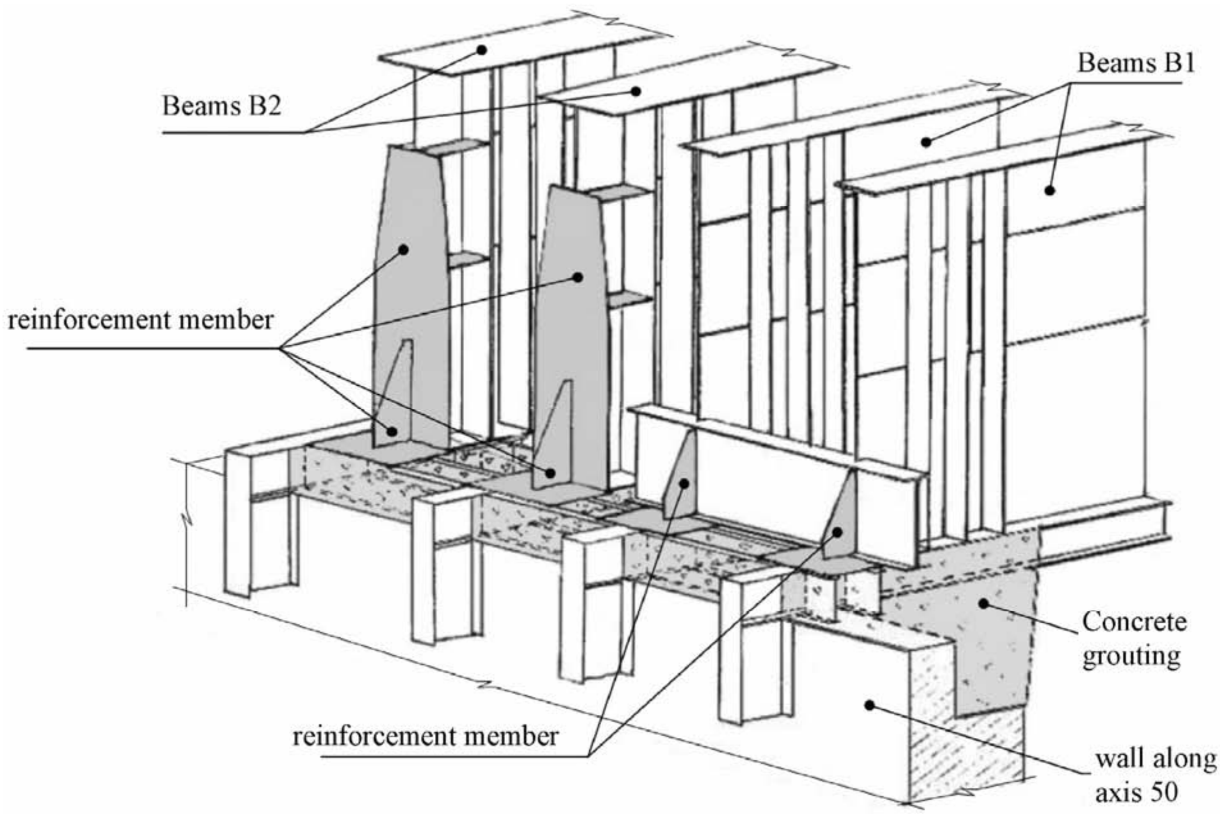


Fig. 5.15. *B-1 and B-2 reinforcement (in colour additional reinforcement as of 1999).*

Design documentation for the mentioned stabilization measure was developed by the International consortium ICC (MK) consisting of the Washington Group International Inc. (USA), BNFL Engineering Ltd. (Great Britain) and Ukrainian organizations: Kiev Institute ‘Energoprojekt’ (KIEP), Scientific Research Institute of Civil Structures (NIISK) and Institute for Safety Problems of NPPs (ISP NPP).

In 2002-2003 the KSK Consortium consisting of KIEP, NIISK and ISP NPP prepared and got concurred by the Regulatory Authorities of Ukraine the working design stipulating urgent stabilisation of the most important structures that ensure overall integrity of the SO facility and its separate zones, namely:

- western zone;
- upper tier of Deaerator Stack framework and damaged ceiling slabs;

– Mammoth beam western and eastern supports;
– connection joints of southern panels and southern ‘hockey-stick’ panels;
– northern Buttress wall and its connection joints with the northern ‘hockey-stick’ panels;
– ventilation shafts;
– light roofing.

The Working Design for Stabilisation was implemented in accordance with requirements of the effective normative documents on ensuring nuclear and radiation safety, construction engineering norms, and with consideration for specifics of construction and installation works implementation in radiation hazardous environment of the SO.

Prior to stabilisation measures commencement the set of preparatory works aimed at arrangement of the infrastructure required for stabilisation and construction site preparation for construction and installation works was carried out. In particular, the following facilities were constructed: Change Facility for 1430 people (fig. 5.16 look the coloured inset), Small Stroybaza, Training Center (TC), Equipment and Tools Decontamination Site, and Modernized Dust Suppression System.

Shelter western zone stabilisation is the major among the set of stabilization measures with consideration for the extent of construction and installation works, number of personnel engaged and collective exposure dose.

The idea of the SO western zone stabilisation was construction of two spatial steel towers west of the Buttress wall, installed on heavy reinforced concrete foundations and joined by spatial trusses at three levels (fig. 5.17 look the coloured inset).

The towers were arranged with cantilevers to support B1 and B2 beam blocks functioning as main load-bearing elements of the existing roof system over the destroyed reactor unit.

Such solution enabled load removal from the damaged framework and wall of the western zone and its transfer to newly erected tower structures.

The Deaerator Stack framework stabilization plan envisaged installation of additional steel angle braces joining upper part of columns inclined considerably towards the Turbine Hall with ceiling structures located below and having no significant defects.

Stabilisation of the ceiling panels that had inadmissible bends and cracks involved metal supports installation under them. These supports precluded collapse of these panels during works on Deaerator Stack framework upper tier strengthening take place, and also facilitate stability of these panels till deconstruction works upon New Safe Confinement construction.

Stabilisation of the Mammoth beam western support anticipated strengthening of cross couplings by increasing their thickness via welding of additional elements. The Mammoth beam eastern support strengthening was resolved by filling openings in its base with concrete.

The southern zone of the roof was stabilised by joining flat panels and ‘hockey-stick’ panels in the area of their leaning on the Mammoth beam. The above was achieved by bracing truss installed on the outside of the roofing (fig. 5.18 look the coloured inset).

Stabilisation within the northern zone of the Shelter Object involved simultaneous resolution of the following two problems:

– joining of the following northern elements into a single structure: ‘hockey-stick’ panels and Buttress wall;
– strengthening of the Buttress wall.

The joining of the ‘hockey-stick’ panels and Buttress wall was performed by anchors installation and fixation to bearing parts of the ‘hockey-stick’ panels and Buttress wall, they were installed in the free from concrete wall inside with its further concreting.

In view of the challenging radiation environment in ventilation shafts, a constructive decision was taken regarding western zone stabilisation that allowed rejection of local strengthening of ventilation shaft walls in the areas of B-1 beams support.

The light roofing was repaired by new corrugated decking installation within 40 % of the roof area.

The set of organisational, health physics and technical measures was taken in order to ensure radiation protection of personnel who were engaged in stabilisation works.

The organisational measures involved training of contracting organisations personnel at the Training Centre, development of particular procedures on arrangement of safe construction and installation works implementation, permanent control of compliance with radiation and industrial safety requirements. Prior to training receipt at the Training Centre personnel was subject to medical examination in Kyiv under the BIOMED program. The personnel that did not pass the medical examination were not admitted to the following preparation stages.

The training polygon was specially arranged with structural mock-ups and mock-up trainers for drilling of particular process operations.

Among the basic health physics and technical radiation protection measures, which enabled considerable personnel exposure doses reduction, as well as minimization of environmental contamination, the following should be mentioned:

– sanitary and access control arrangement;
– zoning of working areas;
– radiation monitoring;
– supply of personnel with basic and additional personal protection equipment, as well as control of their adequate use;
– shielding;
– dust suppression and decontamination.

Arrangement of the sanitary and access control created conditions for precluding radioactive contamination spread beyond the SO area limits, thanks to control of building machinery and personal protection equipment contamination, their sending for decontamination, as required, changing of overalls by personnel and their sanitary treatment. Personnel access the SO site and return only through the change facility.

The following working places zoning was established to limit spread of radioactive substances within the SO site: construction and installation works areas were divided into zones with differing radioactive contamination levels, temporary mobile sanitary locks were located on borders of these zones.

The radiation monitoring was performed in consistency with requirements of the effective SSE ChNPP documents and involved dosimetric monitoring, radioactive contamination spread control and environmental monitoring.

Personnel were provided with personal protection equipment (PPE). While selecting PPE preference was given to the models, which in addition to the required protection had a least effect on a functional state of worker’s organism and his efficiency.

A certain amount of works was carried out at a distance from the major ionizing radiation sources, located in the SO. In particular, most of the preparatory works for west zone stabilisation took place at the Small Stroybaza, and Steelwork Pre-Assembly Area distant from the SO. It helped reduction of personnel exposure doses.

Since external gamma radiation presented the major factor of hazardous impact on personnel during stabilisation works implementation, therefore, permanent or temporary shielding was one of the most effective means for builders’ radiation protection.

The permanent shielding involved protective walls or shields installed on the existing or new structures in the course of preparatory works related to access routes and working locations arrangement. Such shielding arrangements were not subject to (when not required) to dismantling and were used under the stabilised structures monitoring and maintenance effort.

The temporary shielding was installed to ensure protection of personnel only over the period of works and involved utilization of portable protective structures (box type), factory-made shielded suspended and portable platforms and boxes.

0.4 m thick and 9.6 m concrete wall (fig. 5.19 look the coloured inset) installed to protect the personnel operating at the Steelwork Pre-Assembly Area is an example of successful use of shielding.

In the course of stabilisation works, building machinery and vehicles, tools and equipment, structural members of removed contaminated facilities, inner surfaces of the process premises occupied by personnel (protective box, temporary sanitary lock) were subject to decontamination. Special trays were envisaged for footwear decontamination.

Both the Modernised Dust Suppression System and mobile units were utilised for dust suppression within working areas and along personnel access routes. Efficiency of the compounds used for dust suppression was supported by long-term practice of this operation during normal operation of the SO.

Collective effective exposure dose of the personnel who were engaged in stabilisation measures was around 14 man·Sv, which is lower than stipulated by the design. It was achieved mostly due to implementation of organizational and technical radiation protection measures, as well as additional measures aimed at increasing an efficiency and productivity of the construction and installation works.

The stabilisation was completed within 2004–2008, and stabilised structures were accepted for operation based on the Deed of the State Commission dated 29.10.2008. The successfully completed SO engineering structures stabilisation still remains the most ambitious task completed under the SIP.

The completed stabilisation measures provide acceptable level of SO safety in view of the fifteen years period of stabilised structures operation, considering completion of the New Safe Confinement construction within the claimed period. In future, the unstable SO structures issue of must be resolved through their deconstruction or reinforcement inside the NSC. Should the NSC construction be delayed, the stabilisation measures scope must be expanded with consideration for the present SO engineering structures degradation rates.

5.1.3. Construction of the New Safe Confinement

The Law of Ukraine ‘On General Principles of Further Operation and Decommissioning of Chernobyl NPP and Conversion of the Destroyed Power Unit Four of This NPP into an Ecologically Safe System’ stipulates that «the confinement is a protection facility that includes a complex of process equipment for removal of fuel containing materials from the destroyed ChNPP Unit 4, for RAW management and other systems designed to support its conversion into an ecologically safe system and protect workers, public, and the environment».

Construction of the NSC must facilitate pursuing of the following goals:

– protection of workers, public, and the environment from impact of nuclear and radiation hazard sources inherent in the existing Shelter Object;
– Create the required conditions to support physical activities on the Shelter Object conversion into an ecologically safe system, including removal of nuclear fuel remains and FCM, RAW management activities, and deconstruction/stabilization of the unstable Shelter Object structures.

One of the major NSC functions is prevention of radioactive substances and ionizing radiation transport outside the NSC under normal operation conditions, in the event of normal operation disturbance, emergencies and accidents, and shall be fulfilled due to:

– Integrity of NSC protecting structures over a long period of its operation (at least 100 years);
– precluding collapse of the Shelter Object unstable structures by means of their deconstruction or strengthening for the period governed by the NSC safety operation conditions;
– limitation of precipitations penetration into the facility;

- protection of hydro-geological environment from contamination with radioactive substances located in the NSC;
- limitation of radioactive substances spread inside the NSC.

In view of the current radiation conditions outside the Shelter Object, as well as expediency of radioactive effect decrease only within the areas attended by personnel, no additional requirements for the NSC engineering structures to function as a shielding are set. Shielding must be designed only within the areas of structures and systems maintenance, as well as implementation of other radiation hazardous works.

Process support and physical protection is among other NSC functions.

The process support function is fulfilled by means of systems and components accommodation and functioning, as well as creation of conditions required for normal NSC operation, deconstruction/strengthening of the Shelter Object unstable structures, radioactive waste (RAW) management and future removal if fuel containing materials (FCM).

The physical protection system lies in physical protection of nuclear and radioactive materials that are in the SO.

The above listed functions evidence that the NSC represents a multifunctional facility that must be designed with consideration for numerous interrelations between the newly constructed systems and elements, and existing Shelter Object components.

It should be mentioned that shortly after the Shelter Object construction in view of low reliability and durability rates of engineering structures, specialists proposed various options of additional protecting engineering barriers, in particular in the form of so called 'Shelter- 2'.

However this idea was subject to a far more systematic and thorough elaboration starting from 1998 in the course of the Shelter Implementation Plan (SIP).

The International Consortium 'Chernobyl' formed by the Washington Group International, Inc (USA), BNFL Engineering Ltd (UK) and Ukrainian organizations: Kyiv Institute 'EnergoProekt' (KIEP), Research Institute of Engineering Structures (RIES) and Institute for Safety Problems of NPPs (ISP NPP) performed comprehensive analysis of all the earlier technical decisions, stated NSC conceptual design criteria and requirements, and proposed the strategy of its construction. The following three confinement options: FRAME, DOCK-CAISSON and ARCH of a very similar performance were proposed for further refinement at the stage of feasibility study.

Further evaluation of the above mentioned options with independent Ukrainian experts representing the International Advisory Group involved resulted in the 'ARCH' option selected.

The Governmental Interagency Committee for Comprehensive Resolution of Chernobyl NPP Problems lead by Prime Minister of Ukraine took the decision reflected in Minutes No.2 dated 12 March 2001: 'With the objective to accelerate activities on Shelter Object conversion into an ecologically safe system and with consideration for insistent recommendation of EBRD and independent experts ARCH type design of the confinement shall be recognized as a basic that will reflect prospective technical decisions of other projects.'

In 2003, the International Consortium comprised of the Bechtel International Systems (USA), Electricite' de France (France) and Battelle Memorial Institute (USA) with the participation of KIEP, RIES and ISP NPP developed the NSC Conceptual Design (NSC CD). Following the result of the State Comprehensive Expert Review the NSC CD was approved by Cabinet of Ministers of Ukraine Decree No.443-p dated 05 July 2004.

During 2004–2007 the Tender exercise for the NSC construction took place, the Consortium NOVARKA was selected as a preferred bidder that provided its Technical Tender based on the NSC CD adaptation. In September 2007 the contract was signed between the SSE ChNPP (Employer) and NOVARKA (Contractor) for design, construction and commissioning of the NSC Commissioning Stage (NSC CS-1).

According to the NSC project implementation strategy elaborated in document [18] and endorsed by the regulatory authorities of Ukraine, NSC shall be constructed in three stages.

The **first stage** is dedicated to preparatory works that must enable safe and effective NSC construction, in particular:

- Pioneer Wall Berm removal;
- area clearance, levelling and excavation for NSC foundations and assembly area construction;
- arrangement of NSC construction infrastructure;
- New Ventilation Stack construction.

The Pioneer Wall Berm removal was required due to NSC foundation designed within this area. In view of Berm structure various methods and technical means for deconstruction of concrete and reinforced concrete monolithic structures, precast structures, and removal of complex backfilling materials (crashed stone, sand, soil, concrete and metal pieces). The activities were carried out in the radiation hazardous environment in the vicinity of the Shelter Object (fig. 5.20 look the coloured inset). Moreover, removed materials were contaminated to a different extent, which required a set of radiation protection measures be developed and implemented with regard to the personnel engaged in works and environment. The Pioneer Wall Berm removal was successfully completed in April 2008.

Prior to major NSC construction works, a tremendous amount of works was performed involving area clearance and levelling, excavation of trenches for construction the NSC Erection, Transfer and Service Zone foundations, as well as Arch structures Pre-Assembly Area (fig. 5.21 look the coloured inset).

Complexity of the mentioned works implementation was caused by a considerable contamination rate of the facilities subject to deconstruction, as well as technogenic soils within the excavation sites that were placed in the category of radioactive waste (RAW), including high-level waste. In the course of excavation the process system for RAW management was introduced that provided radiation monitoring during each operation, sorting of RAW into categories, their hauling to the Temporary Laydown Area or Disposal Site.

In the effort to enable timely and effective NSC construction activities early works on required infrastructure arrangement began, in particular including construction/reconstruction of the following activities:

- temporary buildings and facilities for personnel;
- motor roads, railway and port facilities for equipment and materials delivery;
- Arch structures Pre-Assembly Area arrangement;
- materials and equipment pilling/storage areas arrangement.

Since the existing ventilation stack VS-2 interferes with NSC east end arrangement, it must be dismantled prior to sliding of the confinement to its design position. Accordingly, the New Ventilation Stack (NVS) must be constructed and commissioned prior to VS-2 dismantling. The design documentation has been concurred, the Contractor has been selected and preparatory works for NVS construction are currently underway.

Design and construction of the NSC, the whole set of the required tests and its commissioning is understood to be the **second stage**. The NSC is anticipated to be split into the two commissioning stages:

- Commissioning Stage 1 (CS-1) – protective structure with process life-support systems and required infrastructure;
- Commissioning Stage 2 (CS-2) – infrastructure for SO unstable structures dismantling.

CS-1 engineering structures and process systems are being designed based on the design criteria and requirements set forth in the ‘CS-1 NSC Concept Design Safety Document’ (CDSD) [19], concurred by the Regulatory Authorities of Ukraine. Ukrainian partners of NOVARKA also participate in the design: KIEP and Ukrainian Research Institute of Steel Structures Design.

As per [18], design of the deconstruction facilities (CS-2) must have started in parallel with the CS-1 design. Unfortunately, this design plan has not been implemented and considerable delay is CS-2 design has surfaced.

Early SO unstable structures dismantling within the scope determined during the deconstruction working design will commence at the NSC project **stage three**, upon CS-2 commissioning.

CS-1 is designed of the following constituents represented by the NSC main structures and facilities:

- steel Arch is the main structure;
- Operation and Control Facility (OCF) and Technological Building (TB);
- Technical Area.

The Arch is about 270 m wide, 164m long and 110 m high, including both end walls the eastern and western (fig. 5.22 look the coloured inset).

The main bearing structure of the Arch consists of 16 arch trusses, installed with a pace of 12.5 m. The arch trusses in their design position (in the Service Zone) shall lean on the foundations by means of special supports. Span of the arch trusses is 257.44 m.

An arch truss is formed by two chord (upper and lower) and orthogonal lattice bracing of triangular type. Chords are at 12.00 m from each other. Truss chords form a single node at the point of rest on foundations. Arch truss chords are manufactured of tubes 813 mm in diameter and from 12.5 to 40 mm thick.

The upper chord of arch trusses supports external cladding purlins, internal cladding members are fixed to the lower chord. Leak tight Annular Space is formed between the external and internal cladding, it protects Arch structures from external climatic effects and potential condensate inside the NSC.

Frame girders to support crane equipment are attached to arch trusses at the top elevations.

Design of the Arch west wall is represented by the system of vertical lattice columns and horizontal trusses, and bracing. The entire West wall will be suspended from the Arch prior to its sliding to the Service zone, and at the stage of operation will rest on foundation being supported by one additional column installed in the central zone of the wall.

There is a lift, escape staircases and passages inside the west wall between its external and internal cladding. A ventilation stack of 4.00 m diameter is attached to the west wall from the outside, as well as gallery for ventilation equipment to be installed.

The Arch east wall is similarly to the west wall formed by the system of vertical lattice columns and horizontal trusses, and bracing. The east wall is suspended from the wall and transfers no forces to the existing structures. The east wall has a certain number of tilting panels to enable its travel over the protrusion of the existing structures during the Arch sliding to its design position. These panels will be reclined during sliding and set in their design position only upon definitive placement of the Arch in the Service Zone.

It is designed to connect Arch load bearing members, including west and east walls using high-strength friction bolts.

Total weight of the Arch steel structures is about 20 thousand tons.

The following three types of foundations have been designed:

- foundations within the Arch assembly area (Erection Zone foundations);
- foundations within the zone of Arch sliding to its design position (Transfer Zone foundations);
- foundations within the zone of Arch setting into its place (Service Zone foundations).

The Erection Zone foundations are designed as pile monolithic reinforced concrete ground beams. 26.00m long steel driven piles are accepted in the form of pipes 1.02 m in diameter, and 30mm thick wall in the top part, and 16mm along pile remainder.

Strip shallow reinforced concrete foundations are designed for the Arch Transfer Zone.

The Service Zone foundations are designed as pile monolithic reinforced concrete ground beams. CFA piles are assumed 1.00 m in diameter and 19.00 m long.

General approach to selection of the Arch construction technology is based on the concept of minimal operation under the Shelter Object radiation hazardous conditions, and envisages the following:

– manufacturing of Arch members of the largest possible size and weight in shops;
– preassembly of erection blocs (Arch segments) in the Preassembly Area;
– final assembly of the Arch from Arch segments in the Erection Zone;
– sliding of the Arch in its design position.

Arch segments will be assembled from the shop manufactured members in the Preassembly Area located at a considerable distance from the SO (about 1 km). 12 special benches will be provided on the area for this purpose, equipped with demountable templates and patterns. Assembled segments of the Arch shall be transported by means of four trailers to the Erection Zone located at the distance of about 300 m from the SO (fig. 5.23 look the coloured inset).

The Arch will be assembled in the Erection Zone in several stages (fig. 5.24 look the coloured inset). Firstly, Arch east part, including the east end wall will be erected, and then it will be transferred to waiting position. Subsequently, west part of the Arch will be assembled including the west end wall. Certain process systems and equipment will also be installed in the process of the Arch assembly (in particular, crane girders, a lift, ventilation, power supply, control and others). At the next stage the east part of the Arch will be transferred for further connection with the west part of the Arch. East and west parts of the Arch will be connected and Main Cranes System will be also installed. The final stage is dedicated to the pre-commissioning works and acceptance of process systems and equipment of the Arch prior to sliding into the design position.

Hoisting equipment, as well as special auxiliary erection equipment, in particular lifting towers and beams, support beams, supports, locking devices, temporary braces, jacks, carriages, winches, and so on will be used for Arch erection.

Arch will be slid to its design position by means of a horizontal jack system. Upon completion of the Arch sliding to its design position, temporary support nodes will be successively replaced by permanent supports. That done, junction of the Arch to the Technological Building and existing structures of the ChNPP Stage II Main Building, as well as process systems hook-up to the stationary power supply sources will be done.

The Operation and Control Building and Technological Building are located next to the Arch west end wall. Moreover, part of the Technological Building is situated inside the Arch. Vehicles, mechanisms and personnel will access the Arch through airlocks of the Technological Building, and sanitary lock located from the south of the ex-power unit 4 Turbine Hall.

Construction of the Operation and Control Building and Technological Building must be completed before sliding of the Arch to the design position.

The Technological Building includes the Technological Block, Additional Unit, Southern and Northern Airlocks, Annex to accommodate Liquid Radwaste Treatment System.

The Operation and Control Building is divided into separate functional blocks connected between themselves and Technological Building by the technological gallery and personnel access gallery.

The Technical Area is located some way from the NSC (~ 500 m). Technical Area facilities will provide for permanent NSC engineering support as to electrical power, hot and cold water, fire water and portable water supply. Specialised pipe racking will connect the Technical Area and NSC facilities.

It is expected that the entire NSC Design will be completed by the middle of 2011. It is worthy of note that NSC design and construction works in general are considerably delayed as against the initial SIP schedule. In view of the current situation it can be projected that NSC construction and commissioning will be completed not earlier than in 2014.

Another issue is that the current NSC construction value is estimated at 1 milliard Euro, which is more than twice higher than the initial price reflected in the Contract with NOVARKA.

Only NSC CS-1 design documentation is currently developed. NSC CS-2 design will at the most start in early 2011; it may result in imperfect consideration of the demands associated with SO unstable structured deconstruction in NSC CS-1 development.

The equally serious issue poses the fact that no design work is currently carried out on construction of a new and reinforcement of the existing ChNPP Stage II structures that will be integrated in the NSC enclosure.

The abovementioned failures are to a wide extent caused by imperfection of the SIP, which lies in the fact that the single problem of the Shelter Object conversion was split into numerous tasks and packages with a lack of interface ensured between a variety of Contractors. This approach creates certain risks related to making optimal technical decisions.

5.1.4. Strategy of further Shelter Object conversion into an ecologically safe system

Development of safe methods and infrastructure for removing fuel containing materials from the Shelter Object and their further management is a prerequisite to resolution of the problem of converting this facility into an ecologically safe system. Resolution of this problem is of utmost importance to ensuring future environmental safety of Ukraine and neighbouring countries, and raising world public opinion of nuclear engineering development issues.

According to the ‘Shelter Object Conversion Strategy’ FCM removal efforts must be implemented at the final third stage of the SO conversion into an ecologically safe system.

Judging by the condition and composition of the FCM accumulated in the Shelter Object they represent long-lived radioactive waste (RAW). Additional surveys of some inaccessible FCM accumulations are required in view of their potential nuclear hazard. That is should uncontrolled FCM remain inside the SO it will never be released from nuclear regulation and control.

It should be mentioned that potential hazard of FCM may grow with time due to spontaneous failure of lava-like FCM surface accompanied by high-level dust generation. Generation of such dust inside the Shelter Object is of radioecological hazard of equally local and global nature. Therefore, FCM removal and conditioning prior to their widespread failure is really pressing.

A part of the previously completed works dedicated to the problem of FCM removal from the SO was based on the approaches that did not envisage construction the new confining structure (Shelter-2). Such approach cannot be considered acceptable in view of the challenge of personnel and environmental protection.

Other designs, in particular of ISP NPP and Design Bureau ‘Pivdenne,’ contained process decisions anticipating operations on FCM removal utilizing various NSC options (‘Start,’ ‘Dock-Caisson’ and other projects). However, given that definitive decision on NSC arch option has been already taken, and design and preparatory works for its construction are underway, therefore process decisions regarding FCM removal should be developed based on the actual situation.

SIP Task 19 ‘Study and Development of FCM Removal and RAW Management Strategy’ and Task 20 ‘Development of RAW Removal Process’ concerned the issue of FCM removal and further management. Results of the above mentioned tasks served as a basis for program decision P7 taken in December 2000, which stipulated preliminary strategy of FCM removal and RAW management. Basic provisions of the strategy are as follows:

- FCM must be removed within the NSC life time;
- removal duration is 40÷50 years;
- removal of FCM and other long-lived RAW directly to the final disposal storage facility in stable geological formations is of higher priority;

- selective FCM removal should start upon deconstruction of SO unstable structures and completion of FCM removal method testing;
- mass FCM removal must start upon resolution of their storage and disposal issue.

Moreover, decision P7 was reviewed similarly to the previous one that must be validated by the key decision P8 based on the results of demonstration experiment on FCM removal at the SO Industrial Site. The need for a demonstration experiment on FCM removal was reflected in program decision P9 taken in June 2001.

However, the document accepted in 2005 'Shelter Object FCM and Waste Management Strategy. Action Plan' [20] got concurred by the State Nuclear Regulation Committee states that:

- At present, there are no additional data regarding applicability of various technologies at the OS for FCM removal, which could be used at the conceptual level as a basis to revise the preliminary FCM removal strategy stated in P7, and adopt key decision P8. Therefore, any further works on conceptual study of FCM removal strategy and technologies are not beneficial at this stage;
- At this stage of SIP implementation no additional information about FCM was received to permit the decision on their early removal to be made. The existing information regarding long-term behaviour of FCM needs to be supplemented by the elaboration of a FCM monitoring and control program before and during their removal;
- The detailed design and demonstration of FCM removal technology prototype has been acknowledged to be not effective in terms of cost and schedule.

At the same time, document [20] specifies the following Action Program to achieve P8 key decision:

- Pending approval of the key programmatic decision P8, during construction activities related to stabilization of the Shelter structures, construction of the NSC and early dismantlement of the unstable Shelter structures, the RAW, including FCM, will be managed in the framework of the 'Integrated RAW Management Program at the Stage of ChNPP Shutdown and Shelter Object Conversion into an Ecologically Safe System';
- Task 14 will provide input data for development and installation of the FCM behaviour monitoring system, and for the creation of systems maintaining optimal temperature and humidity environment for storing FCM inside OS. This will allow obtaining information on negative tendencies in FCM behaviour in timely manner;
- The forecast FCM behaviour model and the data obtained by means of the FCM behaviour monitoring system, as well as nuclear safety monitoring system will enable implementing timely preventive activities related to reduction of risk of any hazardous effects associated with deterioration of the FCM condition, as well as taking a decision on the need for FCM early removal. Based on the forecast model and the results of FCM monitoring, the 'FCM Removal and Waste Management Strategy' will be finalized and approved through the P8 Decision.

Given that FCM behaviour monitoring system development and introduction is not exercised, taking of P8 key decision does appear to be feasible in the nearest future.

Consequently, the NSC is being designed in circumstances where clear strategy of future FCM removal and RAW management is missing. The only requirement for the NSC in the context of NSC CS-1 design is provision of process room for future allocation and implementation of FCM and other RAW removal methods. This poses certain risks of that FCM removal utilizing the NSC systems may be considerably complicated or event impossible as regards particular FCM accumulations. Moreover, development of FCM management processes and infrastructure will take much time, but all the FCM removal-related activities must be completed before the NSC process systems become worn out and outdated. NSC radiation conditions may change significantly in the process of FCM removal, which must be considered in development and justification of a set of additional radiation protection measures.

It should be mentioned that arrangement of several leak tight barriers precluding from any effect on the environment is a prerequisite to safe storage of spent nuclear fuel. The NSC is not a leak tight facility, consequently, the risks of effect that power unit 4 nuclear fuel remains may have on the environment will be valid until it is removed from the SO.

Therefore, development of critical process decisions regarding FCM removal utilizing NSC systems, as well as substantiation of their safe implementation that must be concurrent with the NSC design and construction to allow consideration of future FCM removal needs to the maximum possible extent in the course of NSC construction, is of immediate interest. This effort is being currently implemented by the ISP NPP.

In order to successfully implement final stage of the ‘Shelter Object Conversion Strategy’ a geologic repository for FCM and other long-lived RAW disposal should be arranged under the national program. Today a set of prospecting, estimate, scientific and methodological, research and design works is envisaged under the ‘National Ecological Program for Radioactive Waste Management’ in order to select sites that are potentially available for geological repository arrangement. Completion of the mentioned efforts is scheduled in 2017.

In the circumstances concerned, the most optimistic date for the mass removal of FCM from the SO to commence is 2030. Completion of these works within the NSC life time is of importance.

The Shelter Object does not have a single analogue in the international practise, i.e. the issue of its conversion into an ecologically safe system presents a unique challenge, handling of which involves efforts of Ukraine and world community.

5.1.5. Biomedical and biophysical monitoring of Shelter Object conversion safety

The Shelter Object conversion into an ecologically safe system is one of the high priority national programs of Ukraine, medical and dosimetric measures aimed at maintenance of personnel health engaged in these works is among central problems of contemporary clinical radiobiology, health physics and radiation protection [21, 22].

SIP works uniqueness lies in that personnel in fact performs set technical tasks being exposed to high-level open radionuclide ionising radiation sources in destroyed ChNPP Unit 4 premises or in the close vicinity of it within the contaminated area. Activities in the SO are carried out under multifactor hazard with the radiation factor prevailing, intensified by hazardous industrial and contamination factors in conditions of hard-to-get-to temporary working places located in premise of the destroyed nuclear facility.

These activities make possible incorporation of transuranium element radionuclides in a human body (plutonium-238, plutonium-239, plutonium-240, plutonium-241, americium-241), and also stronsium-90, cesium-137. The listed radionuclides are of extremely high radiobiological toxicity. Nevertheless, it is practically impossible to detect most of them (except for cesium-137) directly in a human body. Moreover, high psychoemotional tension during works should mentioned. Accordingly, specific requirements are imposed to somatic health and psycho-physiological characteristics of personnel.

There are the following risk factors:

- aggressive chemical aerosols, including welding ones;
- high humidity rate and uncomfortable temperature conditions in any season;
- absence of forced exchange ventilation inside the SO;
- insufficient and more often artificial lighting;
- ‘confined space’ factor in the bulk of SO premises;
- height factor;
- difficulties of accessing working places under ionizing radiation exposure;

– personnel protective equipment effect;
– synergic effect possible as a result of combined action of risk factors.

Consequently, personnel perform operations on SO conversion into an ecologically safe system under synergy of radiological and industrial risks, as well as high psychoemotional tension.

Following recommendations of the Ministry of Health of Ukraine, the State Establishment 'National Centre of Radiation Medicine' (NCRM) of the National Academy of Medical Science of Ukraine as the major scientific and medical institution of Ukraine in the area of health physics, dosimetry and clinical radiation medicine, and the WHO Radiation Emergency Medical Preparedness and Assistance Network (WHO-REMPAN) were assigned to develop and lead the program of medical and biophysical support of the SO conversion into ESS.

The system of medical and biophysical monitoring of engaged personnel health status and performance capability was established based on the gained unique experience in medical, biological and dosimetric support of works in terms of extreme radiation and non-radiation hazard factors affecting medical condition and performance efficiency of personnel with consideration for requirements of basic normative documents, as well as national and international consensuses regarding diagnostics of conditions representing contra-indications to operation under specific dangerous and hazardous working conditions (SDHWC). Major elements comprising the system is initial, regular, final and special (including emergency) medical and psycho-physiological examination; among additional elements is individual inspection and routine (preshift) medical examination (fig. 5.25).

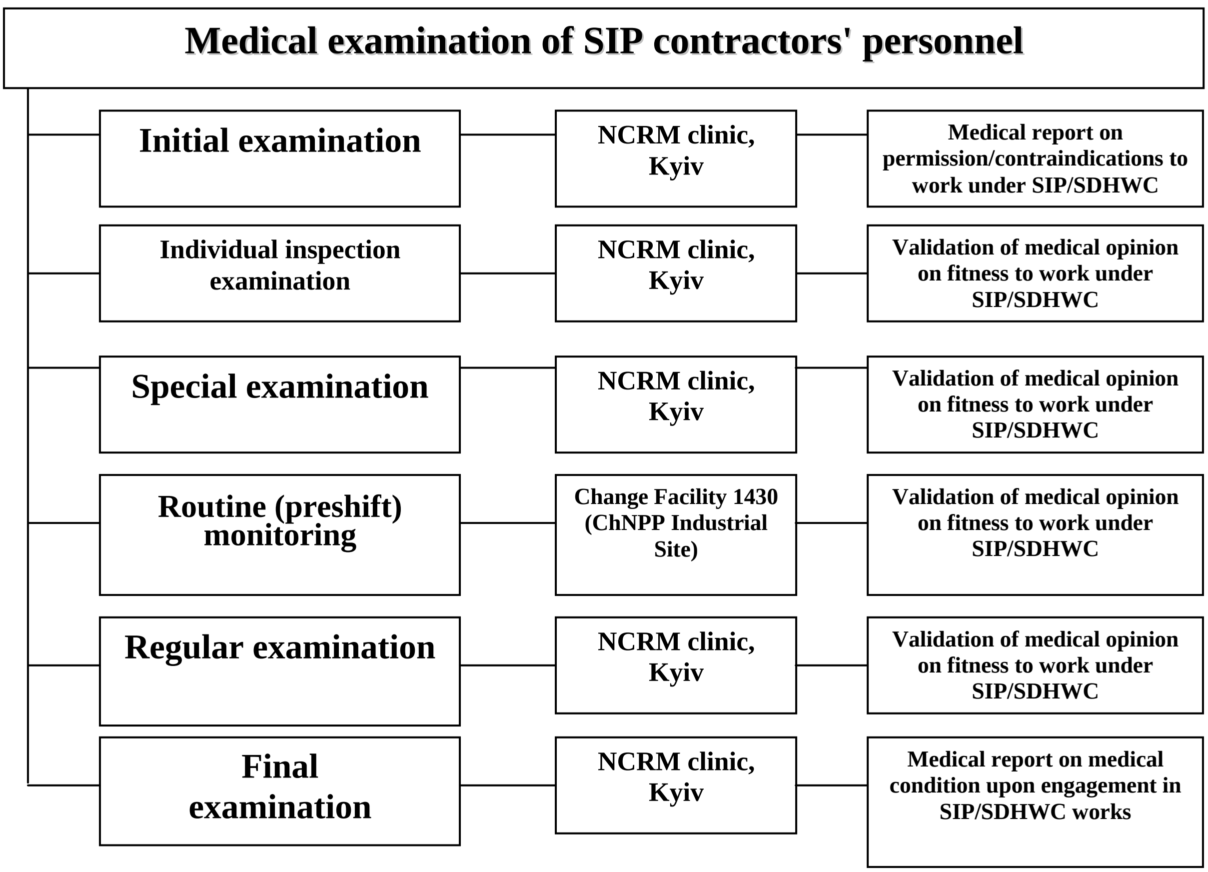


Fig. 5.25. *Chart of SIP contractors' personnel medical examination*

Major tasks of the Program for medical and biophysical monitoring of SIP personnel stipulate the following:

1. Prevention of admission of personnel who are unable to perform works due to somatic or psycho-physiological unfitness to work under specially dangerous and hazardous conditions.

2. Prevention of any process accidents and incidents that may be caused by dramatic deterioration of worker’s health. Especially in the event when deterioration of health state results in considerable exposure dose or any other hazardous consequences.

3. Monitoring of potential internal exposure dose. Ascertain that workers do not get internal exposure in the course of SIP works.

4. Radionuclide intake is precluded by means of training and workers’ discipline, as well as adequately selected personnel protection means. An advantage of the program is an independent assessment of personnel exposure risk enabled by available means.

5. Should radionuclide intake exceeding the permissible rate be observed, additional medical and biophysical examination is carried out aimed at checking potential overexposure as a result of internal and external exposure, and possibility of further worker engagement in works at the ChNPP.

Biophysical monitoring (fig. 5.26) being a set of physical and biodosimetric measures aimed at identification of cases of radioactive substances incorporation in workers’ organisms, calculation of actual individual internal exposure doses resultant from these events and validation of compliance of radiation and hygienic conditions at working places with Ukrainian sanitary legislation is a constituent of the Program of access and ensuring monitoring of SO works radiation safety [23].

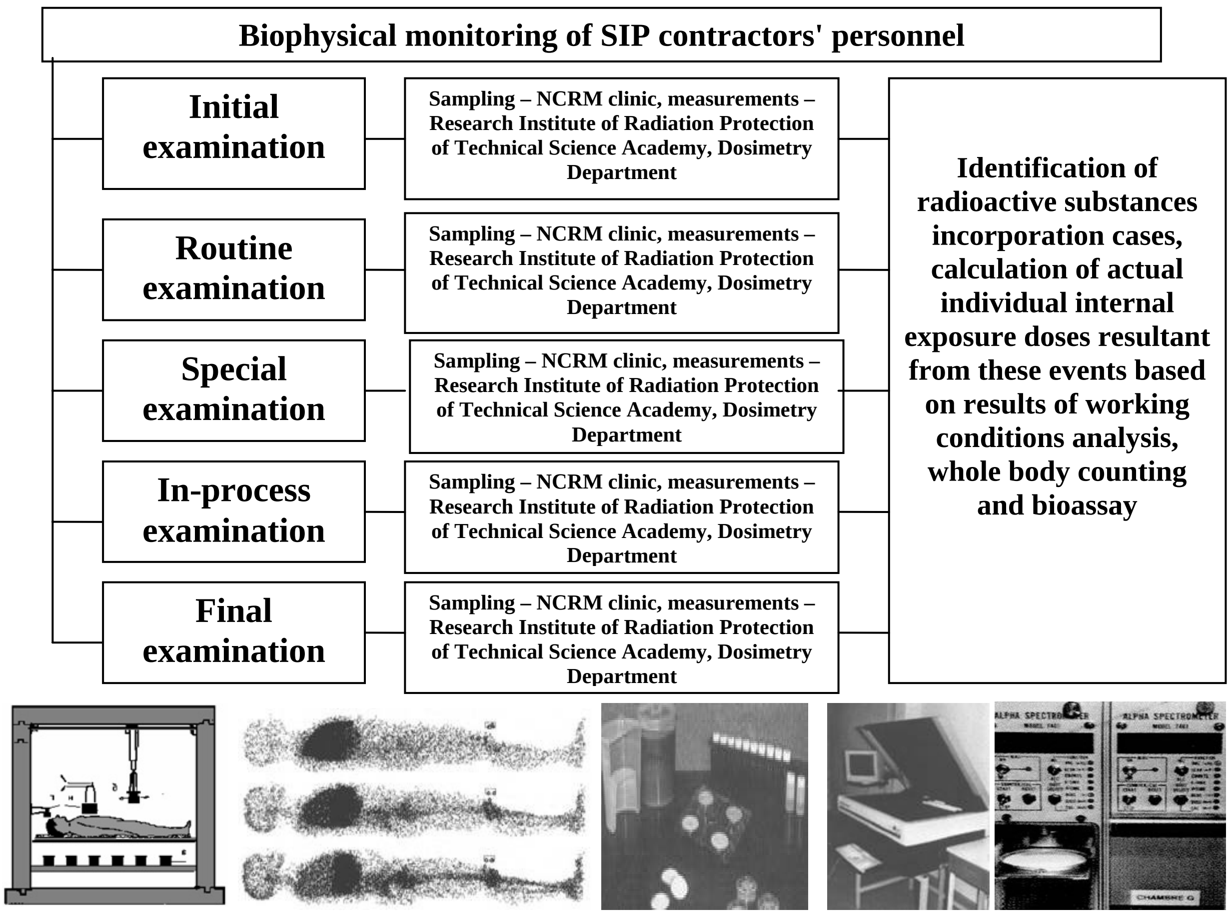


Fig. 5..26. *Procedure of SIP contractors’ personnel biophysical monitoring*

In the context of SIP works, biophysical monitoring includes collection on initial dosimetric information about a worker and working place, and also routine health physics and biophysical monitoring. Initial and final, special, urgent (emergency) biophysical monitoring is performed simultaneously with medical examination.

6510 employees of contracting organizations engaged in SIP works were subject to medical and biophysical examination during 2004 – December 2009 in terms of obtaining permission to work at the SO. Besides, 783 employees were subject to special medical examination (Table 5.4 and 5.5).

Table 5.4.

Results of SIP contractors' personnel medical examination over the period from 12.10.2004 through 31.12.2009

Examination type	Fit	Unfit	Total
Initial	3125 (48.00%)	3385 (52.00%)	6510
Regular	654 (62.82%)	387 (37.18%)	1041
Inspection	605 (68.13%)	283 (31.87%)	888
Special	783 – individuals, 909 – cases		
Final	465		

Table 5.5.

Scope of biophysical monitoring of SIP contractors' personnel completed over the period from 12.10.2004 through 28.02.2010

Bioassay year and month	Biophysical monitoring type				
	Initial	Routine		Special	Final
	Faeces samples activity measurement, expert WBC	Faeces samples activity measurem ent	Radiometric measurement s of nostril smears	Number of cases	Faeces samples activity measurement, expert WBC
12.10.2004 through 28.02.2010	7268	8133	60491	1009	425

Final biophysical monitoring has not practically resulted in radionuclides observed in organisms of candidates for participation in SIP works, as well as radionuclides in bioassays (faeces, urine).

The data obtained during routine biophysical monitoring of personnel engaged in SIP works evidence of measured $^{239+240}$Pu doses in examined personnel faeces samples. The number of cases of $^{239+240}$Pu content exceeding 1.5 mBq/sample measured in faeces samples, which required special medical and biophysical examination of workers, equals 1009 (while some workers were subject to special examination three and more times).

Individual internal exposure doses assessed based on special biophysical monitoring results do not exceed 3 mSv, which is the reference level for individual internal exposure dose adopted at the ChNPP.

In October – November 2005 after the first year of medical and biophysical support of the SIP works the Employer – SSE ChNPP evaluated the Program by means of the international audit. The audit team was formed by specialists who represented the RTI International (Research Triangle Park, North Carolina, the USA), Battelle Memorial Institute (Richland, Washington, the USA) i Duke University (Durham, North Carolina, the USA). According to the international audit conclusion this project merits high opinion and full support both for the methodology used and works organization with some recommendations regarding streamlining of its management. The SIP works audit conducted by the Mouchel Parkman Corporation in February 2007 resulted in the report stating that the Medical and biophysical monitoring program turned out to be extremely successful in achieving its main goal: ensuring medical fitness of SIP workers and precluding trials due to damaged health of the present and former SIP workers.

The above presented medical and biophysical monitoring results evidence of the critical importance of further medical and biophysical support of SIP works, since exactly the issue of personnel exposure is the key one in the course of operations under similar radiation and hygienic conditions.

5.2. Chernobyl NPP: focal points of decommissioning

5.2.1. Current status of Chernobyl NPP power units

The SSE 'Chernobyl NPP' (Fig. 5.27 look the coloured inset) is currently at the shutdown stage that envisages implementation of the following activities:

- maintaining safe condition of the power units;
- removal of nuclear fuel from the power units;
- removal of working media and potentially hazardous substances from systems and equipment;
- final shutdown of systems and elements;
- removal of accumulated radioactive waste (RAW) from the power units;
- performance of the comprehensive engineering and radiation survey (CERS);
- dismantling of external (with regard to reactor facilities) equipment;
- reconstruction of decommissioning (DM) life support systems;
- DM documentation development;
- DM infrastructure development.

Safety on the Chernobyl NPP site is a high-priority. Notwithstanding the fact that the ChNPP Units are shutdown and do not generate power now, they still pose a nuclear and radiation hazard. With the objective to promote the already achieved level of safety at the Chernobyl NPP, the following set of activities to maintain safe condition of the power units is being performed:

- maintaining operating condition of safety-important and process control systems, testing the systems in accordance with the requirements stated in regulations and specifications;
- operation of systems and equipment in strict adherence to the requirements of technical specifications and manufacturer's instructions;
- maintenance of the required temperature and humidity conditions in buildings and structures;
- maintenance and routine repairs of equipment as frequently as established by regulations and specifications;
- maintenance of the already created fire prevention conditions on the pant's site;
- ensuring an appropriate sanitary and access control, including a system of barriers on the ways of radionuclides' possible carry-over beyond the SSE ChNPP and Exclusion Zone boundaries;
- ensuring radiation monitoring of the facilities and technology, including but not limited to:
  - in-process radiation monitoring;
  - radiation dosimetric monitoring;
  - radiation monitoring of the protective barriers' condition;
  - control over non-proliferation of radioactive substances;
  - radiation monitoring of the environment.
- strict adherence to the already established reference levels for a radiation well-being;
- continuous effort towards maintaining proficiency and qualification upgrades of the personnel.

Both the SSE ChNPP management and independent supervisory bodies strictly control fulfilment of safety assurance activities. Over the past few years, no accidents or emergencies, cases of an unauthorised elevated exposure to personnel and carry-over of radioactive substances beyond the design-basis boundaries were registered at the Chernobyl NPP site.

Removal of nuclear fuel out of the power units is the major factor that determines a term of decommissioning. In early March 2010, fresh nuclear fuel was exported to Russia (in the amount of 68 fresh fuel assemblies and 3 fuel elements).

Since 2006, SNF is being removed from the power units to ISF-1, an already available storage facility, due to a delay in construction and commissioning of the new Interim Spent Fuel Dry Storage Facility (ISF-2). The objective is to mitigate risks during decommissioning and transformation of the Shelter Object into an ecologically safe system, as well as to reduce expenses for the power units' safe condition maintenance. Prior to start localization of additional SNF in ISF-1, the SSE ChNPP has accomplished a large volume of work to reassess safety of the existing storage facility. Based on the safety reassessment results, the 'Plan for ISF-1 Safety Improvement' was developed and is being successfully implemented now. Accomplishment of the Plan's first-priority tasks (first of all, reconstruction of transport and handling equipment) has provided the SSE ChNPP with an opportunity to obtain the License for ISF-1 operation and to start SNF removal from the power units.

Removal of spent nuclear fuel (SNF) is performed in three phases:

- the first phase envisages transportation of spent nuclear fuel from Unit 3 to ISF-1;
- the second phase shall include transportation of fuel (exclusive of damaged one) from Units 1&2 to ISF-1;
- at the third phase the damaged nuclear fuel shall be removed from Units 1&2.

The first phase was successfully implemented in September 2010; the nuclear fuel was completely removed from Unit 3. Now, nuclear fuel in Units 1&2 is only present in the cooling pools adjacent to the reactors. The damaged NF in the cooling pools of Units 1&2 is stored in special canisters of various configurations constructed through an independent effort of the SSE ChNPP. Currently in progress are ate preparations to start the second phase of activities that envisages removal of nuclear fuel from the power units.

Development of the ChNPP decommissioning documentation

Over the past five years, development of the conceptual documents concerning the Chernobyl NPP power units decommissioning was completely finished. Before 2009, 'The Comprehensive Program of the Chernobyl NPP Decommissioning' approved by Resolution No. 1747 issued by the Cabinet of Ministers of Ukraine on 29 November 2000 was the principal national-level document that guided activities for the Chernobyl NPP power units decommissioning and transformation of the Shelter Object into an ecologically safe system. In 2009, following adoption of the Law of Ukraine titled 'On the National Program for the Chernobyl NPP Decommissioning and Transformation of the Shelter Object into an Ecologically Safe System', the Comprehensive Program became out-of-date and ceased to be effective. The National Program describes strategies for decommissioning the Chernobyl NPP units and transformation of the Shelter Object into an ecologically safe system. Also, the document includes estimation of funding needs and a list of top-priority activities (till 2013) required to implement the strategies.

During 2008-2009, the following were developed, approved, and carried into effect:

- 'Program for ChNPP Units Decommissioning';
- 'Health Physics Criteria of the Final Condition Resulting from the ChNPP Decommissioning'.

The above documents include a detailed description of the decommissioning activities scheduled till completion of the process (till 2064) and establish numerical values for radioactive contamination levels at the ChNPP site after the decommissioning completion.

Development of the 'Project for ChNPP Units Final Shutdown and Mothballing (FSM)' is in progress. The Project shall become a basic document for obtaining a permission to start the first stage of ChNPP decommissioning activities.

The Project includes a great number of documents. These are 9 separate projects related to mothballing of Units 1,2&3, a set of safety justifications (SAR, EIA, SCR), the Phase Implementation Program to guide the FSM phase activities. The Program is a detailed action plan for the period of 2013-2022.

Development of the 'Program for Research and Development Support to the Activities for the Chernobyl NPP Decommissioning and Transformation of the Shelter Object into an Ecologically Safe System' is in progress. 'The Integrated Program for the SSE ChNPP Radioactive Waste Management' has been revised.

Information technologies

As per 'General Provisions on Nuclear Plants Safety' NP 306.2.141-2008, an operator shall adjust to new conditions an informational support system for decommissioning process prior to start works and operations for a nuclear power plant (unit) decommissioning.

The following were developed and put into operation at the SSE ChNPP:

- CERS database (INFODEC);
- RAW inventory database;
- Integrated Shelter Database (ISDB).

The activities for development and commissioning of the following are in progress:

- integrated system for informational support to decommissioning;
- visualization centre for the Chernobyl NPP decommissioning.

In spite of a lack of experience in large nuclear industrial facilities decommissioning, a large number of works has been accomplished at the ChNPP site. Presently, at the Chernobyl NPP Units shutdown stage, during 2000–2010:

1. working media and potentially hazardous substances were removed out of over 200 process systems;
2. over 370 systems and 700 pieces of equipment and elements were finally shutdown, that is 63% of all existing systems and elements and 98% of a number of the systems and elements subject to final shutdown prior to the fuel complete removal;
3. with the objective to pilot dismantling techniques and gain a relevant experience, over 1000 tons of equipment were dismantled, 12% of the dismantled equipment were decontaminated down to the levels permitting a release from regulatory control;
4. nuclear fuel was removed from Units 1,2&3 reactors that were finally shutdown;
5. comprehensive engineering and radiation surveys of Units 1,2&3 were accomplished;
6. Unit 1 CERS data were updated, update of Unit 2 CERS data was started;
7. a 10-year extension of operating life was ensured for the systems and elements of Units 1&2 that are involved into RAW and SNF management processes (Unit 1 – till 2017, Unit 2 – till 2018). In 2010-2011, the effort to extend operating life of Unit 3 systems and elements is in progress.

5.2.2. ChNPP decommissioning strategy

In accordance with 'The Chernobyl NPP Decommissioning Concept' approved in 2004 that was developed to meet specific conditions of the decommissioning license and with due regard for the international and national experience, regulatory system of Ukraine, and actual condition of the ChNPP site, decommissioning includes the following three phases (Fig. 5.28):

- final shutdown and mothballing of reactor facilities (mothballing of the reactors and the worst radioactively contaminated equipment shall be accomplished at this stage (tentatively till 2022);
- cooling of reactor facilities over the period ensuring natural reduction of radioactivity down to acceptable levels (tentatively till 2045);
- dismantling of reactor facilities (at this phase the equipment shall be dismantled and the site shall be cleaned with the objective to maximally remove restrictions and release regulatory control (tentatively till 2065).

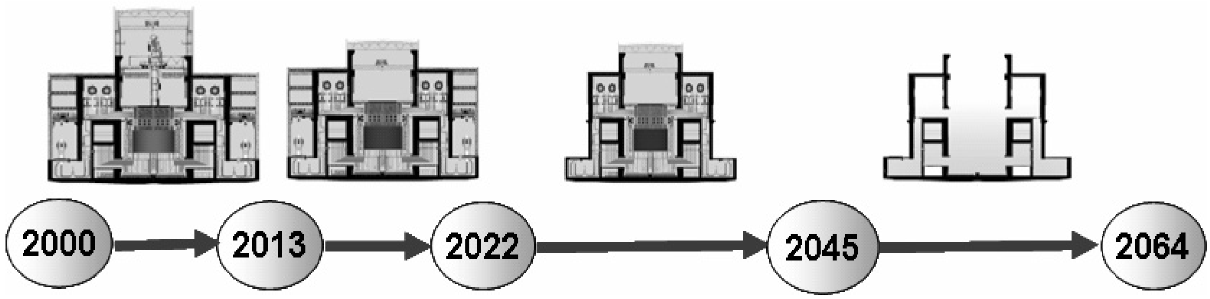


Fig. 5.28. *The Chernobyl NPP decommissioning strategy.*

The Concept outlines the following strategy for the ChNPP decommissioning:

- deferred dismantling (SAFSTOR method, as per the internationally accepted classification)
- early removal of FC;
- dismantling of lifting equipment in CH;
- reconstruction of CH marquees;
- dismantling of external structures;
- cooling of primary circuit (PC) and reactors, up to 50 years;
- engineering structures dismantling and ChNPP site cleanup are not decommissioning activities, they shall be considered within the framework of activities for mitigation of the accident consequences and recovery of the Exclusion Zone.

Currently, the Chernobyl NPP is at the shutdown stage. This is a preparatory stage preceding decommissioning. During this phase, nuclear fuel shall be removed from the power units and dispatched to a long-term storage facility. This is the main task inducing duration of the phase. It shall be completed no earlier than 2013.

The following are the major tasks of the Chernobyl NPP at the shutdown stage:

- maintain safe condition of power units 1,2,3 and existing spent nuclear fuel storage facility;
- develop the infrastructure needed to manage spent nuclear fuel and radioactive waste at the Chernobyl NPP industrial site;
- remove nuclear fuel from the power units;
- complete construction and commissioning of the following:
  - the second storage facility for spent nuclear fuel;
  - liquid radioactive waste treatment plant;
  - industrial complex for solid radioactive waste management;
- develop and approve the following projects:
  - for the phase of Units 1,2,3 final shutdown and mothballing;
  - for reconstruction of transport and process sectors at the existing spent nuclear fuel storage facility;
  - for the damaged nuclear fuel management;
  - for the cooling pond decommissioning;
- upgrade the infrastructure facilities (power supply network, heat and water supply, fire suppression system, telecommunications, etc.);
- remove working media and potentially hazardous substances from systems and equipment;
- finally shutdown, decommission, and partially dismantle some systems and elements at the power units;
- accomplish the comprehensive engineering and radiation survey (CERS);
- implement administrative and technical measures for management, operation, maintenance, and repairs of the systems that shall be in further operation, ensure safety monitoring.

At the stage for the Chernobyl NPP power units' final shutdown and mothballing the following major activities shall be implemented:

- dismantle external (with regard to a nuclear reactor) systems and elements of the facilities that do not impact safety and shall not be required at further stages;
- improve the barriers that prevent from release of radioactivity into the environment;
- safely mothball those parts of the facilities that are not subject to dismantling;
- ensure conditions to allow temporary monitored storage of radioactive substances at the facilities;
- collect and condition the radioactive waste accumulated during the abovementioned activities, transfer the radioactive waste to specific enterprises.

During the reactor facilities cooling phase the following major activities shall be implemented:

- operation of the systems and elements ensuring safe storage of the radioactive substances contained in the mothballed facilities;
- periodical survey of a mothballed facility condition;
- dismantling of equipment that was not subject to mothballing;
- collection and conditioning of the radioactive waste accumulated during the abovementioned activities, transfer of the radioactive waste to special enterprises.

The following are planned for a phase of the reactor facilities dismantling:

- dismantle and remove systems and elements, which contamination level exceeds the removal levels, with the objective to dispatch them for interim storage in radioactive waste storage facilities;
- collect and condition the radioactive waste accumulated during the abovementioned activities, transfer the radioactive waste to special enterprises;
- execute final radiation survey of a site with the objective to confirm that the decommissioning activities are complete.

Since the ChNPP is located within the area that was radioactively contaminated as a result of the 1986 accident and some engineering structures of Unit 3 are common with the Shelter Object, the end goal of decommissioning ChNPP is such a condition that conventionally may be called a 'brown spot'. The 'brown spot' is a condition of a site, where dismantling of equipment, structures, and buildings is complete and radioactivity of engineering structures, being the sources of ionizing radiation, is within the levels established for a restricted release from regulatory control. Actually, this is a cleanup of the site and engineering structures down to the contamination level similar to the one present within the Exclusion Zone around the ChNPP and resulting from the 1986 accident. However, in the current context such a final status of the ChNPP site is economically inadvisable.

Currently, the ChNPP is endeavouring to prepare a new Decommissioning Concept that will identify the site's new final status, i.e. an 'industrially developed site'. Development of the ChNPP site shall not only remove the burden from the state budget that is imposed by the upkeep of the Exclusion Zone, elimination of the Chernobyl accident consequences and ChNPP decommissioning, but also recover economic activity on the restricted lands, take the maximum benefit, turn the lands into an economically developed area. For this purpose, it is necessary to efficiently use the following specific features of the Exclusion Zone and ChNPP industrial site:

- simultaneous decommissioning of three metal-intensive units;
- availability of the undeveloped operational structure, i.e. the systems of communications, power supply, physical security, water supply, radiation monitoring and railroad and motor access ways;
- isolation from centres of population;
- availability of the personnel competent in radioactive material management;
- location within the Exclusion Zone, being the a restricted use area.

We propose to more actively use the above specific features and potentialities of the ChNPP industrial site and Exclusion Zone for the needs of Ukraine's nuclear industry, with regard to the final link in a nuclear energy uses technique (nuclear power plant units decommissioning and radioactive material management), for example:

- develop a centralized system for the Ukrainian NPPs SNF management within the Exclusion Zone and provide the ChNPP with an operator status;
- launch production of RAW long-term storage/disposal containers for Ukraine's nuclear industry and establish an integrated unified SNF and RAW transportation and processing pattern to enable the following:
  - recycle the Exclusion Zone's radioactively contaminated materials for the purpose of RAW storage containers production, which will also allow a significant reduction in the total volume of radioactively contaminated waste;
  - save government funds spent on disposal of the branch-produced RAW;
- establish a complex facility for the NPPs' RAW management within the Exclusion Zone, the facility shall include:
  - a plant for large-sized equipment processing and interim storage;
  - a complex facility for processing and remelt of the radioactively contaminated metal from nuclear facilities (including the ChNPP and Exclusion Zone) and industrial complex of Ukraine.
- on the basis of the Chernobyl NPP training centre, establish a head training centre in Ukraine for training, retraining, and advanced vocational training of personnel in decommissioning and RAW management techniques.

5.2.3. Development of RAW management infrastructure

According to the National Program of Decommissioning, the most crucial now are RAW management activities, in terms of the Chernobyl NPP safe decommissioning and the Shelter Object (SO) transformation.

The total volume of RAW subject to processing during the ChNPP Units DM and the SO transformation into an ecologically safe system in the course of 35 years (prior to a start of the decommissioning phase) amounts to 140 000 m^3 (exclusive of the SO structures as such). Therefore, development of an integrated RAW management system applicable to the ChNPP conditions is among the urgent tasks faced by the SSE ChNPP today.

Currently, the following facilities are available at the ChNPP:

for RAW management:

- ChNPP and SO floor drain processing system;
- solid RAW storage facility;
- liquid RAW storage facility;
- solid & liquid RAW storage facility;
- solid RAW interim storage facility

for radioactively contaminated material management:

- decontamination sites;
- interim storage sites for contaminated large-sized equipment;
- interim storage site for process materials.

The existing system for RAW management was designed for an operating NPP. The task was to change the RAW management system into a system for RAW management at an NPP subject to decommissioning. For the first time, the strategy of an integrated RAW management system development at the ChNPP site was outlined in the ChNPP Decommissioning Plan (CDP) elaborated in

1996 under TACIS Program. The document specifies a list and key features of the facilities to be constructed on the plant's site in order to ensure the process for power units decommissioning and radioactive waste (RAW) management: a plant for liquid radioactive waste collection, transportation, and cementation; a plant for solid radioactive waste collection and processing, the RAW disposal site.

Currently, the above listed facilities are being developed at the Chernobyl NPP site under the international community's support through a number of projects:

– liquid radioactive waste treatment plant;
– industrial complex for solid radioactive waste management;
– complex for producing metal drums and reinforced concrete containers to store radioactive waste;
– improvement of the Chernobyl NPP facilities for long-length scrap fragmentation.

Liquid Radwaste Treatment Plant (LRTP)

The LRTP (fig.5.29 look the coloured inset) is designed for treatment of liquid radioactive waste accumulated over the operation time, those generated in the course of ChNPP decommissioning, and also operation SO LRAW. The LRTP is designed to process LRAW over the 10 year operation life. It minimal design capacity is 2500 cubic meters of unprocessed LRAW per a year. The plant is within the ChNPP protected perimeter in the vicinity of the Liquid Radwaste Storage Facility and is interfacing with the latter through process pipelines installed on the enclosed pipe rack.

The LRTP is built up from: the unit for liquid radioactive waste (LRAW) removal from the existing storages; the unit for LRAW hauling to the treatment unit; the treatment unit – LRAW concrete fixation aimed at sealing and immobilisation.

Hardened liquid radwaste in the form of concrete compound, i.e. final product is packed in 200-liter drums and is hauled in reinforced concrete containers to the location of conditioned RAW long-term controlled storage. This location is LOT-3 of the Industrial Complex for Solid Radioactive Waste Management.

LRTP Design was approved by the Cabinet of Ministers of Ukraine Decree No.105p dated 22 March 2001.

The plant is constructed under the Chernobyl NPP Nuclear Safety Project funded by EBRD financed under the Nuclear Safety Account as per Grant Agreement with the European Bank for Reconstruction and Development dated 12.11.96. The works were commenced in 1999 under Contract No.ChNPP C-1/2/036 dated 16.09.1999. Consortium formed by BELGATOM\SGN\ FINMECANNICA SpA D'AZIE A ANSALDO NUCLEARE was the Contractor. Initial schedule had 31.12.2001 as the construction completion date.

In view of repeated works cost increase and project duration period extension, and also due to inadequate performance of the Contractor it was decided at consent of the Nuclear Safety Account Donor Countries Assembly to transfer LRTP completion from the Consortium lead by Belgatom, the Main Contractor, for direct management by the Employer (SSE ChNPP). On 18.09.2006 all the works at LRTP were stopped, one month was spent for proper transfer of the facility from the Contractor to the Employer as a result of LRTP contract termination. The LRTP has been in the 'incomplete construction' status since the date of contract termination. The SSE ChNPP maintains life support systems of the facility.

The Contractor handed over the facility to the Employer in the state actual at the moment of execution of the agreement (construction and installation works were complete for 90%, installation of equipment for 16 %, the design was 50 % inconsistent with normative and technical documentation). Contract Value increased by approximately 50% over that period.

From the moment of contract termination till positive decision on further funding of LRTP completion works (at the Donor Countries Assembly conducted 17–18 July 2007) the SSE ChNPP conjointly with the Chernobyl Safety Project Management Unit carried out the following activities aimed at further implementation of the LRTP project:

- technical assessment of systems and facility state upon termination of the contract with consortium;
- determined the scope of works on LRTP project completion;
- estimated LRTP project completion cost;
- determined LRTP project completion duration;
- project implementation risks were determined and analysed;
- 'LRTP completion strategy' was developed and concurred by EBRD;
- 'LRTP completion plan' was developed and concurred by EBRD.

As per the developed 'LRTP completion strategy' all the activities required for project completion were divided into 4 packages:

A – design and safety justification;

B – procurement, installation, setup, testing of equipment and entire plant;

C – ensuring functioning of automated process control systems;

D – expert and advisory services.

Tender exercises take place and contracts are signed for each package as per the EBRD Procurement Policies and Rules. LRTP construction activities are currently nearing completion. Commissioning is scheduled to start in the latter half of 2011.

Industrial Complex for Solid Radioactive Waste Management (ICSRM)

The Industrial Complex for Solid Radioactive Waste Management (ICSRM) (fig.5.30 look the coloured inset) is designed for solid RAW removal from the ChNPP Solid RAW Storage Facility (SRSF), processing, packing and temporary storage. The ICSRM is formed by four interfacing units (lots):

Lot 0: Temporary Storage Facility for Solid Waste of Category III, Low- and Intermediate Level Long-Lived Waste (HLW & LIL LLW);

Lot 1: Unit for RAW removal from the SRSF;

Lot 2: Solid RAW sorting, conditioning and processing plant (SRPP);

Lot 3: Specially Equipped Shallow Ground Repository for Solid Low- and Medium-Level RAW, located at the 'Vektor' Complex site.

The Employer and Beneficiary in respect of Lot 1 and 2 is SSE ChNPP, as regards Lot 3 – SSE 'Tekhnotsentr.' ICSRM construction works were carried out in accordance with the design approved by CMU Decrees No.816-p dated 26.12.2003, No.659-p dated 27.12.2006. As per Contract 1L10/99 signed on 05.03.2001 the NUKEM Technologies GmbH (Germany) was the Contractor. All the works under the Contract have been completed to date. On 24.04.2009 the Contractor was provided with the Completed Facility Acceptance Certificate, authorization for Lot 1, 2 commissioning was obtained. Works on Lot 3 were completed in February 2010. Commissioning is expected to be complete in the former half of 2011. However, it should be mentioned that the below listed issues having direct impact on facilities operation efficiency are still pending:

- criteria of solid RAW acceptance to the SRPP are too conservative, which will require additional operations be performed on characterisation and sorting of solid radioactive waste generated in the curse of ChNPP decommissioning and SO conversion prior to their acceptance for conditioning;
- too conservative criteria of conditioned RAW acceptance for disposal that will result in their amount increase;
- high operating costs.

Complex for Producing Metal Drums and Reinforced Concrete Containers to Store SSE ChNPP Radioactive Waste (CPMD&CR)

The Complex for Producing Metal Drums and Reinforced Concrete Containers to Store SSE ChNPP Radioactive Waste (fig. 5.31 look the coloured inset) shall facilitate safe processing, transportation, and storage of the processes RAW. Casks of 3 m^3 in capacity and round metal drums (primary package) with lids of four types differing in size, design, materials and operation life will be produced. The Complex is constructed under Contract No.99691 dated 28.12.2007 by the Ukrainian Corporation 'UkrTransBud.' The project is funded by the European Union. Construction and installation works at the construction site in the Slavutich Industrial Zone are currently nearing completion. Works completion as scheduled under the Contract is second quarter of 2011.

Improvement of the Chernobyl NPP facilities for long-length scrap fragmentation

Equipment and special products utilised in reactor cores during operation (fig. 5.32 look the coloured inset) are currently stored in cooling pools, process pits, as well as ChNPP Unit 1, 2, 3 reactors. Their processing will result in approximately 2000 m^3. Moreover, ISF-1 cooling pools contain about 18000 stainless steel canisters over 10 m long, currently containing Spend Fuel Assemblies (SFA) and will be empty once SNF is sent to ISF-2. Practically all the special products are from 6 to 22 meters long, which requires using special equipment and process for their treatment (fig. 5.33 look the coloured inset). Furthermore, special products activity varies along their length depending on location relative to the core centre. Therefore, differentiated approach shall be applied while radiation condition is determined and in selection of preliminary treatment methods for the special products. Improvement of the Chernobyl NPP facilities for long-length scrap fragmentation is exactly aimed at handling these problems.

The improvement of the Chernobyl NPP facilities for long-length scrap fragmentation project is implemented being supported by the EU under Contract TACIS/2007/132-889 dated 03.08.2009, the Contractor is AMEC Nuclear International Ltd, (UK). Project completion date is 02.02.2013 (365 days warranty period included).

With progress of works on decommissioning and Shelter Object conversion into an ecologically safe system amount of RAW differing in type and activity considerably increases requiring quite a few facilities for RAW management in accordance with effective norms and standards. This applies to removed reinforced concrete structures and metalwork, cable products, building refuse. According to comprehensive engineering and radiation survey 90 thousand tons is the amount of contaminated metal from 3 power units, 80% of the amount are radioactively contaminated. Therefore arrangement of an integrated RAW management system at the ChNPP Site is one of priority tasks.

The listing of additional facilities required has been generated under the 'National Ecological Program for Radioactive Waste Management' (Table 5.2):

Required facilities	Commissioning date
Plant for LRAW Preliminary Treatment including TUE and Organic Substances Removal	2012
Buffer Storage for LML-SLW, Buffer Storage for Removed Contaminated Equipment	2013
Solid LML-LLW Management Area	2012
Cable Products Processing Plant	2012
LLW and HLW Storage Facility	2013
Complex for Radioactively Contaminated Metal Processing	2013
Fragmentation and Large-Size Equipment Disassembling Area	2012

Activities have started on some of the items. For instance, a pilot plant for organic substances and TUE removal from SO water is currently under trial operation, since it will be used for proposed treatment method testing. These activities are supported by the IAEA. Upon its approbation the next phase will start, i.e. full-scale plant construction.

Construction and commissioning of the new ChNPP facilities will substantially expand processing capabilities for radioactive waste generated in the course of units decommissioning and conversion of the Shelter Object into an ecologically safe system.

5.2.4. Interim Spent Nuclear Fuel Dry Storage Facility (ISF-2)

Spent fuel assemblies (SFA) of the Chernobyl NPP are stored in the spent fuel pool (ISF-1), commissioned in 1986, and at-reactor spent nuclear fuel (SNF) cooling pools.

More than 21 thousand nuclear fuel elements (spent fuel assemblies) have accumulated at the Chernobyl NPP site over the period of its operation. Design capacity and design period of safe ISF-1 operation do not allow placement of all the ChNPP SFA for long-term storage, which raised the need for another spent fuel storage facility be constructed (ISF-2) (fig. 5.34 look the coloured inset).

The 'Memorandum of Understanding between governments of the G7 countries, European Commission and Ukrainian government regarding decommissioning of the Chernobyl NPP' was concluded on 20 December 1995. Power units defueling is the prerequisite to transfer from the shutdown stage to decommissioning. Following the domestic and world experience of spent fuel management the open international tender resulted in a dry fuel storage facility with fuel stored in leak tight canisters located in ventilated concrete modules selected for construction at the Chernobyl NPP.

ISF-2 construction will facilitate long-term storage of the gross volume of SNF accumulated at the Chernobyl NPP, as well as ISF-1 decommissioning. On 12.11.1996 Grant Agreement No.006 was signed between the European Bank for Reconstruction and Development (hereinafter – EBRD), Ukrainian Government and Chernobyl NPP, and ratified by the Verkhovna Rada of Ukraine on 18.03.1997. According to this Agreement with EBRD the ISF-2 construction is funded by the Nuclear Safety Account.

The FRAMATOME Company was the first Main Contractor. ISF-2 construction was stopped in April 2003 due to considerable deviations from the Terms of Reference, and the Contract with FRAMATOME was terminated. Contract ChNPP/C2/10/062 for ISF-2 project completion was signed between the SSE ChNPP and Holtec International on 17.09.2007.

Pursuant to the Contract terms the project is implemented in two the stages (Authorisations):

- Authorisation 1 – design documentation development, support of the State Comprehensive Expert Review and design approval, support of the process for obtaining authorisation for resumption of the construction;
- Authorisation 2 – supply of materials and equipment, construction and installation works, pre-commissioning test, support of obtaining authorisation for ISF-2 commissioning.

As per the Contract Work Schedule the design 'SSE ChNPP. Interim Spent Nuclear Fuel Storage Facility (ISF-2). Construction Completion Design' and ISF-2 Preliminary Safety Analysis Report (PSAR) have been developed. ISF-2 will facilitate acceptance for storage, preparation for storage, and storage over 100 years of more than 21000 SFA of LWGR-1000 (light-water-cooled graphite-moderated reactor) at the capacity of 2500 SFA per a year. ISF-2 is composed of the two parts:

- Spent Fuel Storage Preparation Unit (SFSPU).

SFSPU function lies in preparing for storage and packaging of more than 21 000 SFA, about 2 000 SFC (spent fuel canisters) and over 23 000 shim rods received form ChNPP power units 1, 2 and ISF-1. The Unit is designed for ensuring minimal annual productive efficiency of processing 2500 SFA or SFC.

- Spent Fuel Storage Zone (SFSZ)

The following operations are performed in the SFSZ:

- hauling of canisters filled with spent fuel from the SFSPU to SFSZ by means of the Canisters Handling and Transportation System;

– placement of canisters into horizontal concrete storage modules (CSM) of 100 years design life;
– storage of nuclear fuel canisters over 100 years.

The forecast date of ISF-2 construction completion and start of its commissioning is middle of 2013.

5.3. International collaboration for Shelter Object conversion and ChNPP decommissioning

The accident of 1986 at the ChNPP affected drastically life of millions of people and resulted in a deep concern of the world community. Overcoming of its consequences required efforts of the global community be integrated, therefore international collaboration became essential for the accident consequences elimination. Since 1990 international collaboration was focused on improving safety and the following priority directions were determined: final shutdown of the ChNPP and conversion of the destroyed unit four into an ecologically safe system.

Conversion of the Shelter Object into an ecologically safe system was and remains one of the major challenges associated with elimination of the Chernobyl accident consequences and environmental safety.

The first step within the international collaboration in the mentioned direction was the international contest of designs and technical solutions for SO conversion into an ecologically safe system announced in 1992. The contest resulted in the Concept of gradual conversion of the SO an ecologically safe system selected, which included stages of stabilisation of the existing Shelter Object, construction of a new structure confining the SO (‘Shelter-2’), construction of shallow ground repositories, removal, conditioning and placement of SO radioactive materials in storage facilities.

In 1993 the European Commission called for tenders for feasibility study (FS) of the first concept stages, i.e. stabilisation of the existing Shelter Object and ‘Shelter-2’. The ‘Alliance’ Consortium lead by the French Company ‘Campenon Bernard SGE’ became the selected tenderer.

On 11 September 1995 Brussels hosted the European Commission session attended by Ukrainian delegation and dedicated to determination and coordination of further joint measures based on ‘Alliance’ Consortium studies. The meeting resulted in the agreement concluded in the frame of the TACIS project between the European Commission and ‘Alliance’ Consortium and ‘Trischler und Partner GmbH’ Company for development of short and long-term measures. The Recommended Policy establishing potential short- and long-term measures and proposing set of first-priority measures was developed under this project.

Further efforts under the project ‘Chernobyl Unit 4. Short- and Long-Term Measures’ at cooperation of the European Commission, Ukraine, the USA and international experts group resulted in the ‘Shelter Implementation Plan’ (SIP) developed, which was accepted at the meeting of the Group of Seven in June 1997. The Plan established the main concept, including the set of steps aimed at SO conversion into an ecologically safe status.

On 20 November 1997 the conference of the Donor Countries took place in New York; attendees pledged liabilities for the specially established Chernobyl Shelter Fund (CSF) for the Plan implementation. The European Bank for Reconstruction and Development (EBRD) was entrusted with the Fund management task. The Agreement (‘Framework Agreement’) between Ukraine and EBRD was also signed at the conference. Today, the number of Donor Countries equals 28.

On 20 April 1998 the Contract for SIP Project Management Unit Consultant was signed with the selected tenderer. The Consortium formed by Bechtel (USA), Battelle (USA) and EDF (France) became the winner.

The SIP was recently progressing. In 2008 the first phase of the Plan was completed. Shelter Object structures were accepted for operation upon their stabilisation measured under the Deed of the State Acceptance Committee dated 29 October 2008. Design for Stabilisation was developed by the

Ukrainian consortium formed by the Kyiv Institute ‘EnergoProekt,’ Research Institute of Engineering Structures and NPP Safety Problems Institute of the National Academy of Sciences of Ukraine. Construction was performed by the Main Contractor composed of the ‘AtomBudEksport’ Close Corporation Close, ‘Rivno NPP Construction Department’ Corporation, ‘UTEM’ Public Corporation, Ukrainian Design and Technological Institute ‘AtomEnergoBudProekt,’ and State Enterprise ‘UTEM-Engineering’. This is the major project implemented under the SIP. The tender for the New Safe Confinement (NSC) construction was held in the same year and the contract was awarded to the winner, the NOVARKA Consortium. NSC construction works are in progress. While not every safety important measure envisaged by the SIP is implemented. For instance, development of a method for fuel containing materials (FCM) removal from the destroyed unit four (Task 20) and removal of transuranium elements and organic substances from Shelter Object water (Task a 13) were postponed for indefinite term and their funding under SIP was stopped. Collaboration with the Donor Countries must be renewed at the national level regarding resumption of these measures critical in terms of safety within the SIP and potential fundraising thanks to new donor countries.

The ChNPP also actively collaborates with the global community as for the decommissioning.

Initial attempts of estimating ChNPP decommissioning cost were made under the TACIS program. In 1996 the AEA Technology Company developed the ‘Chernobyl Decommissioning Plan’ (CDP). According to the CDP equipment mothballing within the existing structures for at least 30 yeas including minimal work on reactor installations dismantling was acknowledged to be the most appropriate option.

Moreover, the CDP provides approximate man-hours calculations, financial needs of the whole ChNPP decommissioning project before the mothballing phase, lists and provides basic characteristics of major facilities to be constructed at the plant site to enable power units decommissioning and radioactive waste (RAW) management.

In 1996 the ChNPP Nuclear Safety Project was launched. The project is funded under the Grant Agreement between Ukraine and EBRD, and also Nuclear Safety Account. ChNPP Unit 3 safety enhancement measures were implemented under this project, and process of the Liquid Radwaste Treatment Plant and Interim Spent Fuel Storage Facility (ISF-2) design are currently subject to improvement.

In 1997 works on Heat Plant (HP) construction completion commenced funded through the international aid (the US Department of Energy), as well as Ukrainian contribution. The Heat Plant designed for heat supply to the site facilities upon final power units shutdown, was commissioned in June 2001.

Today, Ukraine is one of the major countries receiving technical aid from the European Union. 5 projects initiated in the frame of the TACIS Technical Aid Program for the CIS countries are at different implementation stages at the ChNPP Site:

- the put into operation Industrial Complex for Solid Radioactive Waste Management (ICSRM);
- additional works associated with ICSRM are underway, including installation of ventilation system in building 84;
- Complex for Producing Metal Drums and Reinforced Concrete Containers to Store SSE ChNPP Radioactive Waste;
- improvement of the Chernobyl NPP facilities for long-length scrap fragmentation;
- arrangement of the ChNPP decommissioning information support system.

The project ‘Arrangement of the ChNPP decommissioning information support system’ was launched on 26 May 2009 as a result of the need for storing and update of information gained in the course of ChNPP units decommissioning. Implementation of the project will allow selection of the most optimal organizational and technical solutions for decommissioning; ensuring support for planning of the decommissioning; storing and update of information gained at each stage of the decommissioning.

Since 2001 the IAEA provides purposeful support to Ukraine as regards decommissioning of the ChNPP. Starting from 2001 the ChNPP receives technical aid under four national projects that are mostly aimed at supporting implementation of the tasks set forth in the National ChNPP Decommissioning Program, and also radioactive waste management at the Chernobyl site. The IAEA support is exercised in the format of seminars, trainings, expert missions, visits aimed at experience exchange. Major directions within the collaboration is transfer of experience and knowledge regarding development of documentation on decommissioning, decommissioning safety assessment, dismantling and contemporary equipment decontamination methods; support in arrangement and improvement of the ChNPP RAW management system, including SO radioactive materials; establishment of the personnel management system for the decommissioning purposes.

IAEA experts participate in development and update of a number of important documents, such as ‘Integrated RAW Management System’, ‘Decommissioning Design’ and other documents governing the RAW management process and decommissioning issue.

Furthermore, the following projects implemented during 2004–2006 supported by the UK Department of Trade and Industry (DTI) should be also mentioned as they are aimed at elaboration of documentation on decommissioning and other new facilities required for licensing. Norway is currently expressing its readiness to render support for activities concerning ChNPP units decommissioning and Shelter Object conversion, which was reflected in the Protocol of Intent signed on 28.11.2006.

We hope that attention of the international community to the Chornoyl NPP and Shelter Object will not cease on the day, when Arch will be slid, and Ukraine will not be left alone with its problems.

6. MANAGEMENT OF RADIOACTIVE WASTE GENERATED AS A RESULT OF THE CHERNOBYL CATASTROPHE

6.1. Chernobyl accident RAW: management history, types and amounts of RAW, current status, issues and paths forward

Since 26 April 1986 over the course of time the constituent of problems related to radioactive waste of Chernobyl (accident) origin within the state system of radioactive waste (RAW) management has been reducing. It is not only due to considerable waste activity lowering as a result of natural radionuclides decay, especially short-lived, but to the course to further nuclear energy utilisation for electrical power generation, proclaimed by Ukraine, which requires development of the industry.

Nevertheless, basic strategic tasks on reliable RAW confinement, including high-level and long-lived waste, are still vital. Reliable protection from adverse radioactive waste effect may be ensured to the present and future generation only in case of geological repository construction.

Analysis of the Chernobyl catastrophe consequences elimination leads to understanding of the need in having the own national system of nuclear legislation. Based on the experience of the most advanced countries, public relations must be managed legally at any activities in the nuclear energy field, establishment and functioning of the legal bases for the system of nuclear and radiation safety control and management, ensure obviousness of the priority of public and environmental protection against ionizing radiation effect.

Rather complete and balanced national legal system was established, when Ukraine gained its independence. The Verkhovna Rada of Ukraine ratified a number of international conventions, namely:

Convention on Nuclear Safety;

Convention on the Early Notification of an Accident;

Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency;

Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and so on.

The Law of Ukraine 'On Nuclear Energy Use and Radiation Safety' enacted in 1995 presents the basic law in the area of nuclear energy utilization. The following laws of Ukraine could be also regarded to the nuclear legislation system:

'On Radioactive Waste Management';

'On Population Protection against Ionizing Radiation Impact';

'On Physical Protection of Nuclear Facilities, Nuclear Materials, Radioactive Waste and Other Ionizing Radiation Sources';

'On General Provisions of Further Operation and Decommissioning of the Chernobyl NPP and Conversion of Destroyed Unit Four of the NPP into and Ecologically Safe System';

'On Licensing Activities in the Nuclear Energy Field';

'On Civil Liability for Nuclear Damage and its Financial Provisions,' etc.

The Law of Ukraine 'On Radioactive Waste Management' [1], development of which was initiated by specialists of the State Committee of Population Protection against Consequences of Accident at the Chernobyl NPP, introduced rather progressive for that time legislative regulations, specifically, legally established isolation of the radioactive waste management field from nuclear energy application in order to preclude departmental approach to ensuring safety in case of their long-term storage or disposal. Entities generating radioactive waste were prohibited from radioactive waste disposal. Disposal of liquid waste, as well as waste in explosive, inflammable and nuclear-hazardous form was also prohibited. In view of considerable period of radioactive waste hazard the law sets forth that RAW become property of the state, once they are transferred by waste generators to specialized entities.

The law [1] states that the state RAW management policy-making process includes development and implementation of the State RAW Management Program, which is subject to revision and approval by the Cabinet of Ministers of Ukraine every three years.

The next step in establishing of the state radioactive waste management system was approval of the State RAW Management Program by Cabinet of Ministers of Ukraine Decree No.480 dated 29 April 1996 [2]. This program was further revised and approved by Decree of the Cabinet of Ministers of Ukraine (CMU Decree No.542 dated 05.04.1999 [3], No.2015 dated 25.12.2002 [4]). Though the status of the State RAW Management Program was lowered to a comprehensive program in its following revisions**.**

Major tasks set forth in the State RAW Management Program are as follows:

- development of normative and legal environment on RAW management;
- ensuring activities compliance with legal requirements;
- commissioning of the ‘Vektor’ Complex Stage One for decontamination, transportation, processing and disposal of RAW from the territory that was subject to radioactive contamination as a result of the Chernobyl catastrophe;
- design and construction of the ‘Vektor’ Complex Facilities Stage Two for processing and storage of high-level and long-lived RAW;
- technical re-equipment and change of function of state regional specialised complexes of the State Corporation ‘Ukrainian State Association ‘Radon’ for collecting and containerised storage of any RAW from all Ukrainian radioactive waste generators;
- establishment and maintenance of the state register of RAW and state cadastre of RAW storage and disposal sites;
- construction of a geological repository for radioactive waste and so on.

The experience gained in implementation of actions under the State RAW Management Program evidences of required conformity to plan and coordination of works unachieved, as well as incompliance with results of previous studies on geological repository construction. One of the reasons is lack of permanent funding. The National Report of Ukraine ‘Twenty Years After Chernobyl Accident. Future Outlook’ states that owing to lack of aggressive and efficient management and, consequently, permanent financing none of the state of programs on radioactive waste management was fully implemented [5].

6.2. Establishing system for containment, storage and disposal of RAW generated as a result of the Chernobyl catastrophe

The accident at the ChNPP led to generation of enormous amounts of RAW being considerably larger than amounts of RAW collected as a resultant of other types of activities associated with utilisation of nuclear power, ionising radiation sources and radiation technologies.

Major locations of RAW generated as a result of accident at the ChNPP are as follows:

- Shelter Object;
- RAW disposal sites (Radioactive Waste Disposal Site (RWDS) ‘Buriakivka’, ‘Pidlisnyi’, ‘ChNPP Stage III’);
- temporary RAW localisation sites (TRWLS);
- natural and technogenic environment within the ChNPP Industrial Site and adjacent territory;
- decontamination waste storage sites (DWSS) and machinery special treatment sites (STS) located outside the Exclusion Zone.

As of 2010 [6] total amount of RAW in the Exclusion Zone (excluding the Shelter Object) is about 2800 thousand m^3, 1940 thousand m^3 of which are located at RWDS and TRWLS of total activity about 7.25E+15 Bq (according to the 4-th state inventory reconciliation, 2010 [7]). Overall activity of radioactive substances on natural sites of the Exclusion Zone (in upper layer of soil, benthal deposits, vegetation, etc.) is above 8.50E+15 Bq.

RAW of Chernobyl origin are extremely varied in radionuclide composition, specific activity levels and material constitution. Presence of a wide range of radionuclides, including long-lived ones, is characteristic for these wastes. As accident ones, they are stored under conditions that do not fully comply with the contemporary normative requirements for radiation safety. Radionuclide release followed by ground water contamination is observed at most of the Exclusion Zone RAW storage facilities. It is the resultant of absence of an adequate system of engineering barriers and recurrent underflooding of some TRWLS.

Shelter Object operation, including the period of its conversion into an ecologically safe system (stabilisation stage), leads to generation of great amounts of solid RAW disposed at the RWDS 'Buriakivka'.

Overall amount of up to 500 thousand m^3 of low and medium-level RAW is represented by soil, metal, concrete, equipment, various materials and so on are located at the ChNPP Industrial Site. As of 01.01.10 [6] solid and liquid waste storage facilities contain:

SRAW – 2500 m^3 of activity 1.40E+14 Bq,

LRAW – 19800 m^3 of activity 3.85E+14 Bq.

According to the approved 'Strategy of Shelter Object Conversion into an Ecologically Safe System' fuel containing materials, high-level and other long-lived waste must be removed from the Shelter Object and hauled to geological repositories. The first stage of the Strategy – Shelter Object structures stabilisation and the second – NSC construction and preparation for FCM removal are implemented under the project 'Shelter Implementation Plan'.

The issues involved in Shelter Object conversion in to an ecologically safe system associated with substantiation of unique NSC structure reliability should be supplemented with the need for developing technical means for FCM removal, their sorting, conditioning and packing, as well as means for their transportation to storage facilities. Problems of management of radioactive waste generated in the course of preparatory works for NSC foundations construction also require resolution.

From 1987 to 2010 the Sate Specialised Enterprise 'Complex' collected, processed and transported RAW within the Exclusion Zone, maintained the functioning radioactive waste disposal site (RWDS) 'Buriakivka', was monitoring the mothballed RWDS 'Pidlisnyi' and RWDS 'ChNPP Stage III', as well as temporary radioactive waste localisation sites (TRWLS). RWDS and RWTLS within the Exclusion Zone were created under extreme post-accidental conditions in 1986 and do not comply with the effective normative requirements to facilities designed for RAW management.

The RWDS 'Buriakivka' has been in operation since 1987. The RWDS 'Buriakivka' was aimed at storage of RAW with exposure dose rate (EDR) up to 1 R/h at waste surface. Decree of the Government Committee authorized receipt of waste of EDR up to 5 R/h. The RWDS is still operating. As of 01.01.2010 overall capacity is 690 thousand m^3, 606 thousand m^3 occupied, activity is 2.51E+15 Bq [6].

RWDS 'Buriakivka' storage facilities are surface, trench type. Total number of trenches is 30. Design capacity of a filled trench is 22 thousand m^3. The space available at the RWDS is about 35 thousand m^3, which resulted in its reconstruction planned.

Due to occupied design capacity of the RWDS 'Buriakivka' the operator SSE 'Complex' plans reconstruction of the RWDS 'Buriakivka' in order to create extra facilities for disposal of low-level RAW that will be generated as a result of works at the Chernobyl NPP and Exclusion Zone. Safety reassessment in terms of ensuring operational and long term disposal safety with consideration for all RAW amounts planed for disposal and protective barrier status has been also designed.

The RWDS ‘Pidlisnyi’ has been in operation since December 1986 through 1988. RAW of EDR up to 50 R/h were accepted by the RWDS ‘Pidlisnyi’, then based on Governmental Committee Decree RAW of EDR up to 250 R/h were received. Overall amount of RAW is 11000 m^3, total activity is assessed as 2.59E+15 Bq [6].

To date, preliminary assessment of the RWDS ‘Pidlisnyi’ safety has been made. Considering the above mentioned assessment, mothballing design was developed, implementation of which will allow of strengthening of the existing engineering barriers of the storage facility and monitoring system improvement. Expert review of nuclear and radiation safety of the design is nearing completion. In its implementation, major attention should be paid to ensuring radiation safety of personnel engaged in works under complex radiation conditions on the territory of the storage facility.

Practically all RAW of the RWDS ‘Pidlisnyi’ are long-lived ones and should be disposed in a geological repository. Numerous cracks in concrete foundation and walls of the facility necessitate full-scale examination of its structures and implementation of required safety enhancement measures.

The RWDS ‘ChNPP Stage III’ (was in operation till the end of 1986) was constructed for RAW with EDR up to 1 R/h, but waste with higher EDR were accepted there. The RWDS contains 26.0 thousand m^3 of low and medium-level waste, including long-lived ones, of total activity 3.43E+14 Bq [6].

Design of this RWDS mothballing has been developed; its implementation will allow of additional barriers installation to preclude ingress of atmospheric precipitations to the storage facility, as well as monitoring system improvement. Positive conclusion was provided as a result of the state comprehensive expert review for NRS of the storage facility mothballing design.

There are nine TRWLS within the Exclusion Zone: ‘Yaniv Station’, ‘Petroleum Storage Depot’, ‘Sandy Plateau’, ‘Red Forest’, ‘Former Construction Laydown Area’, ‘New Construction Laydown Area’, ‘Prypiat’, ‘Kopachi’, ‘Chystogalivka’.

Temporary RAW Localisation Sites (TRWLS) present facilities constructed in 1986–1988 as a result of decontamination of sites and Exclusion Zone territory with wastes localisation in situ, in common trenches or piles having no engineering barriers. TRWLS trenches were excavated, filled and backfilled by Civil Defence paramilitary units under high levels of ionising radiation, consequently, design documentation is absent, as well as topographical coordinates of the sites.

There are about 1000 trenches and piles within the overall area of the nine TRWLS of approximately 10 km^2. For convenience of record keeping trench groups are divided into sectors named after the territory.

Over a half of TRWLS has not been investigated to date even after twenty five years after the accident. Neither location nor characteristics of accumulated RAW are known for part of TRWLS to date. TRWLS ‘Petroleum Storage Depot’ and ‘Sandy Plateau’ were completely examined, ‘Red Forest’ and ‘Yaniv Station’ were partially examined over the previous years. Wastes in TRWLS are presented by contaminated soil, equipment, metal, concrete, building materials, wood, remains of destroyed domestic houses, debris and so on. According to estimates TRWLS contain up to 1300.0 thousand m^3 of waste of total activity 1.80E+15 Bq [6]. Bulk of them is low-level RAW. Practically all wastes contain long-lived radionuclides. All the TRWLS are situated within the territory of high water table; about 100 waste trenches are permanently or periodically flooded.

They should be characterised (amount and activity of RAW, nuclide composition, storage conditions) in order to assess their safety, determine radionuclide migration dynamics and develop measures for minimisation of their negative effect. Advisability and sequence of RAW removal from current locations and re-disposal may be determined only on the ground of the above mentioned assessments.

Safety analysis and environmental impact assessment are necessary for a decision be taken on further brining of RAW storage facilities in compliance with radiation safety requirements and optimisation of RAW conservation or re-disposal costs. Particular administrative measures, risks and countermeasures assessment shall be developed to prevent incidents during construction and operation of new RAW management facilities. Consequently, assessment methodologies for risks, emergency response plans and countermeasure designs should be updated and approved. Introduction of an integrated monitoring system for RAW storage facilities, environment within RAW storage facility areas, especially general hydrological and hydrogeological situation within the Exclusion Zone, is vital for taking informed decisions.

Since 2002 TRWLS examination and inventorying have not been done. 235 disposal locations were identified, 15 % of those are flooded. Flooding depth (from trench bottom to ground water table) is from 0.3 to 2.2 m in during flood season.

Re-disposal is a possible way of fundamental changing the situation for precluding release of radionuclides from TRWLS. However not all the trenches are filled with radioactive waste. Some of them may be released from regulatory supervision due to corresponding levels reached.

In the course of accident consequences mitigation activities outside the Exclusion Zone a certain number of special sites was created that are still under monitoring and being maintained, namely:

- machinery special treatment sites (STS) designed for vehicles and machinery decontamination;
- decontamination waste storage sites (DWSS).

As of 01.01.11, total number of such sites that are registered and controlled is 54, including: Zhytomyr oblast – 29 DWSS 18.7 thousand m^3 in capacity; Kyiv oblast – 16 DWSS 143.7 thousand m^3 in capacity; Chernihiv oblast – 3 DWSS 9.3 thousand m^3 in capacity; and 6 STS in Kyiv oblast [6].

Decontamination waste storage sites were created in 1986-89 as a result of decontamination of populated localities that remained populated by Civil Defence units. Similarly to the Exclusion Zone design documentation for these sites is not available, particular coordinates of their location, as well as waste amounts and activity are not known.

In early 90-s the Ministry of Ukraine for Population Protection against Consequences of Accident at the Chernobyl NPP launched broad program of decontamination of radioactively contaminated populated localities [14]. However decontamination of buildings, facilities and territory was not the main target of these activities. At that time it was clear that decrease of population exposure doses (in 3-4 years after the accident) via decontamination of settlements would be very low at extremely high costs. The major task for that period was improvement of social and living conditions of people as set forth in Ukrainian SSR CM Decree No.106 dated 23 June 1991.

Such buildings contain decontamination waste disposed that, according to their specific activity, do not present radioactive waste, but posed certain threat to people and environment at that period of time.

Decontamination waste storage sites and machinery special treatment sites are being monitored and maintained by the Kyiv State Regional Specialised Complex of the State Corporation ‘Ukrainian State Association ‘Radon’.

Decontamination activities after the accident at the ChNPP as a counter radiation measure (interference) require a separate explanation.

Efficiency of the populated localities decontamination, considering analysis of practise and contemporary approaches to planning and streamlining of countermeasures (interference) in the event of radiation accidents, was assessed based on the ‘Instructive and methodological recommendations for streamlining of direct countermeasures at a late phase of radiation accident’ developed by the Scientific Centre of Radiation Medicine of the Academy of Medical Science of Ukraine [8].

As any other countermeasures, decontamination has planning stage and is carried out in accordance with radiation protection principals. So, according to the propriety principal benefit for society and individual from a dose precluded by decontamination and, consequently, precluded potential unwanted health effects associated with irradiation shall exceed total harm (medical, economical, social and psychological and so on) associated with the interference. According to the optimisation principal format and scale of decontamination shall be selected in the way for difference between total benefit and harm to be not only positive, but maximal. In other words, any planned countermeasures must be justified and optimal.

Since 1991, when the Concept of population residence on territories of higher radioactive contamination levels as a result of the Chernobyl catastrophe was approved (Ukrainian SSR Cabinet of Ministers Decree No. 91–12 dated 27 February 1991) and corresponding laws were adopted [9, 10], large-scale decontamination activities were planned and implemented. The decision was taken to carry out decontamination within the voluntary resettlement zone (zone III) in populated localities with total value of annual effective dose of additional (accident) irradiation exceeding 1 mSv. According to the mentioned decision only the Scientific and Technical Centre for Comprehensive RAW Management developed over 40 designs for decontamination and recovery measures within settlements of Kyiv, Zhytomyr, Chernihiv, Cherkasy, Rovno and Sumy oblasts during 1992–1993 under an order of the Ministry of Ukraine for Population Protection against Consequences of Accident at the Chernobyl NPP. However, propriety and optimality of decontamination works was not always substantiated at the stage of their planning. Consequently, most of decontamination works performed in 4–10years after the accident turned to be inefficient in terms of reducing accident population exposure.

The Korosten town of Zhytomyr oblast was one of the populated localities subject to large-scale decontamination. In 1995-96 specialists of the Scientific Centre of Radiation Medicine of the Academy of Medical Science of Ukraine carried out the research on comprehensive radiological monitoring of Korosten including analysis of decontamination efficiency [11].

The Korosten town that covers an area of above 46.2 km^2, 20 km^2 of which are occupied by domestic and public buildings, having a population of up to 70 thousand citizens is placed into zone 3, i.e. the Guaranteed Voluntary Resettlement [12]. Average density of radioactive contamination of the town territory by caesium-137 according to estimates as of 1991 was 6.9 $Ci{\cdot}km^{-2}$, but some areas of the town were characterised by higher contamination levels. For instance, caesium-137 contamination density of above 50 % of the territory of microdistrict Pashyny was over 10 $Ci{\cdot}km^{-2}$, and 20% – above 15 $Ci{\cdot}km^{-2}$. During 1988–1996, the Korosten town, as against any other town of Ukraine, was subject to the most complete and detailed radiation monitoring of the environment, and a set of decontamination activities aimed at decrease of population exposure doses caused by radionuclides of Chernobyl origin was performed there.

Decontamination was carried out on the territory of the town from 1988 to 1996 and included the following activities:

- removal and hauling of the ‘dirty’ layer of soil from private possessions and pre-schools;
- delivery of ‘clean’ soil;
- re-roofing of houses and public buildings;
- yard concreting and arrangement of blind area around public buildings;
- asphalting of areas in public places and roads;
- liming of gardens on plots of land attached to houses.

In the course of activities, thousands cubic meters of decontamination wastes were generated; according to Civil Defence town headquarters those wastes were hauled to the DWSS and Exclusion Zone.

Upon the decontamination, collective annual town population exposure doses caused by caesium radionuclides precluded by the decontamination were assessed.

While evaluating the competed protective measures based on the criterion of cost of a precluded exposure dose unit, they proceeded from that any radiation protection activity may be efficient and, consequently, justified, should its costs not exceed a particular amount that society (state) may afford to spend for precluding a collective exposure dose unit (1 man-Sievert). In the international practice, this parameter is determined by two constituents of harm to the health of exposed people. The objective constituent (α-component) is a money equivalent of negative (stochastic) exposure effect for human health. Another constituent – β-component is determined by moral, political, social and other constituents of a harm, and presents a money equivalent of compensation for exposed people health risk. Details for application of optimisation procedure and decision-making can be found in the methodology of the International Committee for Radiation Protection (Published Paper No.55).

According to estimates made by researchers of the Scientific Centre of Radiation Medicine of the Academy of Medical Science of Ukraine cost of α-component 1 man-Sievert accepted at that time was up to the amount equivalent to 400 US dollars.

Cost estimate based on prices as of 1990 evidences that 4.4 mn roubles or 6.87 mn US dollars (1 US dollar = 0.64 roubles in 1990) were spent for precluding the collective effective dose of 2.91 man-Sievert in the Korosten town over the period of 1988-96. Minor value of the precluded collective effective dose and considerable share of β-component in the expenses give grounds to consider that protective measures implemented in the Korosten town over different years lacked economic justification. They can be regarded as beneficial only indirectly due to 'social' effect, which is also ambiguous. Accordingly, estimated demonstrated that considerable costs spend for decontamination activities on the territory of Korosten in 4-10 years after the accident had minor effect on exposure doses (1.2%), and did not change radiation risk for health of town citizens.

Results of studies and other similar researches confirm the fact that decontamination, as counter radiation measures within radioactively contaminated populated territories, at a late stage (over 2-3 years) of a radiation accident, such as the Chernobyl catastrophe, lack efficiency [13].

6.3. Arrangement of the infrastructure for long-term storage and disposal of RAW generated as a result of the Chernobyl catastrophe

The radioactive waste that are currently contained on a temporary basis in trench-type storages both within and outside the Exclusion Zone pose radioecological threat for the living and future generations. The plan is to remove RAW from temporary storages and relocated to contemporary storage facilities fitted out with multi-barrier engineering protective systems that will safety isolate hazardous radioactive materials to preclude their negative effect on the environment.

Removal of waste of the Chernobyl origin from TRWLS, STS and DWSS is held not only by unavailability of costs, methods and process equipment to facilitate safety of personnel and prevent contamination spread in the course of works, but mostly by absence of storage facilities, where removed waste could be hauled for storage or disposal.

In 1996 the SSE 'Tekhnotsentr' was established and entrusted with functions of the customer for design and construction of the 'Vektor' Complex aimed at processing and disposal of radioactive waste from the territories contaminated as a result of the accident at the Chernobyl NPP.

The site of the 'Vektor' Complex located within the Exclusion Zone at a distance of 1 km from RWDS 'Buriakivka' and 20 km from the Chernobyl NPP within the so called Chernobyl contamination trace, occupies an area of 160 ha, ground water table is 18-21 m. In 1996, radioactive contamination density within the site area reached 290 Ci/km^2 for caesium-137, 140 Ci/km^2 for strontium-90, 3.2 Ci/km^2 for plutonium isotopes, 1.7 Ci/km^2 for americium-241. Consequently, the territory lacks any prospects in terms of being populated, unless a large-scale decontamination takes place.

The SSE 'Tekhnotsentr' was entrusted with the function of the operator for RAW disposal storage facilities and according to requirements set forth in legal and normative documents the enterprise obtained RAW disposal shallow repositories design, construction and operation licenses. The 'Vektor' Complex is designed for solid radioactive waste (RAW) collection, transportation, processing, storage and disposal. It presents a complex of facilities aimed at RAW management, located at the same site within the Exclusion Zone together with the infrastructure required for operation support. In accordance with the executive documents construction of the 'Vektor' Complex is split into the two stages: 1) disposal of radioactive waste from the territories contaminated as a result of accident at the Chernobyl NPP; 2) processing and storage of radioactive waste from the territories contaminated as a result of accident at the Chernobyl NPP. In order to optimise expenses and accelerate commissioning of the ‘Vektor’ Complex the Commissioning Stage was isolated within the Stage I design that includes one storage for disposal of each type of RAW (SRAW-1 and SRAW-2) and infrastructure facilities.

Construction of the first stage of ‘Vektor’ facilities was scheduled in 1996 (Cabinet of Ministers of Ukraine Decree No.480 dated 29 April 1996, including amendments), the design was approved in 1997 with construction duration of 5 years, the construction commenced in March1998. Stage one construction estimated cost made up 412.61 mn UAH. The Feasibility Study for investments in the ‘Vektor’ Complex stage two construction was agreed by Cabinet of Ministers of Ukraine Decree No.1605-p dated 23 December 2009 with construction duration of 4 years and total estimated cost of 518.955 mn UAH.

As of 01.10.2010, 189193.7K UAH were spent, including 146629.4K UAH for construction and installation works. Costs were provided irregularly over the entire construction phase and in amounts that were not sufficient for normative construction duration be followed, and it became the long term construction project.

In 2008 the Specially Equipped Shallow Ground Repository for Solid Radioactive Waste (SESGRSRW, or ICSRWM Lot-3) constructed on the ‘Vektor’ Complex site under a separate project in the frame of International Technical Aid for Chernobyl NP decommissioning was accepted for operation. Bulk of facilities within the engineering infrastructure of the ‘Vektor’ Complex that present the minimum required for SESGRSRW operation commencement were accepted in operation in the same year. 43 facilities and systems of the commissioning stage are currently in operation. While SRAW-1 and SRAW-2 disposal storages within the ‘Vektor’ Complex Commissioning Stage One, containers preparation building (building 20) and 14 facilities and systems of the ‘Vektor’ Complex infrastructure remain non-commissioned. Construction of the Commissioning Stage One is actually 70-95% complete. Current status of the Commissioning Stage is shown on Fig.6.1 (look the coloured inset).

In view of the long-term construction, as well as changes in the normative and legislative base, some provisions of the ‘Vektor’ Complex Commissioning Stage One are outdated. However, revision is the ‘Vektor’ Complex Commissioning Stage One construction design is unreasonable due to the following reasons. Firstly, the ‘Vektor’ Complex shall accept for storage and disposal radioactive waste not only from the territories contaminated as a result of accident at the Chernobyl NPP, but the rest of radioactive waste of Ukraine. Secondly, Stage One and Two facilities will be constructed over many dozens of years concurrently with operation of the commissioned facilities, i.e. Stage One and Two should be merged into a single complex design and annually working designs for commissioning facilities should be got approved. Thirdly, it is suggested to change the approval concept for long-term projects with implementation periods exceeding 5 years, namely: omit designs re-approval and be confined to approval of working design for commissioning facilities.

One of the key tasks of the State Program [6] is further development of the ‘Vektor’ Complex – further construction and operation of Stage One facilities, commencement of construction and operation of its Stage Two, which envisages not only disposal, but also a long-term storage and processing of RAW. Facilities of the ‘Vektor’ Complex Commissioning Stage Two will be located on the Stage One site with its infrastructure utilisation. Interfaces between these facilities are demonstrated on Fig.6.2 and are implemented via material (wide arrows) and information (normal arrows) flows. Information flows connect each facility of the ‘Vektor’ Complex with the information and analytical centre, which is facilitated via corresponding digital communication lines anticipated in the design. Fig. 6.2 shows only the part of information flows, which is associated with RAW registration and monitoring systems within the ‘nominally dirty’ zone.

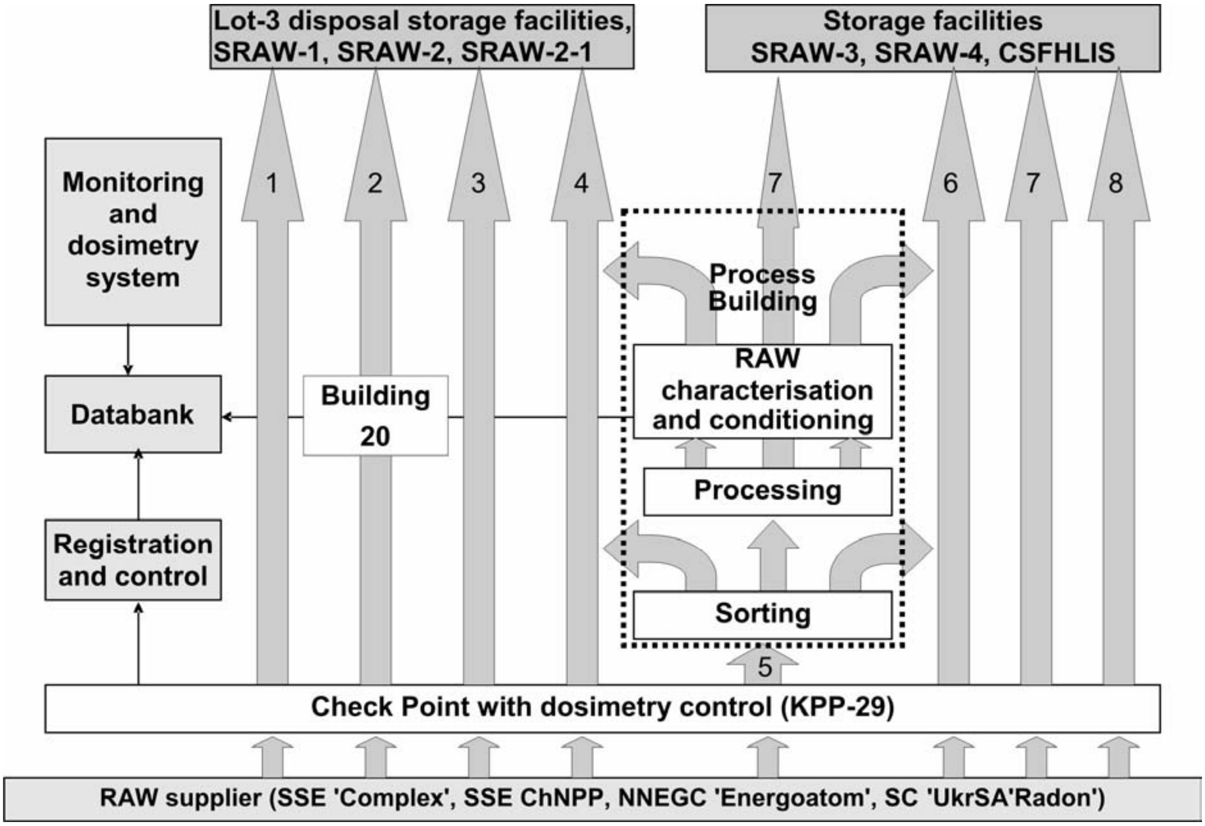


Fig. 6.2. *Process chart of RAW management at the 'Vektor' Complex*

As per the concurred Feasibility Study for investments in the 'Vektor' Complex stage two construction, endorsed by Cabinet of Ministers of Ukraine Decree No.1605-p dated 23.12.2009, construction of the centralised storage facility for long-term storage of spent high-level ionising radiation sources (CSFHLIS) is envisaged, including adoption of their processing and packing method for long-term storage considering further disposal. This project is being currently implemented in the frame of the international technical cooperation, initiated by the G-8 due to financial support of the Great Britain.

Some other facilities are being constructed within the Exclusion Zone designed for management of RAW accumulated at the ChNPP and expected to be generated during plant decommissioning, namely:

- Liquid Radwaste Treatment Plant;
- Industrial Complex for Solid Radioactive Waste Management (ICSRWM) comprised of:
  - Unit for RAW removal from the ChNPP storage facilities (Lot 1);
  - Solid RAW Processing Plant (Lot 2);
  - Shallow Ground Repository for Solid Low- and Medium-Level RAW, located at the site of 'Vektor' complex facilities (Lot 3).

In pursuance of the Law of Ukraine 'On Radioactive Waste Management, 'Provision for the State Radioactive Waste Register' and 'Provision for the State Cadastre of Radioactive Waste Storage Facilities and Temporary Storage Locations', approved by Cabinet of Ministers of Ukraine Decree No.480 dated 29 April 1996; the Register and Cadastre are maintained by the Main Information and Analytical Centre (MIAC) of the State System of Radioactive Waste Registration of the Corporation UkrSA'Radon'. The MIAC receives information from Regional Radwaste Registration Centres. The Regional Radwaste Registration Centres function of the base of the state regional Special Complexes SC 'UkrSA'Radon' and SSE 'Complex'.

The Regional Radwaste Registration Centres under the state regional Special Complexes SC ‘UkrSA’Radon’ register solid and liquid wastes, and wastes presented by closed spent ionising radiation sources stored at special complexes storage facilities, and register radioactive waste located at enterprises served by the special complexes. The Regional Radwaste Registration Centre of the SSE ‘Complex’ registers radioactive wastes of the Exclusion Zone.

For the purpose of radioactive waste observation, ensuring their controlled accumulation and transportation, delivery for storage and/or disposal to special enterprises, effective use of available storage capacities, in order to ensure continuous maintenance and timely update of the Register and Cadastre, regular state radioactive waste and radwaste storage facilities inventory reconciliations take place, including facilities storage facilities for RAW within the territory of waste generators. State radwaste inventorying takes place once in three years. The fourth state radioactive waste inventorying was carried out in 2010 [9].

In 2009, the Verkhovna Rada of Ukraine accepted the Strategy of Radioactive Waste Management [15], developed by the international expert team [16]. It encompasses basic provisions to be implemented that will facilitate stable development of the field, among which there is establishment of the special RAW management fund, National RAW Management Organisation, development of a concept and programs of short-lived low- and medium-level waste disposal, as well as high-level and long-lived wastes in geological repositories and so on. Unfortunately, the RAW Management Fund established in pursuance of the above strategy has not functioned to the full extent. Since selection of a site for arranging a geological repository for high-level and long-lived RAW is a time-consuming effort, the Strategy recommends acceleration of reconnaissance commencement. Only occasional self-motivated research works took place heretofore [17].

7. THE STATE POLICY OF UKRAINE CONCERNING OVERCOMING THE CONSEQUENCES OF THE CHERNOBYL CATASTROPHE

7.1. Analysis of the Regulatory and Legal Framework Created to Overcome the Consequences of the Chernobyl Catastrophe

The history of the formation of the regulatory and legal framework set up to deal with the Chernobyl catastrophe during the Soviet period is described in detail in Section 4.1.

At present, the total number of regulations and laws, covering all aspects of the Chernobyl catastrophe reaches over a thousand. They include not only the most often cited areas of state activity in this field (radiology, medicine and the social welfare of those who suffered as a result of the catastrophe), but also new acts concerning the implementation of radiological monitoring, maintenance of the Exclusion Zone barrier functions, the Chernobyl NPP decommissioning, conversion of the Object Shelter into an environmentally safe system, as well as the creation and development of the radioactive waste handling system..

At the same time, there are general regulatory legal acts which define the legal framework used to overcome the consequences of the Chernobyl catastrophe. The main ones being:

1. The Cabinet of Ministers of Ukrainian SSR Decree «On the Concept of People residing in the Ukrainian SSR territories with the heightened levels of radioactive contamination as a result of the Chernobyl catastrophe», dated 27 February 1991, N 791-XII.

2. The Law of Ukraine «On the legal status of territories contaminated as a result of the Chernobyl Catastrophe», dated 27 February 1991, N 791-XII.

3. The Law of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe», dated 28 February 1991, N 796-XII.

4. The Law of Ukraine «On the National program of overcoming the Chernobyl catastrophe consequences for 2006-2010», dated 14 March 2006, N 3522-IV.

5. Memorandum of Understanding between the Government of Ukraine and the Governments of the Group of Seven and the Commission of European Communities concerning the Chernobyl NPP decommissioning, dated 20 December 1995, No. 998_008 (Ottawa Memorandum).

6. Framework Agreement between Ukraine and the European Bank for Reconstruction and Development concerning the work of the Chernobyl Shelter Fund in Ukraine, dated 20 November 1997.

7. The Law of Ukraine «On the National principles of the further operation of the Chernobyl NPP and the decommissioning and conversion of the ruined Power Unit 4 into an environmentally safe system», dated 15 January 2009, N 886-VI.

8. The Law of Ukraine «On the National program of Chernobyl NPP decommissioning and conversion of the Shelter object into an environmentally safe system», dated 15 January 2009, N 886-VI.

9. The Law of Ukraine «On the National target environmental program of radioactive waste handling», dated 17 September 2009, N 516-VI.

The basic government resolutions:

10. The Cabinet of Ministers of Ukraine Decree «On implementation of the Ukrainian SSR Verkhovna Rada Decrees on the procedure of the Law of Ukrainian SSR implementation: «On legal regime of the territories contaminated as a result of the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe», dated 23 July 1991, No. 106.

11. The Cabinet of Ministers of Ukraine Decree «On the approval of Procedure for performance of the Shelter Implementation Plan», dated 31 March 2003, N 421.

The Government acceptance of the urgency to solve the problems caused by the Chernobyl catastrophe is reflected in the Basic Law of Ukraine – the Constitution of Ukraine [2]. Constitutional rights and responsibilities apply to all citizens of the state and, naturally, to victims of the Chernobyl catastrophe.

The following are the most important resolutions in the Constitution of Ukraine to protect the population from the Chernobyl catastrophe [3]:

1. Provision of environmental safety and maintenance of the ecological balance within the Ukrainian territory; overcoming consequences of the Chernobyl catastrophe– the global catastrophe and the preservation of the Ukrainian gene pool are the government obligations (Article 16).

2. A person, his life and health … are the main social values (Article 3).

3. The Constitution has superior legal status. Other laws and legal acts are accepted on the basis they comply with the Constitution (Article 8).

4. Each person has a right to a safe life and environment, and on the compensation for violation of this law… (Article 50).

5. Each person is obliged not to inflict harm to nature, cultural inheritance and to compensate for any damages caused (Article 66).

These provisions of the Constitution of Ukraine are reflected in the various legal acts set up to overcome the consequences of the Chernobyl catastrophe.

Amongst such documents, still in effect at the end of 2010, historically the first document focused on the concept of public health for the population residing within the Ukrainian SSR territory, with its heightened levels of radioactive contamination [4]. The document, hereinafter referred to as ‘the Concept’, has as its declared objective, reducing the impact of the Chernobyl catastrophe on public health.

The Concept’s basic principle lies in the fact that for the critical population group (children born in 1986), the value of additional effective exposure dose associated with the Chernobyl catastrophe, should not exceed 1 mSv (0.1 rem) per year and 70.0 mSv (7 rem) per life, compared with the dose that the population received before the accident, within the certain natural conditions. The Concept’s basic mechanism for radiological population protection (within the given circumstances) is the staged population evacuation to radiologically clean areas in accordance with the temporary criterion of soil contamination density (with radionuclides – cesium, strontium, plutonium).

The Concept and the following laws «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» [5] and «On the legal regime of territories contaminated by the Chernobyl accident» [6] provide the division of all the territory contaminated by the accidental releases on the zones.

The Law of Ukraine «On the legal regime of territories contaminated by the Chernobyl accident» [6] regulates the issue of a radioactively contaminated zone’s usage and protection regime, conditions of the population’s residence, work, economic, research and other activities within these areas. The law establishes and guarantees the usage and protection regime of the areas for the purpose of minimizing the impact of ionizing radiation on human health and ecological systems.

The Law of Ukraine «On the legal regime of territories contaminated by the Chernobyl accident» [6] assigns responsibility to the Cabinet of Ministers of Ukraine for the coordination of activities within the zones to minimize the consequences of the Chernobyl catastrophe (at the time of a law adoption, it was State Chernobyl Committee, then Ministry of Chernobyl, now Ministry of Emergency of Ukraine) and for the provision of necessary information to the population about the radiation situation within the territory.

The Law of Ukraine «On the legal regime of territories contaminated by the Chernobyl accident» [6] defines the types of activities prohibited within radioactively contaminated zones, and the mandatory measures to be implemented within these territories. The Law gives a detailed description of the types of radiation monitoring performed by the certain state agencies, within the subject territories.

The Law of Ukraine «On the legal regime of territories contaminated by the Chernobyl accident» [6] establishes the State's responsibility for governance and monitoring of the legal regime within zones that were radioactively contaminated following the Chernobyl catastrophe, as well as the liabilities for violations of this regime.

The provisions concerning the constitutional rights of citizens who suffered as a result of the Chernobyl catastrophe the protection of their lives and health are defined in the Law of Ukraine «On the status and social protection of the citizen, who suffered from the Chernobyl catastrophe» [5].

This law defines the State's policy principles for the social protection of persons who suffered as a result of the Chernobyl catastrophe, indeed defining «persons who suffered from the Chernobyl catastrophe», «liquidators of the Chernobyl catastrophe», «victims of the Chernobyl catastrophe», «children who belong to the victims category of the Chernobyl catastrophe», and establishes the State's liability to the citizens for damages caused in the aftermath of the Chernobyl disaster.

The above Law establishes criteria that categorize people according to their misfortune and suffering as a result of the Chernobyl catastrophe in order to establish benefits and compensation, and also gives the reasons for the categories. In addition to the categories, the corresponding benefits, compensation, additional payments and/or other remedial measures are presented.

The Law of Ukraine «On the status and social protection of the citizen, who suffered from the Chernobyl catastrophe» [5] defines the reasons for resettlement and establishes the citizens' right to independent resettlement from the radioactively contaminated zones. It also covers the production of food and agricultural products with the specification of acceptable levels of radionuclides therein, and the obligations of government agencies and manufacturers to comply with these regulations law.

Over the years, when adopting the Government budget laws, changes in its provisions were made, which terminated or suspended the validity of some articles or specific articles provisions of the Law «On the status and social protection of the citizen, who suffered from the Chernobyl catastrophe» [5]. The reasons for this shall be examined in detail in Section 7.2. It should be noted that in order to preserve the Law against revisions that would cut the size or scope of benefits, in 2006 the Law was amended with Article 71 «Peculiarities of Law revision» which specifies the following: «The operation of this Law may not be suspended by other laws, the exception being laws on revisions».

Thus, adoption of the Concept and the following Laws of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» allowed legislation of the criteria for that determined radioactively contaminated zones in accordance with the degree of potential negative impact on population health, to define the grounds and priority of resettlement, to create the monitoring system for safe accommodation, and to organize life within the contaminated territories. The Government guaranteed benefits and compensation to every person who suffered as a result of the Chernobyl catastrophe in accordance with established categories [7].

After adoption of the Laws of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» and «On legal regime of the territories contaminated by the Chernobyl catastrophe» work was started relating to the development and execution of subordinate acts allowing determination of the list of settlements in radioactively contaminated zones, and the status of affected individuals and arrangement of their appropriate social welfare.

One of the most important normative acts concerning the implementation of Laws «On the status and social protection of the citizen, who suffered from the Chernobyl catastrophe» and «On the legal regime of territories contaminated by the Chernobyl accident» [5, 6] is the Cabinet of Ministers of Ukraine Decree «On implementation of the Ukrainian SSR Verkhovna Rada Decrees on the procedure of the Laws of Ukrainian SSR implementation «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» [8] dated 23 July 1991, No. 106.

This Decree approved the list of settlements recognized as being within the radioactively contaminated zones and whose residents of get monthly benefits and salary allowances (at premium rates) to compensate for limitations on the consumption of locally produced food.

The Law of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» had been revised 11 times since adoption, the last revision was incorporated on 26 June 2009, there is also an official interpretation of the Law in the Constitutional Court Resolution dated 6 October 2009, No. 24-рп/2009.

The Law of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» had been revised 38 times since adoption, the last revision was incorporated on 2 December 2010, and there are also three official interpretations and explanation of the Law in the Constitutional Court Resolution.

The Decree of the Cabinet of Ministers of Ukraine «On implementation of the Ukrainian SSR Verkhovna Rada Decrees on the procedure of the Laws of Ukrainian SSR implementation «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» dated 23 July 1991, No. 106, had been revised and amended several times in order to complement the approved lists of the settlements. Only one time, in 2004, six towns of Volyn and Rivne regions were transferred from the zone of unconditional (mandatory) resettlement area to voluntary guaranteed resettlement (Section 7.2 contains the detailed information on this subject).

Revisions have not been incorporated into the Concept of population residence at the territories of the Ukrainian SSR with a heightened level of radioactive contamination since the Chernobyl catastrophe; its provisions remain effective at present, despite the significant changes in the radiological situation within these territories.

The practical implementation of the following laws «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» and «On legal regime of the territory contaminated by the Chernobyl accident» [5, 6] were carried out within the framework of a number of urgent programs and other measures concerning overcoming the consequences of the Chernobyl catastrophe, which were approved for a certain period starting from 1991. Within recent years, these measures have been implemented within the framework of the National Program for overcoming consequences of the Chernobyl catastrophe for 2006-2010, approved by the Law of Ukraine dated 14 March 2006, No. 3522-IV [9].

The above laws and government resolutions are the basis of legal relationships to overcome consequences of the Chernobyl catastrophe and are associated with the implementation of social, medical and psychological measures for rehabilitation of the population and their protection from radiation, radiation monitoring and maintenance of the Exclusion Zone barrier functions as well as the economic regeneration of the territories outside the Exclusion Zone boundaries. But there is another aspect of the activities related to overcoming the Chernobyl catastrophe– activities focused on the Chernobyl NPP decommissioning and conversion of the Object Shelter into an environmentally safe system. Also the creation and development of a radioactive waste handling system.

The agreement concerning the Chernobyl NPP shut-down by the end of 2000 and the activities related to its decommissioning and conversion of the Object Shelter into an environmentally safe system was reached during the continuous negotiations with the Group of Seven and the Commission of European Communities. The agreement was fixed in the Memorandum of Understanding between the Government of Ukraine and Governments of the Group of Seven and the Commission of European Communities dated 20 December 1995, No. 998_008 [11] (named the Ottawa Memorandum after the place of its signing).

The Ottawa Memorandum states that the parties came to an understanding on a Comprehensive Program of cooperation to support the Chernobyl NPP shut-down by 2000. It comprises six parts and nine points and provides the following:

Restructuring of the energy sector of Ukraine, the introduction of market reforms, development of a financially efficient electrical power market with pricing fixed according to market principles, which will stimulate the economical production and usage of the energy and energy conservation.

Investment in the energy sector of Ukraine, in profitable projects that are planned on the principle of least cost and, in particular, these projects will develop replacement power capacity for that lost by the Chernobyl NPP to meet the future electricity needs of the Ukraine, in an open market conditions.

Safety enhancement of Chernobyl NPP Power Unit 3 and the plant decommissioning, as well as further cooperation to develop a profitable and environmentally acceptable approach to solve the problem of the Shelter of Power Unit 4.

Assist the Government of Ukraine to develop an action plan to 'mitigate' the social consequences of the Chernobyl NPP shut-down; cooperation in determination of the international and Ukrainian sources of funding and in mobilizing international financial support for the Program's activities. Introduction of the following principle as the primary one: commercial projects are being financed by international loans and Ukrainian 'own' resources. Non-profit projects that directly support the shut down of the Chernobyl NPP are being financed through subsidies and Ukrainian 'own' resources taking into consideration the financial and economic situation in Ukraine.

The Addenda to the Ottawa Memorandum presents summary data of current funding amounts that have already been allocated or reviewed by the Group of Seven and international financial institutions. The Addenda also presents the list of priority projects of the Comprehensive Program.

The following are some of the principles of this Program: Dependency between reforms in the energy sector and achievement of the economic and social reform objectives of Ukraine; The complementarity of measures taken to shut-down the Chernobyl NPP and development of a long-term energy strategy for Ukraine, taking into account rational economic, financial and environmental criteria, which will lead to an efficient, steady, market-oriented energy sector meeting the needs of Ukraine.

Execution of the Ottawa Memorandum was a great step forward towards the Chernobyl NPP decommissioning and conversion of the Shelter object into an environmentally safe system, which allowed searching for specific mechanisms of the agreements implementation, but the uncoordinated obligations of the parties has resulted several times in misunderstandings and hence a delay in the shut-down of the Chernobyl NPP Power Unit 3.

It should be noted that Ukraine has not yet completed the market reforms in the energy sector specified in the Ottawa Memorandum, and hasn't developed a financially rational electricity market with price fixation in accordance with market principles, nor proceeded to planning the energy projects on the principle of least cost.

The following documents, together with the Ottawa Memorandum [10] define a system of legal relationships that address the decommissioning of the Chernobyl NPP and conversion of the Object Shelter into an environmentally safe system: Framework Agreement between Ukraine and the European Bank for Reconstruction and Development concerning the work of the Chernobyl Shelter Fund in Ukraine dated 20 November 1997 [11], ratified by the Law dated 04 February 1998, No. 80/98-BP; the Cabinet of Ministers of Ukraine Decree «On the approval of Procedure for execution of the Shelter Implementation Plan [12] dated 31 March 2003, No. 421 and the «Shelter Implementation Plan» itself; the Law of Ukraine «On the General Principles of the Chernobyl NPP further operation and decommissioning and conversion of the ruined Power Unit 4 into the environmental safe system» dated 11 December 1998, N 309-XIV [13]; the Law of Ukraine «On the National Program of Chernobyl NPP decommissioning and conversion of the Shelter Object into the environmentally safe system» dated 15 January 2009, No. 886-VI [14].

The established systems relating to the projects' management is quite complex. In accordance with the agreement with the European Bank for Reconstruction and Development (EBRD) (which is fixed in Ukraine at the level of legislation), Project Management Units (PMU) were created at the

Chernobyl NPP. The western Consultant heads and is a member of them. The Consultant is to represent the interests of the Employer (SSE Chernobyl NPP) and to assist him in cooperation with the EBRD and the Contractors. One of his main functions is to provide transparency of the sponsor's funds application. However, the raising of project management efficiency requires the strengthening of Employer's role and authorities – SSE Chernobyl NPP.

Legal issues which have arisen during the Chernobyl NPP decommissioning and conversion of the Object Shelter are being resolved systematically by the intercommunication of Western and Ukrainian parties, but perhaps not as quickly as the parties expect.

Lately, it has been decided to exempt from taxation the profit of the Chernobyl NPP, if such profits are used to finance the preparations on the Chernobyl NPP decommissioning and the Object Shelter conversion into environmentally safe system, and to exempt from taxation the enterprises' income received from the international technical assistance or from the funds that are provided by the Government budget as a contribution of Ukraine to the Chernobyl Shelter Fund to implement the international program – Shelter Implementation Plan [15, Articles 154.3, 154.4]. Although there is an undecided question concerning the profit taxation if the work may be classified by the International Advisory Group of EBRD as the work under the Shelter Implementation Plan.

In December 2010, the Cabinet of Ministers of Ukraine Decree «On financial provision of the civil liability for nuclear damage by the State Specialized Enterprise «Chernobyl NPP» dated 22 December 2010, No. 1164 regulated the issue concerning the financial civil liability for nuclear damage by the State Specialized Enterprise «Chernobyl NPP» [16].

The Law of Ukraine «On the National target environmental program of radioactive waste handling» dated 17 September 2008, N 516-VI [17] defines the following Program objectives among the others:

The further development of radioactive waste handling formed as a result of Chernobyl NPP catastrophe;

Creation and operation of radioactive waste handling infrastructure at the Chernobyl NPP and the Object Shelter.

7.1.1. The Regulatory and Legal Framework and the State Policy Efficiency Associated with Overcoming the Chernobyl Catastrophe Consequences

The regulatory and legal framework setup to deal with the Chernobyl NPP decommissioning and conversion of the Object Shelter into environmentally safe system, and the creation and development of radioactive waste handling system formed in the aftermath of the Chernobyl catastrophe is quite balanced and undergoes systematic improvement.

However, the framework has some significant defects when it comes to addressing issues related to the social, medical, and psychological rehabilitation of the population, their radiation protection, the implementation of radiation monitoring, and the economic recovery of areas outside the Exclusion Zone and the zone of unconditional (mandatory) resettlement. The following analysis focuses on this part of the regulatory and legal framework, hereafter referred to as the Chernobyl legislation.

The effectiveness of any means or measures is determined by their ability to meet the assigned objective within the defined terms and resources.

It should be noted that the significant part of the measures initiated to meet the requirements of the Chernobyl legislation were unfinished, and they failed to achieve the expected results. There are several reasons for this failure.

The first reason which is often identified as the main one is a lack of funds for the measures implementation. The second is «insufficiency of central and local authorities' systematic activities in this sphere». But there is another important reason, which significantly contributes to both of these. That is the lack of scientific grounding of the objective (to overcome a particular consequence of the

Chernobyl catastrophe), the tasks that need to be performed in order to achieve that objective, the way it will be implemented, and the terms and resources established for its implementation.

When the Chernobyl legislation at the Ukrainian SSR Verkhovna Rada session in February 1991 was reviewed, attention was paid to the Ministry of Finance calculations of the annual costs to implement the measures. The calculated cost of benefits and compensation was over 4 billion rubles. The cost of implementation of all resolutions and decisions concerning differential wage payments, improvement of health, children's free meals etc., which were accepted and were valid during the legislations consideration, was 580 million rubles [1]. Additional costs for the implementation of legislations were provided on the account of the Union budget and immediately the following procedure was proposed.

The Verkhovna Rada among other things instructed the Council of Ministers of the USSR within the framework of the Resolution «On the Implementation of the Law of the Ukrainian SSR «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» dated 28 February 1991, No. 797, about the following: «Submit the proposal to the Cabinet of Ministers of the USSR on the full funding of the activities and measures related to minimizing the consequences of the Chernobyl catastrophe on the account of the Union budget. In case of refusal to perform this proposal, to provide reduced payments to the Union budget funds required for financing the activities and measures related to dealing with the Chernobyl catastrophe starting from 1 April 1991».

After Ukraine gained its independence, the entire weight of funding the activities related to overcoming the Chernobyl catastrophe laid on the budget of the young State, but above all – the level of benefits and compensation was not corrected.

Table 7.1.

Comparison of Budgeted and Actual Expenditure Required to Overcome Consequences of the Chernobyl accident from 1996-2005 (including social protection of the population) [18, 20, 21]

Year	Requirement in accordance with the effective legislation, (UAH million)	Budgeted Contribution from the State for the respective year, (UAH million)	Budgeted Contribution as a % of Requirement	Actual Contribution from the State (UAH million)	Actual Contribution as a % of the Requirement	Debts at the beginning of year
1996	3363,32	1794,56	53,4	1527,88	85,1	160,59
1997	5681,72	2513,00	44,2	1746,59	69,5	310,04
1998	4548,5	2606,00	57,3	1432,26	55,0	457,75
1999	6015,95	1746,80	29,0	1535,51	87,9	763,21
2000	7479,25	1812,89	24,2	1809,63	99,8	931,48
2001	8744,46	1843,99	21,08	1925,02	104,4	786,4
2002	9957,8	2144,5	21,5	2002,8	93,4	729,3 including 634,6 of social protection
2003	12656,74	1381,16	11,0	1381,16	100,0	760,3 including 596,4 of social protection
2004	14872,5	1667,19	11,2	1640,4	98,4	685,4
2005		2041,77		1877,16	91,9	

In the literature, data on the Ukrainian cost to overcome consequences of the Chernobyl catastrophe is available (see Section 4.1). One can also find data on the ratio of the planned and actual budget expenditures used to finance activities under the Chernobyl legislation since 1992 [18]. But data on the funding of all the measures taken under the Chernobyl legislation and comparison of planned and actual expenditures is only available from 1996 [19, 20, 21], Table 7.1. Lately, the assessment of funding requirements is not carried out every year. Apart from the assessed requirements presented in Table 7.1, the funding requirements of all the measures provided by the Chernobyl legislation in

2007 was UAH 40 billion [22] and in 2010 – UAH 70 billion [21]. The consolidated budget expenditures for overcoming consequences for the Chernobyl accident and the related social protection during 2004-2010 are presented in Table 7.2.

Despite some discrepancies in the figures presented, the data allows certain conclusions to be drawn.

Firstly, according to the effective legislation the funding requirements have a steady increase – from 1996 to 2004 they increased in 4.4 times, and from 2004 through 2010 –3,8 times. The reasons for this increase lies in inflation processes and an increase in the standard of living.

Table 7.2.

The consolidated budget expenditures in 2004-2009 (actual), 2010 and 2011 (plan) provided to liquidate consequences of the Chernobyl accident, showing the contribution toward social protection and pensions provision for those citizens who suffered as a result of the Chernobyl catastrophe, UAH million [21]*

Year	State budget – expenditure required to liquidate the accident's consequences	Expenditure allocated for social protection and pensions provision to the citizens who suffered as a result of the Chernobyl catastrophe – total:	Expenditure allocated for the social protection (without pensions and housing and utility services):
2004	2970,5	2621,5	1640,4
2005	3623,9	3188,3	1877,2
2006	3859,8	3406,2	1939,9
2007	5085,7	4545,4	2388,1
2008	6326,4	5762,8	2164,7
2009	7015,5	6500,3	2171,5
2010	7727,0	6966,0	2559,2
2011	8541,0	7777,1	2561,4

* – There was no National report data concerning the actual expenditures of the consolidated budget for 2010 for the time of Section ***7.1. Analysis of regulatory and legal framework which regulates the legal relationship in the sphere of overcoming the consequences of the Chernobyl catastrophe*** was written.

Secondly, there is a steady reduction in the ratio of budgeted Government expenditure and funding needed to implement the Chernobyl legislation. In 1996-1998, the planned expenditure covered about 44-57% of the need, in 1999-2002 only 21-29% and in 2003-2010 – only 11-14% of expenses created by the effective legislation.

Thirdly, plans to finance the Chernobyl programs till 1999 inclusive were not fully performed, the actual financing was 55-87% of the plan, and only since 2000 has the actual financing been close to the planned one (provided by the Government budget), although significantly lower than that needed by the legislation.

One of the key moments in the area of population protection was the approval by the USSR Verkhovna Rada in 1991 of the Concept of population protection (hereafter referred to as the Concept), for those residing in the Ukrainian SSR territories with their heightened levels of radioactive contamination in the aftermath of the Chernobyl catastrophe [4]. Within this Concept, the basic principle of radiological protection for the population was the staged population resettlement to radiologically clean areas as determined by temporary criterion of soil contamination density (with radionuclides – cesium, strontium, plutonium). The main motive for this principle was the absence of comprehensive information about the additional exposure doses the population would receive by continuing to live within contaminated areas, in addition to the exposure they had already received due to the during Chernobyl accident..

The Concept evolved from the conclusions of the Rada research report and a study of USSR productive forces by the Academy of Sciences of the USSR [23], which was prepared for the Council of Ministers of the USSR. Whilst acknowledging the report justified the measures as being a means of reorganizing productive forces and the rational use of productive capacity, one should not overestimate its importance in promoting the principle of resettlement and the radiological criteria concerning its implementation.

In the Laws of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» the above principle and criteria of contamination density were the basis for zoning territories contaminated as a result of the Chernobyl catastrophe.

The Cabinet of Ministers of Ukraine Decree «On implementation of the Ukrainian SSR Verkhovna Rada Decrees on the procedure of the Law of Ukrainian SSR implementation «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» dated 23 July 1991, No. 106 defined the set of legislative measures focused on protection of the population from the negative impact of the Chernobyl catastrophe and the elimination of its consequences. The Decrees also list those settlements classified as radioactively contaminated zones (total 2293 items) [8].

It should be noted that there is a significant contradiction in the Chernobyl legislation. According to Article 1 of the Law of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe», the territories within which the population can receive an exposure dose exceeding 1.0 mSv (0,1 rem) per year are referred to as contaminated territories in the aftermath of the Chernobyl accident [6]. A similar provision encloses Article 3 of the Law of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe», which establishes the conditions by which the population can residee and work without limitation (due to radioactive contamination). The Article quotes a maximum annual exposure dose of 1,0 mSv (0,1 rem) per year [5]. However, in Article 2 of the above laws among the categories of contaminated territories there is a zone of enhanced radiation monitoring, which is defined as a territory with the soil contamination density over the pre-accident level with cesium isotopes from 1,0 to 5,0 Ci/km^2 or with strontium isotopes from 0.02 to 0.15 Ci/km^2 or with plutonium isotopes from 0.005 to 0.01 Ci/km^2 on the basis that the calculated effective exposure dose to the individual, taking into account the coefficient of radionuclide migration in plants and other factors, exceeds 0,5 mSv (0,05 rem) per year more than the dose an individual obtained during the pre-accident period.

So, according to some articles, a zone of enhanced radiation monitoring does not require restrictions on where people can live or work, but according to other articles within the same laws, radiation protection measures are implemented within this territory, and the population receives benefits and compensation for residing there and there may be limitations on their activities. According to official data [24] the number of people who reside within the radioactively contaminated zones is about 2.15 million, and more than 1.5 million people are residents of areas of enhanced radiation monitoring.

It should also be noted that according to the Concept, the density of soil contamination with radionuclides is used as a temporary criterion for making the decisions until an individual effective exposure dose shall be established. Contamination density, especially at this stage, doesn’t accurately reflect the radiation risk to those residing within the territories classified as contaminated. Using the territories contamination density as a criterion for the territory’s inclusion as a radioactively contaminated zone is not recommended according to current radiological knowledge, since the exposure doses the population receives can differ in many ways as a result of differences in environmental conditions within the same contamination density. But this criterion is still the basic one used in Chernobyl legislation.

In Ukraine starting from 1991, the dosimetric certification of settlements that suffered as a result of radioactive contamination in the aftermath of the Chernobyl catastrophe is being implemented systematically. The individual effective exposure doses of these settlements (so-called certificate doses) and their dynamics are well known and are regularly published [25-33]. Today, because of self protection and countermeasures taken, the content of radionuclides in the environment’s objects has decreased almost two times, and in agricultural products two or more times, which in turn has led to a reduction of external and internal exposure doses of 2-4 times. This reduction is reflected in the settlements distribution changing in accordance with the certificate dose levels, see Table 7.3. For comparison, the same table shows the classification of settlements referred to as radioactively contaminated zones in accordance with the Cabinet of Ministers of Ukraine Decree dated 23 July 1991, No. 106, which is still effective, including six towns of Volyn and Rivne regions, which were transferred from the zone of unconditional (mandatory) resettlement to the zone of guaranteed voluntary resettlement according to the Law «On transfer of some towns of Volyn and Rivne regions to the zone of guaranteed voluntary resettlement» [34].

Table 7.3 presents the striking differences between ‘officially declared’ radioactively contaminated zones, and the dosimetry realities of the present days. As was already noted, according to official data [4], the population size residing in radioactively contaminated zones is about 2.15 million people. However, the numbers who actually reside in settlements where the certificate dose exceeds 0.5 mSv per year, is around 320 thousand persons, and in those settlements where the certificate dose exceeds 1 mSv per year its around 136 thousand people [33]. However, at present there is no procedure for changing the settlements status of the radioactively contaminated zones.

Table 7.3.

Distribution of settlements and the levels of additional exposure doses, defined on the basis of dosimetric certification materials

Year of certification	**Number of settlements with average annual exposure doses**			
	< 0,5 mSv	**0,5-0,99 mSv**	**1,0-4,99 mSv**	**> 5,0 mSv**
1996	1307	333	507	6
1997	1350	359	443	9
1998	1332	375	440	7
1999	1375	380	397	9
2000	1417	298	440	6
2001	1455	314	389	5
2002	1471	317	372	3
2003	1538	338	285	2
2004	1551	410	202	0
2005	1426	297	108	0
2006	1613	285	68	1
2007	1296	242	58	0
2008	1647	236	42	0
1991, CMU Decree No. 106	-	1290 (Zone 4)	841 (Zone 3)	86 (Zone 2)

The mechanism to revise the zone boundaries, as defined in Article 2 of the Law of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» is extremely difficult.

In accordance with the provisions of the above articles, such revision is performed after the regional councils submit the respective proposal. However, despite full awareness of the improvement of the radiological situation within the territories of their jurisdiction, none of the regional councils, except for Volyn and Rivne, have submitted any proposals for the transfer of settlements to a category of reduced contamination. This is despite almost 20 years having passed since the adoption of the Cabinet of Ministers of USSR Decree dated 23 July 1991, № 106, that categorized settlements into zones of radioactive contamination. Only Rivne and Volyn regional councils, at the request of village councils, submitted proposals to transfer settlements to the zone of guaranteed voluntary resettlement when the latter refused to move out of six towns that are within the zone of unconditional (mandatory) resettlement.

Also, the provisions of these articles provide that the Cabinet of Ministers review the zones boundaries based on experts’ reports from a number of organizations and central authorities. However, it is not clear from the provisions of these articles or any other document; what should be the focus of the experts' conclusions, provided by the Bodies or Organizations with the exception of Ministry of Emergency and the National Commission for Radiation Protection of Ukraine. Still the transfer of the settlements between radioactively contaminated zones should be carried out in accordance with the radiological criteria, in accordance with the provisions of Article 2 of the above laws.

For a long time the Government of Ukraine tried to remove the contradiction between the legislation and economic capabilities of Ukraine, to optimize the level of social protection of persons affected by the Chernobyl catastrophe, and to overcome an increasing social and psychological tension within different social groups of citizens. However no remarkable shifts in this area have happened.

Twice, in 1994 and in 2008, the Cabinet of Ministers of Ukraine carried out attempts to revise the Cabinet of Ministers Decree of the Ukrainian SSR dated 23 July 1991, No. 106, which would take into account the actual improvement of the radiological situation within the territories that are within the radioactively contaminated zone, but in both cases, the Cabinet of was forced to suspend or cancel its decision, primarily due to the failure to meet the mechanism of the zones boundaries review established by the Law.

At the same time, in the Verkhovna Rada of Ukraine Presidium Resolution dated 12 September 1994, No. 127/94-ПВ «The suitability of the Cabinet of Ministers of Ukraine Decree suspension dated 29 August 1994, No. 600», the Government guidelines were formulated in such a way that the adoption of a new redaction of the Concept (of population residence within contaminated areas) by the Verkhovna Rada actually stipulated its following policy in this area. This prompted the development of a new document providing a basis to review the laws of Ukraine (related to the Chernobyl catastrophe). Such document was prepared and approved by the Government of Ukraine in 1997-98 and was submitted to the Verkhovna Rada of Ukraine. But at the end of 1999, the document was recalled by the new Government to assess its relevance and to revise it, and it has not been resubmitted to the Verkhovna Rada of Ukraine.

Taking into consideration the Concept's importance, the Decree of the Verkhovna Rada of Ukraine «On parliamentary hearings concerning the fourteenth anniversary of the Chernobyl catastrophe» assigned the National Academy of Sciences of Ukraine, Academy of Medical Sciences of Ukraine, and Ukrainian Academy of Agrarian Sciences to review the draft Concept. During presidium meetings of the above academies, the scientists supported the project as a basis for further improvement of the legislation, but the Government has not submitted this document to the Verkhovna Rada of Ukraine.

This process was completed by Cabinet of Ministers of Ukraine Decree dated 25 July 2002, No. 408-р «On approval of the Concept of the Law of Ukraine «On revision incorporation to the Law of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe». Today, 13 years after its development and nearly 10 years after its approval, some of the document's provisions are still effective, but in general it can no longer serve as a basis for the improvement of Chernobyl legislation.

In recent years another serious problem has surfaced, caused by flaws in the Chernobyl legislation. As mentioned above, the total amount of all payments, additional payments and subsidies to citizens who suffered as a result of the Chernobyl catastrophe provided by the Law of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe», when added together exceeded the Government budget.

Inconsistency between the provisions of the Law of Ukraine «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» relating to the size of compensation payments, additional payments and subsidies and the Cabinet of Ministers of Ukraine Acts that have been issued to ensure their implementation has led to mass appeals in the courts with lawsuits against the State. Their number is growing rapidly.

The drastic coordinated actions of the Cabinet of Ministers of Ukraine, the Verkhovna Rada of Ukraine and the highest judicial bodies of Ukraine are needed to improve the situation.

Another the Chernobyl legislation’s problem is the shift of the Government support priorities: instead of providing unconditional implementation of measures aimed at ensuring the production of products with the acceptable level of radionuclides content, the Government spends much more funds for financial assistance in connection with the limitation of the consumption of locally produced food and for additional payments for work within contaminated territories, which actually has long ceased to be radioactively contaminated according to the criteria defined in the effective regulations.

Thus, the Government budget for 2010 provided only UAH 1.9 million for the radiological protection of population and environmental improvement of territories, contaminated by the Chernobyl catastrophe and in accordance with the Program «Monthly subsidies related to limitation of the local food products consumption and compensations for special provision with products to the citizens who suffered from the Chernobyl catastrophe» and «Additional payments for work within contaminated areas, the preservation of wages while transfer to lower-paid work and payments in relation to resettlement of increased grants and additional vocation to the citizens who suffered from the Chernobyl catastrophe» – UAH 814.5 and 596 million respectively.

At this, the dosimetric certification of settlements that are within the radioactively contaminated zone, the cost of which today did not exceed UAH 10 million, was not carried out due to lack of funds during 2009-2010.

Meanwhile, at present – almost in 25 years after the accident – there are still about a hundred places in Ukraine, where the certificate exposure doses or the radionuclides content in local food products is above the acceptable levels. In particular, in some settlements of Rivne region, the internal radiation exposure dose of children at the account of contaminated milk consumption, reaches the levels that were observed here in 1987.

Next problem is a lack of motivation of the population and local authorities to improve the situation: on the contrary, there is a reverse motivation when the effective system of compensation encourages the population and local authorities to maintain the high levels of radionuclides content in the local food products. No measures for the introduction of positive motivation are arranged by the State.

The National Program on overcoming the consequences of the Chernobyl catastrophe for 2006-2010 [9] provided the following objectives as the most important ones: «improvement of the system of measures aimed at stimulating the production of clean products, economic development of areas that were radioactively contaminated» and «provision of scientific grounded application of funds for implementing measures on social protection of individuals who suffered from the Chernobyl catastrophe, and overcoming its consequences». The expected results are the following: reduction of the amount of funds provided to pay for unemployment benefits, encouragement of innovation activities, creation of competitive industries, including agricultural development, assistance in the increase of the population labor activity and creation of conditions for their productive employment, acceleration of economic development of areas that suffered as a result of radioactive contamination, creation of conditions for their steady development.

However, among the Budget programs provided by the Attachment to the National Program of overcoming the consequences of the Chernobyl accident for 2006-2010 «Amount of expenditures from the Government budget of Ukraine for implementation of priority tasks of the National Program of overcoming the consequences of the Chernobyl accident for 2006-2010», there was not any Program, within the framework of which these tasks could be implemented, and the expected results could be achieved.

It should be noted once again that a system of the budget priorities determines which of the instruments provided by the Programs to implement its policy, the Government considers the most important and which is less important, which instruments provide the opportunity to work and which, being deprived of appropriate funding, remain declarative.

Table 7.4.

Objectives and tasks of the State Programs related to overcoming the consequences of the Chernobyl catastrophe in Belarus, Russian Federation, and Ukraine

Belarus	**Russian Federation**	**Ukraine**
State Program on overcoming the consequences of the Chernobyl NPP catastrophe for 2006 – 2010	Federal Target Program Overcoming consequences of the radiation accidents for the period till 2010	National State Program on overcoming the consequences of the Chernobyl catastrophe for 2006 – 2010
Objectives: • socio-economic and radiation-ecological rehabilitation of the contaminated areas; • creation of conditions for economic management without restrictions by the radiation factor and the further risks reduction on health of affected populations.	The program's objective is the completion in 2010 of the activities associated with provision of protection to the citizens in Russian Federation affected by the radiation impact as a result of the accident at the ... Chernobyl NPP ... and the social and economic rehabilitation of territories contaminated as a result of the Chernobyl accidents..., including the return of these territories into economic circulation, reducing the risk of radioactive contamination of the environment from potentially dangerous sources of pollution.	The objectives of the Program are the following: • health provision of individuals affected by the Chernobyl catastrophe and their descendants; • strengthen and support of the safety barriers, radiation protection of population living in areas that suffered as a result of radioactive contamination, the maximum possible limitation of the radionuclides spread from the Exclusion Zone; • improvement of social protection of the individuals who suffered as a result of the Chernobyl accident, rehabilitation of territories and settlements.
The main tasks: • staged rehabilitation of the contaminated areas and affected populations; • optimization of medical care of victims on the basis of scientific recommendations; • implementation of the preventive measures related to reduction of the radiation exposure doses; • cost-effective production of products that meet the radiological quality of republican and international requirements.	The Program's objectives are the following: • creation of the infrastructure needed to provide the safe living conditions for the population in contaminated areas; • development and implementation of set of measures in the sphere of health protection of citizens affected by the radiation, including the specialized address medical assistance; • creation of conditions for the safe forest management within the affected areas (taking into account the established norms of radiation safety); • improvement of the target monitoring systems and their components, as well as forecasting the situation within contaminated areas; • information support and socio-psychological rehabilitation of the citizens living within contaminated areas	The main tasks of the Program are the following: • health provision of individuals injured as a result of the Chernobyl catastrophe; • strengthen and support of the radiation barriers; • radiation protection of population living in the radioactive contaminated areas; • limitation of radionuclides spread out the Exclusion zone; • social protection of the individuals suffered as a result of Chernobyl accident; • economic rehabilitation of the areas subjected to radioactive contamination and their removing into "clean" category. Main points are expounded in 11 text pages

No better situation was established with determination of the above Program's objectives. The following objectives are declared: preservation of the health of individuals who suffered as a result of the Chernobyl catastrophe and their descendants, strengthen and support of the safety barriers, radiation protection of population residing within areas that were radioactively contaminated, the maximum possible limitation of the radionuclides spread from the Exclusion Zone, improvement of the social protection of the Chernobyl catastrophe victims, rehabilitation of territories and settlements [9]. The above objectives are actually the areas of activity, each of which requires the constant hard work, but all of them, except for rehabilitation of territories and settlements, are not to be the objectives of the Program because it is impossible to achieve them.

Table 7.4 presents the objectives and tasks of the Programs on overcoming the consequences of the Chernobyl catastrophe effective in Belarus, Russia, and Ukraine during 2006-2010. The Belarus and Russian programs are significantly different from the Ukrainian one where a greater emphasis was laid on the territories rehabilitation and their return into economic circulation. The Belarus Program considers the social protection only as one of method of these tasks solution and the rehabilitation objectives implementation.

The Information State policy concerning the Chernobyl problems and radiation risks lacks some consistency, and do not fully presents an effective instrument on overcoming the consequences of the Chernobyl catastrophe.

Within recent years, the requirements of the Law of Ukraine «On legal regime of the territories contaminated by the Chernobyl catastrophe» and «On the status and social protection of citizens who suffered from the Chernobyl catastrophe» has not been fully implemented regarding bringing to the people’s attention and publication at the national and regional mass media of the maps of contamination areas, lists of settlements referred to these areas, and annual dosimetry certification data.

In general, a complex «Chernobyl victim» has been developed among the part of affected population appeared in a social apathy and disbelief in their own strength, mood of doom, depend only on outside help, and getting used to a benefits and compensation.

The effective measures to fight against these negative processes are the measures that are being developed and implemented in Ukraine, including by the UN agencies. In particular these are the measures of the Chernobyl Economic Forum, aimed at stimulating business activity within the contaminated areas, supported by the UNDP in Ukraine, activities of centers of the social and psychological rehabilitation of the population, created under support of UNESCO, as well as measures of the ICRIN information center (International Chernobyl Research and Information Network) of the UN’s organization, in particular the spread of understandable and clear scientific knowledge concerning the Chernobyl catastrophe and its consequences, including recommendation related to healthy life-style based on the reports, results and recommendations of the Chernobyl Economic Forum and the UN Scientific Committee on the Effects of Atomic Radiation.

The executive and local authorities should facilitate such activities of the UN system in Ukraine and seek out and create its own forms of support and provision of steady development and growth of the undertaken initiatives.

To sum up, it should be acknowledged that the Chernobyl legislation despite the high humanistic orientation needs the certain improvement in order to become an effective tool to overcome the consequences of the Chernobyl disaster.

7.1.2. Improvement of the Legislation that Regulated the Relationships in the Sphere of Overcoming the Consequences of the Chernobyl Catastrophe

The issue of overcoming the consequences of the Chernobyl catastrophe is very topical for the Ukrainian society. Therefore, changes in legislation have to be offered considering the open analysis results of the affairs’ condition and involving a wide range of experts to this analysis and to design recommendations.

In the State, there is a number of political (parliamentary hearings, governmental decisions, the President of Ukraine message) and expert (conferences, roundtables, etc.) procedures for analysis of the situation condition in the specific field. Preparation of national report for the anniversary of the

Chernobyl catastrophe is also an open procedure to analyze the situation condition on overcoming its consequences. In addition, there are international organizations and international expert groups which analyze the situation and accumulate its recommendations focused on its improvement. The Chernobyl Forum is the international group of experts who presented their reports on the impact of the Chernobyl accident on environment [35] and health [36], and recommendations to the Governments of Belarus, Russia, and Ukraine related to the further activities [37] on overcoming the consequences of the Chernobyl catastrophe before 2006.

Proposals related to improvements of the Chernobyl regulatory framework should solve problems identified in Section 7.1.1. The following changes are needed to be incorporated:

1. Improvement of the review procedure of the radioactively contaminated zones boundaries, introduction into the Law of the periodicity regulation on such review.

2. Transition to the dose criterion of the radioactively contaminated zones boundaries determination, formed as a result of the Chernobyl catastrophe at the national legislation.

3. Introduction into the Law of regulation associated with the compulsory periodic (annual) dosimetry certification implementation.

4. Introduction into the regulatory legal act of the regulation associated with the mandatory implementation of Whole Body Counter – monitoring of individuals who live within radioactively contaminated zones.

5. Fortification of mechanisms of the positive motivation among the local authorities and residents of settlements to improve the radiological situation in these settlements.

6. Introduction of the business support system within areas classified as contaminated, and those remove from the radioactively contaminated zones.

7. Improvement of the existing system of benefits and compensation.

It is necessary to coordinate the provisions of legislation in the sphere of overcoming the consequences of the Chernobyl catastrophe with the legal norms in the other spheres. In particular, modern system of radiation safety and radiation protection [38] fully takes into account the Chernobyl experience; that is why it’s time to make an attempt to coordinate the provisions of regulatory legal acts in the sphere of overcoming the consequences of the Chernobyl catastrophe with the legislation on the radiation protection.

Improvement of the system of benefits provision shall be performed in accordance with the Strategy on regulation of the benefits system to certain categories of citizens until 2012, approved by the Cabinet of Ministers of Ukraine Decree dated 3 June 2009, No. 594-p [39] and taking into account the peculiarities and practice of benefits allocation to the Chernobyl categories.

Implementation of changes to the Chernobyl legislation requires consolidation of efforts of the expertise, the executive and legislative power, and mobilization of information resources. Today the above can be achieved only if all participants shall consider this issue as something that is of utmost importance.

7.2. Analysis of the State Programs Implementation Related to Overcoming the consequences of the Chernobyl Catastrophe

7.2.1. Radiological Protection of Population

Today, looking back at 25 years and evaluating the measures of radiological (radiation) protection, one must admit that almost all specified countermeasures in the international and national regulations aimed at protection of population from ionizing radiation were realized at the early stage of liquidation of the Chernobyl catastrophe despite an initial underestimation of the scale of event and secret regime.

Immediate measures in cases of radiation accidents were performed – evacuation and resettlement, iodine preventive treatment, sanitation measures, an access restriction to radioactively contaminated areas, limitation of contaminated food consumption, measures in agrarian sector, decontamination of contaminated areas, informing the public and others.

One of the key tasks of State policy at the present stage concerning minimization of the consequences of the Chernobyl catastrophe is the implementation of measures aimed at comprehensive protection of the population, creation of safe living conditions within contaminated territories. The implementation of State policy was performed until 2006 in accordance with the Annual Programs, in which a significant place was occupied by the measures oriented to meet the radiation safety requirements of the population residing and working within the contaminated areas.

In 2006, the Law of Ukraine «On the National Program of overcoming the consequences of the Chernobyl catastrophe for 2006-2010» dated 14 March 2006, No. 3522-IV, defined the objectives and priorities of radiological protection of population at a later stage of overcoming the consequences of the Chernobyl catastrophe [40].

In accordance with the provisions of the National Program, the set of measures aimed at reducing the negative impact of radioactive contamination on public health includes the following: dosimetry monitoring, monitoring the levels of radioactive contamination of food and raw materials, provision of the radiation monitoring network with devices of new generation; radiological rehabilitation of the territories; conversion of farms, retraining and certification of specialists in radiological protection, informing of the population about the radiation state of territory.

The efforts were focused first of all on reducing the collective additional exposure dose on population through the respective reducing of the total intake of radionuclides with the products of consumption, and fixation of qualitative indicators achieved in the production of clean products within areas that suffered as a result of radioactive contamination. The efforts were also directed to those «critical» settlements and facilities where there is a danger of exceeding the average annual total dose over 1 mSv.

An objective assessment of radio ecological conditions of living within the affected areas was and remains at present the basis for the measures planning related to radiological protection. A leading role of this task implementation belongs to the dosimetry monitoring, consisting of the following: dosimetry and thyrodosimetric certification of settlements and determination of internal exposure doses, according to data of the direct measurement of radiocaesium content in the human bodies.

The system of general dosimetry certification of settlements was established in 74 districts, 12 regions, and 2139 settlements after 1991. The system provides the estimation of the certificate dose of the settlements referred to the radioactively contaminated zones. The data of radiation contamination density with ^{137}Cs and ^{90}Sr and its concentration in milk and potatoes is used to estimate such dose.

A set of activities includes the following:

- sampling of food products (milk and potatoes) and their spectrometric and radiochemical analysis («milk» monitoring);
- measurement of radionuclides content in the human body;
- calculation of exposure doses of the population;
- final measurements for quality assessment of the dosimetry certification;
- compilation and issuance of the dosimetry certificates to the settlements.

As a result of calculations, the following data are obtained:

- the average density of Cs137, Sr90 fallouts in soil for the settlements (and its environs);
- value of the average concentration of Cs137, Sr90 in milk;
- values of the calculated certificate exposure dose of the passport.

In accordance with the procedure for work implementation related to specification of the radiation condition and radioecological monitoring performance within the contaminated areas of Ukraine, the following is established:

Double sampling and analysis of milk in **503** settlements of the guaranteed voluntary resettlements zone.

A sampling in other **1627** settlements referred to the radioactively contaminated zone.

Sampling of potatoes is performed one time per year (in August – September) in the settlements, where according to the observation of previous years, the certificate exposure dose exceeds 0.5 mSv/year, in average about 16670 samples of potatoes and milk were taken.

That is, the monitoring of the soil and the basic foods radioactive contamination is being carried out during the implementation of general dosimetry certification of settlements.

The certificate dose is the weighted average dose per professional and age structure of residents of the settlement and is intended only for support decisions made by the Government authorities in accordance with the effective legislation. It was noted that the use of this dose in epidemiological studies is unacceptable.

Results of the general dosimetry certification of settlements are summarized in special issues, the collection of which contains over 13 collections. The latest collection includes a generalized data for 2008.

The materials of radiation and dosimetry monitoring (see Section 2.1.2) are the basis ones to develop the Program of rehabilitation of territories and, under the condition of insufficient funding, gives the possibility to estimate and optimize the measures implementation associated with the territories rehabilitation. The scope of measures related to radiological protection of population and ecological improvement of the territories that was radioactively contaminated, greatly depends on the amount of funding of the respective section of Chernobyl Program (Table 7.5).

Table 7.5.

The Program financing according to the Section «Radiological protection of population and environment enhancement of the territories affected by the radiation contamination»

Items of financing	Financing per years, UAH thousand				
	2006	2007	2008	2009	2010
Provided by the State	19500,0	15000,0	20000,0	20000,0	20000,0
Approved by the Government budget	12743,0	12743,0	13609,5	1361,0	1861,0
Practically financed, including:	11517,1	11518,2	10367,1	1361,0	1861,0
Rehabilitation of the territories: 1. meadow and pasture formation and reformation	2013,0	1660,1	1275,0	0	0
2. liming of acid soils	1000,0	642,0	0	0	0
3. applying the heightened doses of mineral fertilizers	1547,2	2815,0	1830,0	0	0
4. introduction of mixed fodders, mineral and saline briquettes basis of ferrocene and zeolite	1287,0	1145,2	1595,0	0	500,0
5. set of countermeasures within the zone of unconditional (mandatory) resettlement	350,0	450,0	450,0	150,0	200,0
6. Radiological examination of land	400,0	250,0	220,0	0	0
7. Assessment of the countermeasures and their support effectiveness	165,0	120,0	128,6	0	0
8. Targeted programs at the animal breeding sphere	616,0	615,0	702,8	0	0
9. Fire-prevention measures in the woods	5585,0	385,0	3310,0	0	0
Radiation monitoring system: **10.** Procurement of the radiation monitoring devices, their maintenance, calibration	310,3	324,0	123,0	0	0
11. Dose-monitoring (certification of the settlements)	862,6	797,0	1007,0	0	0
12. Radiation monitoring of the products (radiation monitoring network)	2221,0	2185,0	2485,7	1111,0	1035,0
Training	160,0	130,0	240,0	100,0	126,1

Upon the justified need (for 2006-2007) in UAH 43.7 million per year, in recent years funding has been significantly reduced, first in 3-4 times, and later starting from 2009, financing of the measures implementation oriented to the territory rehabilitation and dosimetry certification was ceased at all. This disparity in funding of countermeasures against the background of general funds which are allocated by the Government to overcome the consequences of the Chernobyl catastrophe, holds in clean products production, makes it impossible to influence effectively the reduction of population exposure dose and do not assists in reducing of the social and psychological tensions within the regions affected by Chernobyl catastrophe.

The Laws of Ukraine provide the possibility to review zone boundaries in case of change of radiological situation and gradually return them into the commercial use without restrictions, however, the drawbacks in the legal procedure are practically blocked its action, and despite the fact that at present within a great part of the radioactively contaminated area, the population exposure doses is below the criteria established by the effective legislation, the boundaries of areas had not been reviewed for 20 years (apart from 6 settlements in Rivne and Volyn regions).

Countermeasures in Agricultural and Forestry Economy Sectors

One of the main courses of the radiological protection of the population living within contaminated territories is the implementation of optimized countermeasures based on radiation monitoring, in particular associated with the provision of food production in compliance with the Government hygienic standards on the radionuclides content.

According to the recommendations on agricultural production in areas contaminated as a result of the Chernobyl accident, the main measures which considered to be the most effective, are as follows: meadow and pastures formation; liming of the acid soils; putting the heightened doses of fertilizers; introduction of mixed fodders on the basis of ferrocene and zeolite admixtures; introduction of mineral and saline briquettes on the basis of ferrocene; conversion of farms to «beef cattle» and «reproductive swine breeding»; additional radiological examination of certain critical territories and complex of anti-radiation measures in forestry.

The program of rehabilitation of contaminated territories provides the implementation of the main task – significantly reduce the expected collective exposure dose on individual residing within the contaminated area at the account of implementation of comprehensive countermeasures aimed at the production of clean agricultural products. Only on account of the countermeasures performed at the agricultural areas, the dose loading at the population has decreased in two times which was officially recognized by the International community and was fixed at the IAEA documentation.

The maximum effect of the basic countermeasures introduction was achieved in 1991-1992. The actual volumes of liming and of radical improvement of meadows and pastures in 2008 compared with 1991 decreased from 69.99 to 0.76 (Figure 7.1) thousand hectares and from 112.15 to 0.964 thousand hectares, respectively. The volumes of application of mixed fodder, premixes and zeolites are also reduced (Figure 7.2). Financial cuts, which began in the mid-90, resulted in this situation with the introduction of countermeasures (Table 7.5).

For 25 years passed since the Chernobyl accident, a series of decisions had been taken in the sphere of forestry, which, in general, were aimed at provision of safe working and living conditions for the forest workers and their families, and also aimed at production, the radioactive contamination of which has not exceeded the established norms.

Time requirement is a need to obtain adequate timely information about the forest radiation conditions in case of any nuclear incident, which in turn requires the availability of a team of experts in the forest Radiology within the State Forestry Committee on a regular basis, since forests are the critical landscapes in terms of formation of internal radiation doses of the population, particularly in the Ukrainian Polesie. At a time when most people in one way or another use the forest products, characterized by the high content of ^{137}Cs, the contribution of the latest to formation of internal radiation dose is significant. An important component in minimizing the consequences of the Chernobyl accident is prevention of the production and distribution of products containing the excess radioactive substances out of contaminated area border.

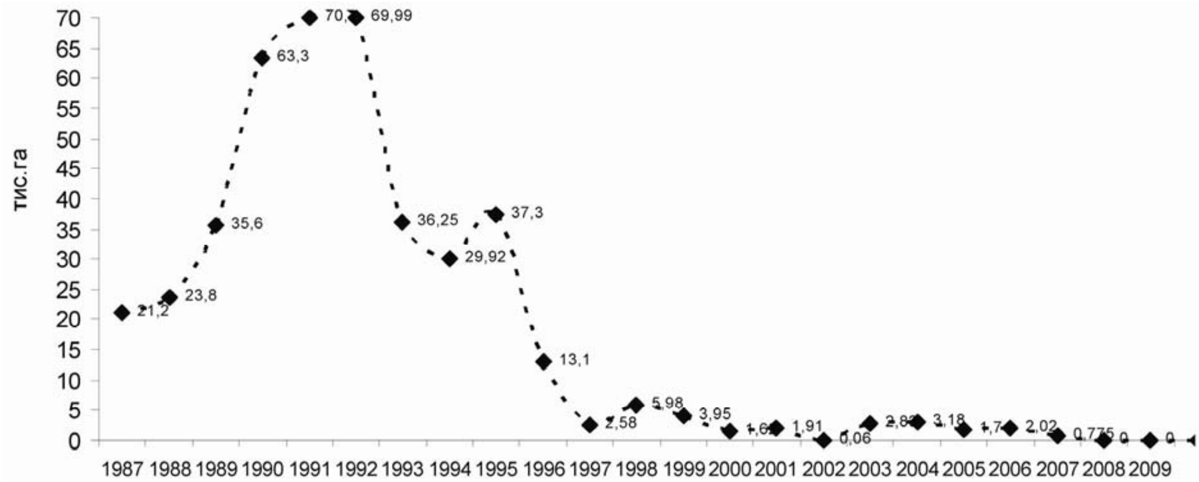


Fig. 7.1. *Volumes of liming of the acid soils contaminated as a results of Chernobyl disaster, thousand ha*

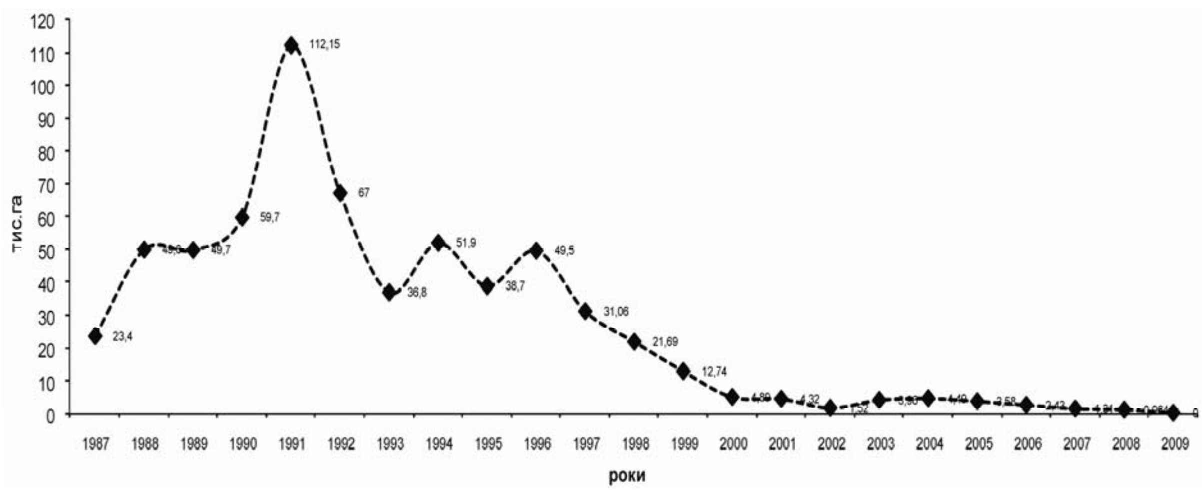


Fig. 7.2. *Volumes of the root improvement of the meadows and pastures contaminated as a result of the Chernobyl disaster, thousand ha*

During the acute period after accident, the top priority countermeasures at the Forestry Management Enterprises were the activities of the restrictive character. The following are found among them: reduce of working hours, termination of economic activity in some areas with high levels of radioactive contamination, evacuation of enterprises and employees to the safe zone, the prohibition of certain types of industrial activities of the Forest enterprises (procurement and selling of the wild berries, mushrooms, medicinal raw materials, wood, etc).

The new recommendations for the forest management in conditions of radioactive contamination have been developed on the basis of scientific research to ensure the production activity of Forestry enterprises located within contaminated areas (2008).

The countermeasures during the acute and remote period after the accident at different levels of the State regulation in the Forestry sector prevented the irradiation of workers, preserved of their health and led to the stability of enterprises and growth of the production scopes.

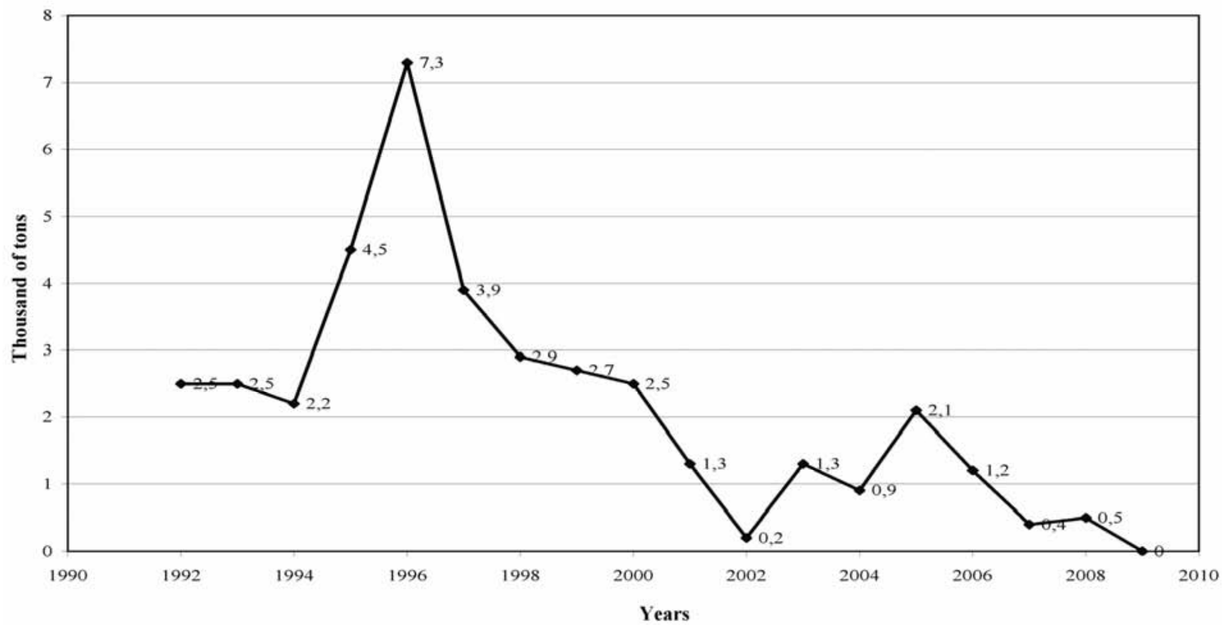


Fig. 7.3. *The volumes of mixed fodder, zeolites and premixes application within the territories contaminated as a result of the Chernobyl catastrophe, thousand tons*

During the remote period after the accident, the most effective implemented countermeasures are the following: restriction of public access to woodlands with the contamination density more than 555 kBq m-2; provision of radiation monitoring of the forests, radiation control of places for storing the forest resources, and the medicinal raw materials; the provision of individual dosimetry monitoring of workers, working places, equipment and machinery; timber sorting according to specific activity of radionuclides, use of special technological methods of wood processing from cutting areas; provision of the radiation monitoring of forest products.

Since 1989, all measures to overcome the consequences of the Chernobyl catastrophe in Forestry management have been performed and funded within the framework of the State program on minimization the consequences, which allowed performing significant scope of work, avoiding irradiation of forest workers and reduce the collective dose on the population in general. Since 1992, funding to minimize the consequences of the Chernobyl catastrophe in Forestry management has been reduced by 50%, and from 2009 terminated at all. At present these activities are carried out by own funds. The situation with the financial support of radiation monitoring of forest products can lead to a complete stop. The population usage of wild berries, mushrooms, medicinal raw materials without radiation control will eventually lead to an increase of the collective exposure dose of the population.

Summarizing the analysis of the State program tasks implementation on the radiological protection of population, it should be noted that in Ukraine there is still more than 300 settlements in which the average annual exposure doses of the population, or the locally produced agricultural products do not meet the hygienic standards despite the fact that the total area contaminated by the Chernobyl catastrophe (more than 37 kBq m^{-2} by ^{137}Cs) was shortened almost in two times, and the annual radiation dose decreased in 7-30 times (depending on the place of living). According to the experts' assessment, without the countermeasures implementation, the number of such settlements will decrease very slowly.

When planning and introducing the long-term measures on radiological protection, it should be taken into account that the choice of rehabilitation measures should be optimized per the radiological, economic, social, psychological, and environmental feasibility criteria.

The following is still the basis of the radiological protection: dosimetry monitoring; reliable, scientifically grounded awareness of the population on radiological situation within the territories contaminated by the Chernobyl catastrophe; and the optimized countermeasures in agriculture and forestry, as such countermeasures during the remote period of overcoming the consequences of the Chernobyl catastrophe preserves a high radiological and economic efficiency.

7.2.2. Medical Protection of Population

Medical protection of victims was carried out permanently after the accident. Within recent years, the protection was performed in accordance with the tasks defined by the National Program on overcoming the consequences of the Chernobyl disaster for 2006-2010 (hereinafter referred to as the Program).

To realize this direction of the Program, the Ministry of Emergency of Ukraine together with the Ministry of Health Protection and the Government Administration developed a set of measures that included the following: the provision of hospital medical aid; annual medical examinations (clinical); development and operation of the State registry of affected persons; arrangement of the Interdepartmental Experts Commissions work related to establishment of a causal connection of disease, disability and death with the action of ionizing radiation and other harmful factors as a result of the Chernobyl accident; equipping of medical facilities with modern diagnostic and therapeutic medical equipment; provision of medicines and expendable medical supplies; treatment of seriously ill patients; social and psychological rehabilitation; introduction of scientific developments in medical practice.

A network of specialized centers, clinics and medical facilities in an amount of more than 300 healthcare facilities, including 36 scientific and clinical institutions of higher accreditation and 77 central district hospitals were established in order to provide continuous medical care to victims and to countrymen who live within contaminated territories.

Necessity to implement the above measures was stipulated by the high levels of morbidity and mortality among victims of the Chernobyl catastrophe (see Sections 3.2.1, 3.2.5). Affected people every year need the scheduled and unscheduled treatment, preventive measures of chronic diseases exacerbations in order to prevent disability and aggravations.

The country has a system of medical care for victims, which consists of annual clinical examination, ambulatory, according to indications, in-patient treatment, and rehabilitation measures in health resorts and rehabilitation centers.

In accordance with the established manner, the annual medical examinations of disabled persons and the accident liquidators are performed before the Chernobyl disaster anniversary, and the children examinations – before the beginning of summer health-improving season.

The coverage rates for annual medical examinations have been stable within recent years and among the liquidators of the accident are equal to 97.3–97.8%, among the adult population – 95.2% and among the affected children – 99.2%.

The following also affects the morbidity level of the affected population: the transition period of economy, changes in the demographic situation and the social and psychological condition worsening, lack of effective measures associated with overcoming the early and remote effects of negative factors of the Chernobyl catastrophe, the low level of provision with the highly qualified personnel and insufficient equipping with laboratory and diagnostic equipment of the regional medical institutions, lack of awareness in the field of radiobiology and radiation medicine by the local governments, medical and teaching staff who work within contaminated areas.

The following reasons substantially affected the reduction of the medical protection efficiency:

failure to take into consideration the combined effect of ionizing radiation and the other environmental risks, including chemical, environmental factors on the human body;

unbalanced diet, and the low level of the population provision with the of animal and vegetable protein, vitamins, essential macro-and micronutrients;

unsufficient equipping of the field laboratory with the portable equipment in order to implement the current population survey in the remote areas;

insufficient social security of victims of different categories;

insufficient funding for implementation of the timely special-purpose clinical examination of persons affected by the Chernobyl catastrophe;

insufficient enlightening of the scientists and specialists’ experience on medical and sanitary consequences of the Chernobyl disaster by the mass media;

failure to implement in full the restoration treatment as at the out-patient level and in sanatoria and health resorts of Ukraine.

The external exposure impact and the radionuclides penetration through inhalation have lost their relevance gradually. At the present stage after the accident at the ChNPP, the main contribution to the exposure of the population of Ukraine belongs to internal exposure due to radionuclides content in food.

Hygienic aspects of this issue are as follows: rationing of the minimum acceptable level of foodstuffs and raw materials contamination, the prohibition of production and consumption of local products, monitoring of the contamination levels of food products and the removal of the most contaminated food from the food ration (mushrooms, berries, milk, meat), under the condition of their replacement with the imported ones; development of technological and cooking methods of food treatment in order to reduce their contamination with radionuclides, increase the protective and preventive properties of food rations.

The State Sanitary Epidemiological Service of the Ministry of Health of Ukraine is constantly performing the radiation control of foodstuffs and food raw material within the framework of the «Comprehensive Program of the State sanitary supervision implementation in the field of radiation safety of Ukraine, radiation monitoring of environmental by the agencies and institutions of the State Sanitary and Epidemiological Service of the Ministry of Health of Ukraine, involving the Research Institutes of the Academy of Medical Sciences of Ukraine for 2006-2010 «(the Order of the Ministry of Health of Ukraine dated 20 March 2006, No. 137), the surface water monitoring is implemented in accordance with the «Program of the radiological characteristics observations of transboundary water facilities with Russia and Belarus» and the «Temporary program of water quality monitoring of Pivdennyi Bug, Dnieper, Dniester and the Severskyi Donets river basins within the bounds of Ukraine.

Every year, the agencies of the State Sanitary and Epidemiological Service of the Ministry of Health of Ukraine make almost 200 thousand gamma and beta-spectrometric surveys of food on the content of radionuclides cesium-137 and strontium-90. Analysis of the obtained results shows that the radiation situation in Ukraine is stable, but there is still fixed the exceedance of the permissible levels of radionuclides in milk, meat, vegetables, and wild mushrooms and berries of the local production in Volyn, Zhytomyr, Rivne, Kyiv and Chernihiv, the regions that were affected by the ChNPP accident the most.

Analysis of the annual monitoring results of about 5 thousand water surveys of economic and drinking water supply and about 2 thousand surface water surveys on the content of radionuclides indicates the non-exceedance of the control levels within the recent years.

The Social and Psychological Centers of the population rehabilitation and their awareness on the issues of overcoming the consequences of the Chernobyl consequences (hereinafter referred to as the Centers) are dealing with the purposeful overcoming of the psychological problems of the affected population. These Centers are located in towns Borodyanka, Boyarka, Ivankov, Korosten, and Slavutich.

The Centers’ specialists have developed and implemented the social projects and rehabilitation programs aimed at psychological and physical health improvement of different age categories of the affected population.

The Centers not only provide the social and psychological assistance to the population but they play an important role in life of the communities located within radioactively contaminated territories.

Activity of the population, its initiative, and independence in solving the social and economic, and cultural problems has increased.

A significant area of the Centers' activity is to promote the youth civic activity in order to attract the younger generation to the social and political life of their city and to cultivate in young people the leadership skills, interest in decisions making that would influence the destiny of the community, and to form an ecological world outlook and healthy lifestyles.

A new area in the public informing is the introduction of modern information technologies. Their own sites in four centers had been created (there were 257.5 thousand visitors on the sites in 2010). Implementation of these technologies allows expanding its activities in the sphere of public information on overcoming social and psychological consequences of the Chernobyl accident, promoting the healthy lifestyles, and examining the requests of the community.

The Centers involve international organizations and their programs in order to implement effectively their projects and programs, and to introduce the advanced international technologies in the processes of recovery and sustainable development of psychological and social immunity of the affected population.

Only during 2010, 85 469 persons applied to the Centers. The Centers' specialists provided an individual work and consultations to 9310 individuals, conducted 8045 group sessions, read 187 lectures and performed 375 publications in the media and issued 132 information publication.

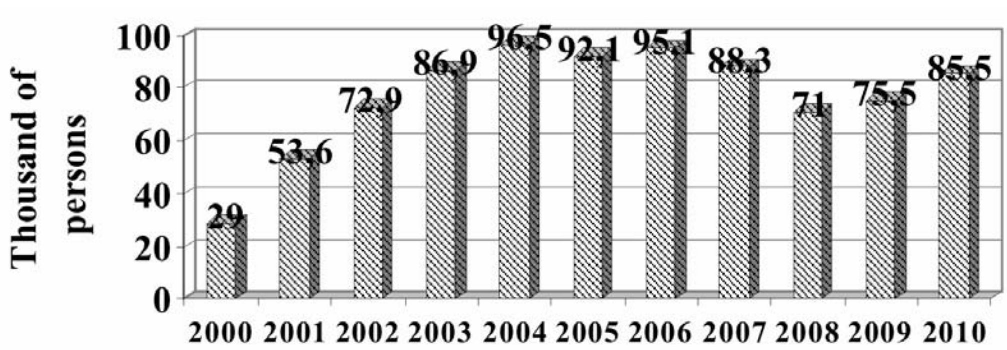


Fig. 7.4. *The dynamics of the population attendance of the Social and Psychological Centers*

Having insuring the continuous work with communities regarding their potential development in governance and participation in local development, these institutions are a guarantee of stable projects results and provide the spread of the positive experience.

The Centers have become integral parts of social infrastructure of cities and regions, aimed at establishment of the partnership connections between the Government institutions, social institutions, and community organizations in order to activate the population through self-development and determination of priorities in the social, economic and ecological spheres of life.

It should be noted that the measures for health protection and social and psychological rehabilitation were implemented under the conditions of permanent deficit of the State and local budgets and underfunding of the approved by the Program amounts of expenditures (see Table).

These problems adversely affect the moral situation of victims, delay the receipt of medical care in a timely manner, and increase the number of appeals to the central executive agencies.

Structural changes in all the central executive agencies, involved in decision making associated with overcoming the consequences of the Chernobyl disaster, are actually led to the destruction of the Government management system in this sphere.

The conclusion about the insufficient funding of the main health protection measures of population residing within contaminated areas during 2005–2008, was unanimously developed by the experts from the State Institution «SCRM of Academy of Medical Science of Ukraine», the Health

Security Head Department of Kyiv Regional State Administration and the National Shupyk Medical Academy of Postgraduate Education, which evaluated the implementation state of the main health protection measures of population residing within contaminated areas during 2006–2008 in order to identify possible ways of their correction.

Table. 7.6.

Financing of the Programs focused on «Comprehensive health care provision and cancer treatment of the citizens affected by the Chernobyl catastrophe using the high-cost medical technologies»

	Years of the Program implementation, thousand UAH					Total
	2006	2007	2008	2009	2010	
Provided by the Program at the account of the Government budget	45000,0	45000,0	45000,0	45000,0	45000,0	225000,0
Planned amount of financing at the account of the Government budget	44570,0	44970,0	27000,0	6300,0	6300,0	129140,0
Actually financed	25469,1	44970,0	21381,5	5534,2	6300,0	103654,7
Percent of the actual financing provided by the Program	56,6	99,9	47,5	12,3	14,0	46,1

Limited amount of funding (the «partial» funding level) were allocated for psychological assistance to the residents of contaminated areas and to the affected individuals by the Chernobyl catastrophe, for informing about the behavior peculiarities when residing within contaminated areas, for preventive measures in order to avoid certain types of diseases and for the rehabilitation treatment. The procurement scope of medicines and supplies was insufficient for provision of the full high-quality medical care. Financing of procurement of the reagents for clinical laboratories and medical diagnostic equipment was also partial. Material and technical base of specialized medical institutions has not been updated during recent years.

Experts have the unanimous opinion concerning that there is a need for additional or specialized care for all categories of victims when the structure of morbidity is available. The system of medical care for residents of contaminated areas remains effective through the principle of consistency between all institutions that provide this assistance.

Factors of the worse medical support than expected ones are as follows:

lack of experts on security of maternal and child health and prevention of certain types of diseases, provision of primary health and extended care, examination and treatment in specialized hospitals, treatment in health and rehabilitation centers, public awareness about the behavior peculiarities when residing within the contaminated areas;

lack of teaching materials and guidance associated with the primary health care, examination and treatment in specialized hospitals, rehabilitation treatment, preventive measures regarding prevention of the certain types of diseases, psychological assistance to certain categories of victims;

discrepancy between the material and technical base and the tasks of complete implementation of annual physical check-ups, examination and treatment in specialized hospitals, rehabilitation treatment, psychological assistance, measures associated with the maternal and child health security and prevention of certain types of diseases, public awareness about the behavior peculiarities when residing within the contaminated areas.

Analysis of the causes of poor or incomplete implementation of measures aimed at preservation of the victims' health, gives grounds to identify three main directions of improvement of medical care of the contaminated areas residents.

The first – includes a set of measures that need improvement in the financing level, namely: primary health care, urgent hospital care, treatment in health and rehabilitation centers, measures associated with the maternal and child health security, procurement of medicines, supplies and reagents for clinical laboratories, procurement of medical diagnostic equipment, maintenance of medical facilities and etc.

The second – work with residents of the contaminated areas associated with formation of their understanding on necessity of systematic observation of their health and the health of their close ones.

The third – comprehensive orientation of activities, namely: informing of the population about the behavior peculiarities and the possibility of residing within the contaminated area under the condition of complete and regular financing, understanding the need for systematic population health observation, the availability of teaching materials and guidance.

The following issues are required to be solved: staffing with the doctors and nurses at the contaminated territories, searching for new ways of aid provision, which will provide modern methods of in-patient treatment of disease (day hospital, home care, the traditional inpatient treatment), detected during preventive examinations, and which will increase the victims' personal responsibility for their own health preservation.

The priority group of population of third after-disaster decade is still the people who have suffered as a result of the acute radiation sickness, namely: liquidators with radiation exposure doses above 250 mSv, evacuated people from the 30-kilometer zone, individuals with high doses of the thyroid gland exposure, pregnant women and children residing within contaminated areas and born of parents who received the high radiation exposure doses.

The following problems should be considered as the most significant ones for the future:

need for government support for work implementation on the study of deterministic and stochastic effects;

development of measures associated with the improvement of the evidence-based treatment of radiation-associated and/or radiation-induced diseases;

development of preventive measures aimed at reducing cancer and oncohematological morbidity;

clinical examination and monitoring of organs and systems disorder that are the most sensitive to radiation exposure in remote period;

medical rehabilitation of the affected population;

support of the programs on studying the medical consequences of the Chernobyl catastrophe during the remote period, especially within contaminated areas where abnormally high levels of incorporated radionuclides are observed;

improvement of health and sanitary base of specialized hospitals, which are constantly provide the medical care to the victims.

7.2.3. Social Protection of Population

Population dynamics of citizens who suffered in the aftermath of the Chernobyl catastrophe.

At present, 2 million 210 thousand 605 persons, almost half a million among whom are the children, have the status of victims of the Chernobyl catastrophe in Ukraine.

The population dynamics of liquidators of the Chernobyl accident is presented in accordance with data of the State Statistics Committee of Ukraine (till 2006 inclusive) and Regional Labor and Social Security (since 2007). (Table 7.7)

Table 7.7.

Population dynamics of liquidators of the Chernobyl accident

Years	Liquidators	Among them disabled persons of the Ist category
1996	363780	41221
1997	358633	44265
1998	343084	49011
1999	346316	56462
2000	340654	58580
2001	335785	60889
2002	329607	62239
2003	324332	63986
2004	318 016	64 808
2005	308 694	65 181
2006	297 850	65 780
2007	276 327	65 361
2008	266 801	66 270
2009	260 807	65 666
2010	255 862	66 489

Over the last 15 years, the total number of citizens affected by the Chernobyl disaster in Ukraine has decreased by 1 002 721 persons, including the number of liquidators of the Chernobyl accident consequences has decreased by 107 918 persons, the number of victims of the Chernobyl catastrophe has decreased by 294 053 persons, number of children who suffered as a result of the Chernobyl accident has decreased by 600 750 people (due to loss of status after reaching 18 years). Number of disabled persons had increased by 50 617 persons.

As of January 2011, the following number of population had been registered in the Social Policy and Labor authority:

- 255 862 liquidators of the Chernobyl accident (its share in the total number – 11%);
- 195 4743 victims of the Chernobyl accident (over 88%), among them 482 357 children (25%);
- 28 548 persons who have the status of a spouse of the deceased citizen whose death is connected with the Chernobyl catastrophe;
- 5 865 persons who participated in the liquidation of other nuclear accidents and were attributed to the relevant categories of victims.

Considering the trends in the future, one can expect that due to natural movement of population (subject to the maintenance of modern criteria of the national legislation) the total number of victims and the share of children victims will be decreasing.

Among disabled people, disability of whom is connected with the Chernobyl catastrophe (total number of them is 112 729 persons), 60% – are the direct participants of the Chernobyl accident consequences liquidation (66 489) Table 7.8.

In 1991, the process on the disability determination has begun only after the Law adoption. More or less stable process has been observed since 1996.

Condition of the Programs funding related to social protection of citizens who suffered as a result of the Chernobyl catastrophe and performance of compensatory payments and allowances.
Amount of expenses on social protection of citizens, who suffered as a result of the Chernobyl catastrophe, is provided annually taking into account the real possibilities of the Government budget of Ukraine expenditures.

In accordance with the Law of Ukraine «On Government Budget of Ukraine for 2010», allocations for the implementation of the Chernobyl budget programs, according to which the Ministry of Labor is the primarily administrator, have increased by 18% – from UAH 2.1 billion to UAH 2.46 billion (Table 7.9).

Table 7.8.

The table is provided in accordance with data of the State Statistics Committee of Ukraine (till 2006 inclusive) and Ministry of Social Policy and Labor (since 2007)

Years	Total of victims	Liquidators of the Chernobyl NPP accident consequences				Victims of Chernobyl accident (adults)					Children who suffered as a result of the Chernobyl accident
		Total	Among them of 1st category (disabled)	Among them of 2nd category	Among them of 3rd category	Total	Among them of 1st category (disabled)	Among them of 2nd category	Among them of 3rd category	Among them of 4th category	
1996	3213326	363780	41221	252939	69620	1766439	20891	86727	489017	1169804	1083107
1997	3227311	358633	44265	246094	68275	1764214	26633	84472	485880	1167229	1104464
1998	3364475	343084	49011	230381	63692	1760769	28498	81165	487119	1163987	1258010
1999	3361870	346316	56452	227135	62729	1748363	30323	80847	486920	1150273	1264329
2000	3278521	340654	58580	221164	60910	1741911	32639	81008	487863	1140401	1193076
2001	3096814	335785	60889	215542	59354	1709146	35109	80220	482894	1110923	1048928
2002	2930184	329607	62239	208567	58801	1696657	36938	78059	485982	1095678	901050
2003	2772060	324332	63986	202973	57373	1692794	41855	78089	485232	1087618	754934
2004	2646106	318 016	64 808	197817	55391	1682280	40443	78255	482113	1081469	643030
2005	2594071	308 694	65 181	191167	52346	1667717	41643	77648	480798	1065022	617660
2006	2526216	297 850	65 780	181748	50322	1636319	41602	72885	481485	1040347	589455
2007	2376218	276 327	65 361	166087	44879	1558250	41242	70232	477153	967361	541641
2008	2307994	266 801	66 270	158296	42235	1529493	43552	65999	466263	951410	511700
2009	2254471	260 807	65 666	154238	40903	1495255	45161	64660	460465	922762	498409
2010	2210605	255862	66489	149664	39709	1472386	46240	63433	452397	908161	482357

Table 7.9.

Amount of the Budget Programs' expenditures associated with the social protection of the citizens who suffered as a result of the Chernobyl accident

Code of the Program Expenditure Classification	The Budget Program description	Amount of expenditures, UAH millions					
		Approved for 2009	In % till 2008	Approved for 2010	In % till 2009	Maximum amount for 2011	(+,-)In % till 2010
1	2	4	5	6	7	8	9
2501200	Additional payments for work within contaminated territories, the preservation of wage when transfer to the low-paid job and in connection with resettlement, increased grants payments and granting of additional holiday to the citizens who suffered as a result of Chernobyl catastrophe	371,1	100,0	596,0	160,6	596,0	100,0
2501210	Compensation for families with children and free meals for children who suffered as a result of the Chernobyl catastrophe	575,4	100,0	579,9	100,8	574,1	99,0
2501230	Monthly financial allowance to the citizens who suffered as a result of the Chernobyl catastrophe in connection with the limitation of consumption of locally produced food and compensations for reduced food provision	742,5	100,0	814,5	109,7	814,5	100,0
2501240	Compensation to citizens who suffered as a result of the Chernobyl catastrophe for the lost property and payment in connection with expenses associated with the movement to a new residence	10,0	100,0	10,0	100,0	9,264	92,6
2501250	Compensation for damage caused to health and the aid for recovery in case of the citizens dismissal who suffered as a result of the Chernobyl catastrophe	46,6	100,0	46,6	100,0	46,6	100,0
2501270	Allowance by temporary disability to the citizens who suffered as a result of the Chernobyl catastrophe	15,2	100,0	37,2	244,7	37,2	100,0
2501300	Maintenance of bank loans on preferential terms granted before 1999, to the citizens who suffered as a result of Chernobyl catastrophe	0,4	50,0	0,383	95,8	0,341	89,0
2501360	Improvement of citizens' health who suffered as a result of the Chernobyl catastrophe	330,0	100,0	383,0	116,1	385,0	100,5
Total		2091,2	99,98	2 467,5	117,8	2 463,0	99,8

But, according to the experts estimations, the complete implementation of the Law of Ukraine «On Status and Social Protection of People who suffered from the Chernobyl catastrophe» (hereinafter referred to as the Law) requires more than UAH 70 billion. This makes the implementation of payments for social protection programs Chernobyl unrealistic.

Except for the above mentioned 8 Budget Programs, the Ministry of Labor finances the Program, entitled «Social protection of the employers released due to the Chernobyl NPP decommissioning», the expenditures of which are defined by the Law of Ukraine «On general principles of the Chernobyl NPP further operation and decommissioning, and conversion of the ruined Power Unit 4 into the environmentally safe system». The implementation procedure of this Program is approved by the Cabinet of Ministers Decree, entitled «On provision of additional State guarantees for the employers released due to the early Nuclear Power Plant decommissioning», dated 21 June 2001, reference number 1090 (Table 7.9).

Table 7.10.

Social protection of employers released due to the Chernobyl NPP decommissioning

Expenditures description	**Amount of expenditures, UAH millions**					
	Approved for 2009	**% till 2008**	**Approved for 2010**	**% till 2009**	**Maximu m amount for 2011**	**(+,-)% till 2010**
Welfare payment for the period of employment for employees that are released due to the Nuclear Power Plant decommissioning, and pensions till reaching the retirement age and the pension premiums	0,87	68,8	1,96	226,4	1,30	54,2

Within the frames of the Budget Program implementation «Additional payments for work within contaminated territories, the preservation of wage when transfer to the low-paid job and in connection with resettlement, increased grants payments and granting of additional holiday to the citizens who suffered from Chernobyl catastrophe», the additional payments are granted to individuals who work within the Exclusion Zone (in accordance with the Cabinet of Ministers Decree, entitled «On additional payments to individuals who work within the Exclusion Zone» dated 10 September 2008, reference number 831), which were financed one hundred percent for the scheduled appointments.

Due to the above Decree, an additional payment is set in the amount of 150 percent of the minimum wage for almost 7.5 thousand employers who work on a permanent basis within the Exclusion Zone and perform activities associated with the reinforcement of the Exclusion Zone's barrier functions, the Chernobyl NPP Power Units decommissioning and conversion of the Object Shelter into the environmentally safe system.

The size of payments for the work within the Exclusion Zone is set in the amount of 150 percent of the minimum wage for the period from 1 January 2009 through 1 January 2012. Such payment is determined in proportion to the worked hours but not more than the established amount. As for 1 January 2010, the amount of such payment equals to UAH 1412 (for comparison, before the CMU Decree adoption it was equal to UAH 264).

The compensatory and additional payments financing, including those provided by the above the Cabinet of Ministers Decree, was fully implemented in accordance with the approved Government Budget for the amount of allocations in 2010.

The Cabinet of Ministers Decree, entitled «On changes incorporation to the List No. 1 of production, activities, professions, positions and indicators at underground works, especially during the activities with particular harmful and particularly difficult working conditions, full-time employment in which gives the right on pension under the concessional terms» dated 24 February 2010, reference number 173, was adopted in order to remove the social tension among the employers of the Exclusion Zone and the Chernobyl NPP and to allocate the pension to the mentioned category of persons through including the worked hours or services to the record and period of work under the concessional terms.

Since 2009, the following was introduced: modern procedure for property evaluation, property rights for the compensation payments for the lost immovable property upon evacuation or voluntary resettlement from contaminated areas (in accordance with the Cabinet of Ministers of Ukraine Decree dated 18 November 2009, reference number 1243 «On approval of procedure for compensation payments for the lost immovable property in case of evacuation or voluntary resettlement from contaminated areas»).

Provision of Pension Benefits to the Citizens who Suffered from the Chernobyl Catastrophe

One of the urgent issues remains the provision of pension benefits to the affected citizens, the expenditures to which exceed the budget allocations for all other benefits and compensation in three times.

As of 1 November 2011, the average size of pensions for the disabled individuals (participants of the ChNPP accident consequences liquidation), was assigned in accordance with the Law of Ukraine «On Status and Social Protection of citizens who suffered from the Chernobyl catastrophe» (hereinafter referred to as the Law), and was established at the following level:

- I group – UAH 2262.98;
- II group – UAH 2374.16;
- II group – UAH 1835.25.

Respectively to increase in 2011 of living wage for people who have lost the working capacity, the size of additional pension for damage to health, and the size of monthly compensation in case of the wage-earner loss, which are allocated under the mentioned Law, is growing.

Government pensions, assigned in accordance with this Law (pension by disability, which occurred as a result of illness or injury due to the Chernobyl accident and the pension by the wage-earner loss as a result of the Chernobyl accident), are allocated from the earnings received from work within the Exclusive Zone in 1986–1990 in the amount of actual damages compensation, which is determined in accordance with the Law (Article 54, first part of the Law).

The minimum size of such pension is set in the Law in multiple size to index of the minimum old age pension (for the disabled of 1st group – 10 minimum old age pensions, for the disabled of 2nd group – 8, for the disabled of 3rd group – 6, part four of Article 54 of the Law).

At the same time it should be noted that the pension insurance of persons whose disability is connected with the Chernobyl disaster, is performed at the account of the Government budget.

According to the second part of Article 95 of the Constitution of Ukraine, any Government expenditures for social needs, size and purpose of such expenditures are determined exclusively by the Government Budget of Ukraine.

Thus, based on the above, the size of minimum pension by disability (with an additional payment) and additional pension for damage to health to persons affected by the Chernobyl disaster, that are paid under the mentioned Law, is established by the Cabinet of Ministers of Ukraine Decrees «Some aspects of social protection of certain categories of citizens» dated 28 May 2008, reference number 530 and «On improving the retirement security of citizens» dated 16 July 2008, reference number 654.

Arrangement of Health Improvement of Citizens who Suffered as a result of the Chernobyl Catastrophe

A special place among the issues of preservation and restoration of the population’s health affected by the Chernobyl disaster belongs to the issue of arrangement of health improvement that is a key area of social protection of citizens affected by the Chernobyl disaster.

The Law of Ukraine «On status and social protection of citizens affected by the Chernobyl disaster» (hereinafter referred to as the Law) provides the health improvement of affected citizens (2.454.471 persons), including the affected children (498 409 persons).

In 2010, 364 417 applications were submitted, among which: 147 121 applications for health-resort vouchers of citizens aged 18 and older (adults), among whom 35 003 citizens assigned to the 1st category; 193 222 applications of children in groups; 24 074 children under 10 years accompanied by a parent (vouchers for mother and a child).

Despite the increased expenditures on these purposes in the Government Budget of Ukraine for 2010 (by UAH 53 million, or by 16%), the amount of necessary funds for Program «Health improvement of citizens affected by the Chernobyl catastrophe» (UAH 383 million) remains insufficient, at this the total funds required for the vouchers procurement is more than UAH 1.15 billion in 2010.

In accordance with the result of tenders, 111 383 vouchers were purchased including 70 194 vouchers for children within the frames of allocated funds.

Such vouchers are distributed between the administrative and territorial units in proportion, according to the submitted applications, taking into account the nosology of diseases.

A positive achievement of health campaign for 2010 is the increase by 48% over the previous year of the number of purchased vouchers for health-resort treatments of disabled persons with spinal problems, from among of victims of the Chernobyl disaster, but unfortunately, it satisfies the need to purchase vouchers for these category of citizens only at 28%.

According to information of the Labor and Social Welfare Central Departments, the health of 89 108 people affected by the Chernobyl disaster, including 56 157 children was improved as of 1 December 2010.

Privileged Provision with the Special Vehicles

Privileged provision with the special vehicles for citizens affected by the Chernobyl catastrophe is defined in Item 13 of Article 20 of the Law of Ukraine «On status and social protection of citizens affected by the Chernobyl disaster.»

In accordance with Item 12 of the Procedure on the Government budget funds applications to implement programs related to social protection of citizens affected by the Chernobyl disaster, approved by the Cabinet of Ministers of Ukraine Decree dated 20 September 2005, reference number 936, the vehicles provision for disabled people is implemented by the Regional Government Administrations' Department of Labor and Social Protection of Population in accordance with the Procedure for the special vehicles provision for the disabled people, approved by the Cabinet of Ministers of Ukraine Decree dated 19 July 2006, reference number 999.

As of 01 January 2010, 87 177 disabled persons are registered to get a special vehicle. Specifically, among them 16 239 disabled people are the victims or liquidators of the Chernobyl accident, including the following:

- I and II groups, who have medical indications for out-of-sequence provision with special vehicles, 4320 of disabled persons;
- II group, who have no medical indications and III group with the medical indications, 11 919 disabled persons.

It should be noted that under the global financial crisis, the Law of Ukraine «On Government Budget of Ukraine for 2009» did not include the costs for provision with special vehicles to the disable people, but relevant proposals have been incorporated during its formation.

The Law of Ukraine «On amending the Law of Ukraine «On Government Budget of Ukraine for 2009», the program was renewed and provided UAH 1.218 million for provision with the vehicles for disabled people..

In 2009, 214 vehicles were purchased only for families in which two or more disabled persons are living, at the account of the special fund amounting to UAH 7.8 million.

The Law of Ukraine «On the Government Budget of Ukraine for 2010» in order to implement the Budget program «Provision with the special vehicles for the disabled people affected by the Chernobyl accident» has approved UAH 89.1 million, among which UAH 88.1 million were allocated to the purchase 2253 vehicles that were provided to the disabled people registered at the Agencies of Labor and Social Protection of Population.

In accordance with the Government budget for 2011, the allocations have increased according to the relevant budget program and are UAH 89.7 million.

Improvement of Legislation

Pursuant to Item 1 of the Plan on the Verkhovna Rada of Ukraine Decree implementation «On the state, activities and prospects of overcoming the consequences of the Chernobyl catastrophe» dated 18 April 2008, No. 276-VI, the draft Law of Ukraine «On amending the Law of Ukraine «On the status and social protection of citizens affected by the Chernobyl disaster» was developed and worked up together with the central authorities, scientists and public «Chernobyl» organizations , which proposes to amend the majority of its articles.

However, it should be noted that acceptance of all proposals submitted to the draft law will expand the circle of beneficiaries and, consequently, will lead to a significant additional load on the Government expenditure budget.

At the same time, this there is a high probability of rejection of the draft law by the public «Chernobyl» organizations and, as a consequence the social tensions among the respective category of citizens' will increase.

Since at present, under the unstable social and economic situation in the country, the Government arranges some activities associated with the strict conditions of the budgetary costs savings during the regular Working Group meeting held on 25 December 2009. It was decided to gradually modify the effective Law of Ukraine «On status and social protection of citizens affected by the Chernobyl disaster «(hereinafter referred to as the Law).

Taking into account the long, almost a quarter of century, period of time after the Chernobyl NPP accident, and limited financial capacity of the State, development of a strategic document that provides a set of measures to optimize the effective system of social protection «Chernobyl people» is urgent and crucial task.

Problems and Solutions

The effective Law of Ukraine «On status and social protection of people affected by the Chernobyl catastrophe» (hereinafter referred to as the Law), adopted during the Soviet period, provides almost 100 different types of benefits, compensation and additional payments. Today the cost of the Law in full is more than UAH 70 billion every year, while the expenses of the Government Budget of Ukraine for 2011 were approved in the amount of UAH 321.9 billion.

The certain articles of the Law provide the implementation of payments, additional payments and aid to the victims of the Chernobyl disaster in the amounts established according to the minimum wage (Articles 30, 36, 37, 39, 48) and the minimum retirement pension (articles 50, 51, 52, 54). It is required UAH 36.8 billion every year to implement these articles of the Law in full.

According to Article 95 of Constitution of Ukraine, the Law of Ukraine «On Government Budget of Ukraine» determines any Government expenditures for social needs, size, and purpose of such expenditures based on actual financial resources of the Government budget.

Therefore, the certain articles of the Law of Ukraine «On the Government Budget of Ukraine» (Article 101 in 2007, Article 73 in 2008, Article 71 in 2009 and Article 70 in 2010) gave the right to the Cabinet of Ministers of Ukraine to set the sizes of social benefits which, according to the legislation, are determined depending on the minimum wage size, in absolute amounts within allocations provided by the respective budget programs.

As a result, a discrepancy has occurred between the size of payments established by the Law to the size of payments established by the Cabinet of Ministers of Ukraine Decrees (the sizes of certain payments provided by the Law, exceed the actual amounts of the benefits paid in accordance with the Cabinet's resolution in 8-10 times).

This led to mass references of the affected citizens to the courts of different instances with the claims. Most of these claims were satisfied in courts in the part of the pension, compensation and allowances payment in full in accordance with the Law.

Therefore, the beneficiaries of the above compensations, additional payments, and allowances are under the unequal conditions: some of them receive social support from the Government on the basis of the court decisions, the majority receive the support the size of which is much lower in accordance with the government's decision.

According to latest information of Regional Department of Labor and Social Protection of Population, there are over 134 thousand of citizens' claims under the trial of different instances totaling more than UAH 1318 million as of 01 February 2011. These claims are associated with the recalculation of compensatory payments in the amount provided by the Law, including 75 thousand judgments worth UAH 832 million that are not subject to appeal. Therefore, the executive body at the end of 2010 had attached 215 arrests to the accounts of the Regional Department of Labor and Social Protection of Population, the total worth of which is UAH 72 million and which are not provided by the Government budget.

Considering that since 1996, the social payments, the size of which depends on the minimum wage and minimum old age pension in accordance with the Law, were determined by the Cabinet of Ministers of Ukraine, and bearing in mind that at present these sizes (Articles 30, 36, 37, 39 , 48, 50, 51, 52, 54) are established by the Cabinet of Ministers of Ukraine Decrees («On establishing payment sizes for some categories of citizens affected by the Chernobyl disaster», dated 20 April 2007, No. 649; «On the compensation payments to individuals affected by the Chernobyl disaster», dated 26.07.1996, No. 836; «On an annual assistance for the rehabilitation of people affected by the Chernobyl catastrophe» dated 12.07.2005, No. 562; «Some aspects of social protection of certain categories of citizens» dated 28.05.2008, No. 530; «On improving the retirement insurance of citizens» dated 16.07.2008, No. 654), the Ministry of Labor together with the relevant central authorities and with the presence of social dialogue participants are designing the Law of Ukraine «On amending the Law of Ukraine «On status and social protection of people affected by the Chernobyl catastrophe» (regarding the size of pension, compensation payments, additional payments and benefits) (hereinafter referred to as the draft law), which would bring into compliance the size of pension, compensations, additional payments and allowance with the size set by the Cabinet of Ukraine guarantees within the expenditure provided by the Government budget for the respective year.

7.2.4. Rise of Level of Radioecology Knowledge and Awareness of Population on the Issues Associated with Overcoming the consequences of the Chernobyl Catastrophe

For 25 years that had passed after the accident, Radiobiology and its special field Radioecology were enriched with the very important actual material. Ecology-biological, medical and socio-demographic consequences of the accident were carefully examined; new aspects of action of small doses of the ionizing radiation and the chronic exposure on the human body were investigated; scientific basis of radiation protection at all levels is developed – from certain individuals to groups of organisms. Radiology, besides the problems of radiation monitoring of the environment, develops the modern methods of economic activities performing, especially in agriculture, within the areas contaminated with radionuclides.

However, despite these achievements, there are some notable contradictions in the treatment of the results obtained by scientists from different fields and by the officials. These contradictions are often lead to incorrect conclusions regarding the contemporary radiation situation. Undoubtedly, this is the result of insufficient radiological literacy not only of population but also of officials working in the field of atomic energy and ecology. This is the result of incomplete ecological education in general at all levels, from primary school till the higher education.

As for the first levels (schools, lyceums, gymnasiums, training colleges), there are no Radiobiology and Radioecology as an independent subject or the section of other subject according to the standards of education. The certain information about Radiology students receive or can receive through the study of Physics, Chemistry, Biology, Basic Life Safety.

Within the secondary special education (technical secondary schools, colleges) the issue of Radiology may be treated while learning the basics of Ecology. However, the scope of information in this sphere and its level largely depends on the individual characteristics of the teacher, his awareness of the problem, his attitude towards it. Nevertheless, it should be noted that during the first 10-15 years after the accident, teaching of the Radiology basics was included in the curricula of some schools of this level, including agrarian area, under the approved special program. A special textbook was published.

Government educational standards of higher professional education provide radiological training courses for a number of specialties and specializations (Radiobiology, Radioecology, Radiology and some other more narrow specialties) in the following scope: 32–48 hours as a rule, for engineer and technical specialties and 48–64 hours for biological, medical and agricultural specialties. However, when preparing the curriculum, these disciplines are often referred to the elective ones (subject to the choice of educational institution) or optional (facultative).

Analysis of radiological education in Ukraine shows that the most satisfactory situation in this context is in the sphere of agricultural and environmental education. In higher agricultural education schools, Radiobiology course with the Radiology essentials as an obligatory subject was introduced in the curricula of veterinary schools and faculties of Soil Science and Agricultural Chemistry for the first time in the late 50's of the last century, when the mass testing of nuclear weapons in the atmosphere took place. Even then it was clear that agricultural lands and vegetation and animal products are the main battery and therefore a source of a human exposure. Exactly these specialists of these directions, who possess the basic knowledge of Radiobiology and Radiology, played a significant role in minimizing the consequences of the Chernobyl accident in the agricultural sector of the country.

Future doctors had received some of the basics radioecological knowledge during the Medical Radiology and Roentgenology courses at that time. Students of the Physics Departments, especially with bias in nuclear physics received some pieces of knowledge in Radiology.

After the accident, the situation as to radiological education has changed for the better. From the school year 1987–1988, the Radiobiology course with a particular bias (Agricultural Radiobiology, Veterinary Radiobiology, Forest Radiobiology, Radiobiology, Radioecology) was introduced not only in all higher specialized agricultural education but also in secondary ones for almost all agro-and bio- natural sciences (with the exception of mentioned Veterinary Medicine, Soil Science and Agricultural Chemistry – for all agronomic specialties, Zoo-Engineering, Forestry and Landscape Architecture, and some others) sometimes in very large scopes (up to 120 hours). But those were also the elective ones. That is why this course is still, though in shortened form, preserved in universities located in officially declared zones of radioactive contamination, and is dismissed from the curriculum, or combined with other disciplines in schools located within the relatively «clean» areas. The most prosperous situation as to learning such discipline should be considered is in the National University of Life and Environmental Sciences of Ukraine (NUBiP of Ukraine) and Zhytomyr Agroecological National University.

For the first time, course of Radiobiology, which constitutes more than half of Radiological sections, as an independent mandatory subject is taught at 11 departments of natural and agricultural areas, namely: Ecological, Biotechnical, Agrobiological, Agrohimservice and Soil Science, Plant Protection, Fruit and Vegetable Growing, Veterinarians, Zoo-Engineering, Fish Farm, Forestry, Landscape Management on the «Bachelor» degree of educational qualification in the scope from 32 to 64 hours. Half of the curriculum is lectures course and half – laboratory studies.

In others agricultural universities for most specialties the Radiobiology course is elective with the exception of mentioned Veterinary Medicine, Agricultural Chemistry and Soil Science and Ecology and Environment.

Specialists as to «Ecology, Environmental Protection and Sustainable Use of Natural Resources» are being trained in more than hundred of public universities of different directions, including agriculture. This direction provides the mandatory teaching of Radiobiology and Radioecology disciplines, which include both lectures and laboratory classes. Depending on the capabilities of the university and its location, the scope of course hours ranges from 144 hours (NUBiP of Ukraine), and up to 64 hours in the most institutions.

The longest course regarding this direction which is being taught at the Ecology Department at the NUBiP Ukraine, apart from extended lectures course and laboratory work, involves the performance of course work, which presents a situational problem solving regarding specific sectors of agriculture in the contaminated territories, and conducting educational and practical training on farms located within the territories affected by the radionuclides.

The two-week practical training includes a performance of gamma-ray survey of an area, sampling of soil, plants and livestock products, preparation of samples for analysis on radionuclides content, the analysis of ^{137}Cs content in the samples, the calculation of coefficients of accumulation and transfer of radionuclides, mapping areas regarding its content in the soil.

The practical training, which is conducted within the framework of the diploma preparation, provides the performance of these common tasks, as well as the others, beyond all, of Radiobiology and Radiation directions depending on the specific topics of certain work.

For students of this specialty, and of the Agricultural Chemistry and Soil Science specialty, a special course in Agricultural Radiology is given on the «Master» degree.

Zhytomyr State Agroecological University trains specialists on the «Radioecology» specialization within the framework of this direction from 1997. Training includes teaching of specialized courses on Radiometry and Dosimetry, Radiation Monitoring, Radiation Protection, Radiation Hygiene and, of course, peculiarities of various agricultural sectors located within the contaminated areas.

The students of this university undertake the training practice on the basis of Laboratory of Radiation Zone Soil Revival of Polesie Agriculture Institute of the National Academy of Agricultural Sciences of Ukraine. As part of the degree work performance of the both qualification degrees, the students are engaged in research work at the stations within the zones of radioactive contamination by the Government subject «To conduct a comprehensive radiological monitoring of contaminated areas and to develop scientific principles of environmentally safe technologies for agricultural production on contaminated territories.»

Within the same area, there is a specialization «Radioecology» in the Odessa State Ecological University and in the Sevastopol National University of Nuclear Energy and Industry. In the Odessa University, ten special courses are held, including the following: «Modeling of physical processes in Radiology», «Methods of nonlinear analysis and dynamic processes in Radiology», «Creation and usage of databases for Radiological Researches», «Physical kinetics of radionuclides» at the Ecology and Economic Department during 3–5 courses in addition to the general basic courses of Radiobiology, Radioecology, Radiation Safety. On the Ecology and Technological Faculty of the Sevastopol University, such courses as «Radioactive Waste Handling», «Radiation Sources», «Radiation Toxicology» are held during 3–4-courses in addition to the basic courses.

Radiobiology Department and discipline «Radiobiology» were started within the first years after the accident at the biological faculty of the Kyiv National Taras Shevchenko University. The curriculum includes a large cycle of such special subjects as Radiation Biophysics, Radiation Biochemistry, Molecular Radiobiology, Cell Radiobiology, Radiobiology of Microorganisms, Radiobiology of Plants, Radiobiology of Animals and Human, Radioecology, Radiological Monitoring, Biogeochemistry of Radionuclides, Radiobiological Consequences of Nuclear Accidents, Radiation and Evolution, Microdosimetry theory, Quantitative Radiobiology, and Mathematical Modeling of Radiobiological Processes. The specialists from the National Academy of Sciences of Ukraine are involved for teaching.

The training courses «Human Health and Safety» and «Biological Effects of Ionizing Radiation», which include the general and specialized sections of Radiobiology and Radiology, are taught at the department of Medical Radiophysics of Radiophysics Faculty of Kyiv National Taras Shevchenko University.

In most of the specialties of Medical specialization, the students get some basic Radiology knowledge during the following courses: Radiology, Radiation Hygiene, Ecology, General Health, Health and Safety. At the National Medical Bogomoletc University, the Radiology course at the respective department was completed with the Radiation Medicine course. The Radiation Hygiene Department was established and some general issues of Radiology and Radiological Monitoring were taught within the framework of the respective course. However, in 2004, the Department was abolished and the course of Radiation Hygiene was shortened and combined with the general Hygiene.

A course on «Selected Issues of Radiation Medicine» was arranged at the Radiology Department of the National Medical Shupika Academy of Postgraduate Education with a total scope of 18 hours. The course foreseens visits to almost every region of Ukraine.

At the Institute of Postgraduate Education of NUBiP of Ukraine, the certain lectures on the radiological situation in Ukraine and the farming peculiarities within the contaminated territories are read almost for all areas of the advanced training courses. Sometimes they are accompanied by laboratory classes, which include familiarization with the operation and practical use of radiometers and dosimeters of different systems.

Teaching Radiology as a separate discipline, and disciplines that include Radiological sections are curtailed in whole despite the fact that Radiology and Radiobiology textbooks and manuals were prepared for all areas in the Ukrainian language, and there are appropriate guides in Russian; and that in general, the country has enough specialists in specialty 03.00.01 – Radiobiology (several doctoral and up to dozen master's theses are defended in this specialty of biological and medical areas at two specialized dissertation councils annually). Radiobiology and Radioecology are actually remained in the list of the main disciplines only for areas for which they had been taught until 1986. For other specialties, except Ecology and Environmental Protection, they are the disciplines to be introduced into curriculum by the Educational Institution's decision, and, respectively, withdrawn in the same way.

That is why over the years after the accident, and after the general improvement of the radiation situation in the country, Radiological disciplines began to feel some pressure – reduction of the teaching scope up to the full exclusion from the curriculum, integration with other subjects (Ecology, Civil Protection, Life Safety and others). Thus, courses were excluded practically from all specialized schools of I-II-levels and in some schools of III-IV-levels located at the southern regions. The scopes of theses subjects teaching were reduced sharply, sometimes in two times, even in the education institutions of agricultural area. Specialized departments were liquidated or combined with others which were created in the late 80's and early 90's. At present time, there is only one special Department of Radiobiology and Radioecology at NUBiP in Ukraine.

There are no reasons and excuses for such reduction. Around the world, after the relative decline of the NPP construction rates caused by the Chernobyl accident, there is a sharp rise of the above rates. The new nuclear units are put and are planned to be put into operation in Ukraine. The number of radiation technologies is increasing using in their processes objects exposure with ionizing radiation or radioactive isotopes. Along with them, an amount of radiation sources is growing, which increases probability of their runaway. There are signs of the nuclear terrorism threat. All this requires the quality improving of radiation environmentality among the population in general and among specialists, training of enough Radioecologists for various economy areas.

Undoubtedly, Ukraine is a nuclear nation. She ranks eleventh place in the world and first in Europe by the uranium resource and eighth place in the world by the number of nuclear units at Nuclear Power Plants, 15 blocks at four Nuclear Power Plants produce half of the electricity volume that the country consume. And if the past 20th century was called atomic, then started 21st century will be even more atomic. And a resident of Ukraine must know all advantages and disadvantages of atomic energy industry, have an idea of how the ionizing radiation effects living organisms, by which ways radioactive substances penetrate into the body and finally how to reduce the possible effects of radiation.

The basic knowledge of Radiology is required not only for the specialists of certain areas, but for everyone involved in the production of material and spiritual values. Radioecology must not be just an area of a general Ecology interest, but she has to become a compulsory part of the continuous environmental educational system.

As it has already been noted, untimely and insufficient awareness of population about the Chernobyl accident consequences by the government has created the psychological and social tension in society. So today, one of the key elements of public policy in overcoming the consequences of the Chernobyl catastrophe is a guaranteed public access to information about the radiological situation within the territories contaminated in the aftermath of the Chernobyl catastrophe.

The effective legislation of Ukraine defines the kind and periodicity of information preparation and distribution among the population by the executive power. This information concerns the exposure doses of the population, contamination density of areas that are within the zone of radioactive contamination and the radionuclide content in food.

In recent years, this information is being prepared in the form of booklets, which, together with information on exposure doses, also provide useful scientific-based information on the patterns of the radiological situation within contaminated areas, and in the form of atlases of the contaminated areas. Atlases contain interactive maps, through which one can obtain additional radiological information for each settlement referred to radioactively contaminated zones.

Scientific National Reports of Ukraine are being prepared annually where lead researchers of Ukraine present a comprehensive assessment of overcoming the consequences of the Chernobyl catastrophe, in particular, assessing the effectiveness of the performed work on overcoming the consequences of the Chernobyl catastrophe. Letters of information about dynamics of the radiological situation in the territories considered to be radioactive contamination zone (in areas sections), were issued for the local authorities.

In order to conduct an educational work in schools and institutions on issues related to the principles of Radioecology knowledge» and «informing the public on issues of safe farming within contaminated lands», the following was carried out: thematic studies on the preparation and performance of training seminars for specialists of management, education, health protection; correction and introduction of information materials related to the living safety within the areas affected in the aftermath of the Chernobyl catastrophe for teachers; replication and introduction of educational film for schools regarding the radio-ecological knowledge basis and so forth.

The centers of social and psychological rehabilitation and public information on overcoming the Chernobyl catastrophe which were established by the Ministry of Ukraine carry out the great work on informing the population on overcoming the consequences of the Chernobyl catastrophe.

7.3. The State Policy of Ukraine Considering the Nuclear and Radiation Safety Provision

7.3.1. Improving the Safety Culture in order to Maintain the Present Level of Nuclear and Radiation Safety at the Operating Nuclear Power Plants of Ukraine

The term «safety culture» had been applied in the document «Final report of the meeting considering the review of the causes and consequences in the «Chernobyl» No. 75-INSAG-1 for the first time, and had been further in use thought the following documents No. 75 INSAG 3, № 75 INSAG 4, INSAG 12, INSAG 13 INSAG 15 and the other IAEA documents.

In Ukraine, the requirements on the «safety culture» provision were specified in the regulations НП 306.2.141-2008 «General safety provisions of Nuclear Power Plants», which takes into account the

IAEA recommendations and the gained national and international experience in the Nuclear Power Plants operation.

The above normative document НП 306.2.141–2008, as well as the IAEA report No. 75-INSAG- 4, define the safety culture as a safety fundamental principle.

The Company activities related to provisions of the safety fundamental principle – safety culture – are focused on creation of an atmosphere of personnel loyalty to the safety objectives, and his personal responsibility and formation of the basic safety culture principles such as following:

- comprehension by the very employee of his activities influence on the safety and consequences, which can be caused as a result as non-compliance or poor compliance with regulations, manufacturing and job descriptions, technical regulations for safe operation;
- strict abidance to discipline within a clear division of powers and personal responsibility of managers and the direct performers;
- meeting the manufacturing instructions and technical regulations related to safe operation, their steady improvement based on gained experience and results of scientific and technical research;
- self-control of the employee’s activities related to safety;
- selection, training and professional development of managers and personnel with an emphasis on the priority of safety and understanding the errors consequences for safety;
- work performance with exclusive liability in accordance with the established procedures;
- systematic evaluation of activities related to safety.

According to the requirements of legislation of Ukraine, taking into account the IAEA recommendations and the Safety statement, issued in SE «Energoatom», the operating organization SE NAEK «Energoatom» (hereinafter referred to as the operating organization) assumes full responsibility for the Nuclear Power Plants’ safety at all life cycle stages and sets an absolute priority of safety purposes over any other objectives.

The main tasks of the operating organization are the following: maintenance of the design level of nuclear and radiation safety, steady improvement of the NPP safety in accordance with rules and standards on nuclear and radiation safety, international best practices and operating experience. The Council of safety culture established within SE «Energoatom» regularly holds meetings. This Council is a body of strategic planning, control and coordination of actions aimed at improvement of safety culture of SE «Energoatom». In separate divisions of a NPP the Councils/Committees of safety culture has been also established.

The SE «Energoatom» Management review an application in the field of safety from time to time, regularly provides implementation of an International Conference of Safety Culture, initiates a review of the organizational structure in order to improve the management system. Responsibilities and duties of management are carefully being analyzed and documented in job descriptions.

On 18–19 November 2010 in Kyiv, the 5th regular International Scientific Conference on safety culture was held. Such Conferences are held every two years. This forum gathers leaders and experts in the field of nuclear energy and there they discuss various aspects related to safe operation and development of safety culture at the Nuclear Power Plants. Specialists of organizations of Ukraine, Russia, European countries that operate Nuclear Facilities and the IAEA are invited to participate in the Conference. The main objectives of the Conference is to exchange experiences and to evaluate the safety provision results related to Nuclear Power Plants, improving the safety culture in the sphere of nuclear power.

The SE «Energoatom» carried out several significant steps related to the safety culture condition assessment at Nuclear Power Plants – methodologies were developed, self-assessment and independent calibrations were performed.

In 2008–2010, Programs of specific actions were developed at the each NPP aimed at establishment and development of safety culture at the separate divisions of NPP for 2008–2010, Program of the safety culture level self-assessment at the separate divisions of NPP. During 2009–2010, at the each separate divisions of NPP and other divisions of the Company, the safety culture level self-assessment had been performed in accordance with the SCART standards. The independent assessment of the current safety culture level at the NPP was carried out in April-August 2010. According to the results of such calibrations (independent assessment) the reports were developed related to the current level assessment of the fundamental principle of safety – the safety culture at the separate divisions of NPP, which identified areas that require improvement of safety culture, and corrective action were developed.

At NPP Power Units a significant number of measures were implemented within the framework of the Concept of safety increase. The Concept's measures implementation is now at the final stage and will be completed by the end of 2012.

The measures associated with the safety increase provided for the Rivne NPP Power Unit 1 are completed, and by the end of the year they will be completed for Power Unit 2, which will ensure the Units' safe operation after the extension of their operation terms.

The implementation of measures to improve safety of the Khmelnitskiy NPP Power Unit 2 and the Rivne NPP Power Unit 4, which were carried out within the framework of a special program, is completed (147 for the KhNPP and 146 for the RNPP). Financing of the measures was performed at the operating organization's expense and at the expense of the MFO credit (EBRD/Euratom). According to EBRD/Euratom creditors – implementation of Modernization Program of Kh2/R4 is the most successful project among those credited by EBRD/Euratom.

At this, the Company does not stop its activities: a Comprehensive (consolidated) Safety Program for NPP Power Units of Ukraine was prepared for the implementation.

An Expert Group of the European Commission and the IAEA had conducted a comprehensive assessment of the Ukrainian NPPs safety for their compliance with effective international standards (92 experts from 20 countries and international organizations, and 32 full-time IAEA employees participated in these Commissions). Similar assessments so far have no analogues in the world. The assessment was conducted to confirm the compliance with the IAEA fundamental standards subject to the following areas: design safety, operational safety, radioactive waste handling and decommissioning, and regulatory issues. The compliance with the IAEA safety requirements was confirmed by all areas.

SE NAEK «Energoatom», making and developing the safety culture, assigns an objective to implement safety culture as a process of continuous improvement, in which everyone can and should contribute – employees and management of the operating body, equipment suppliers, organizations of scientific and engineering support, State management and regulation – to obtain general results – maintenance and increase of the nuclear power safety as a significant component of State energy safety.

7.3.2. Strategy for the Safe Spent Nuclear Fuel Management

For Ukraine, nuclear power is a basic component of the National energy system, stable and reliable operation of which is a condition of the guaranteed provision for national economy with electrical energy, and of the stable economic growth and improvement of the citizens' welfare today and in the future. A the Nuclear Power Plants of Ukraine operate 15 reactors of VVER type, which produce about half the country's electricity at a price half less compared with traditional heat generation. This allows maintaining electricity tariffs at a level suitable for the present economic condition of society.

One of the essential components of the technological cycle of electricity production at Nuclear Power Plants is the formation of spent nuclear fuel (SF), which in accordance with the provisions of the National nuclear legislation belongs to the category of nuclear materials (not radioactive waste, the further usage of which is not expected).

Currently the most countries with nuclear power made the decisions which provide a long-termed storage of spent nuclear fuel at the appropriate facilities on their own territories. Analysis of global experience of the above storages operation that have been already built, indicates a high level of safety and reliability, as evidenced by their low environmental impact.

For Ukraine the problem of SF handling at the Nuclear Power Plants is extremely important. There are no spent nuclear fuel storage facilities in Ukraine, in consequence of which the organization which operates NPP – SE NAEK «Energoatom» is to transport SF outside the Government every year for storing and reprocessing in Russian Federation, under the condition to take back to Ukraine radioactive waste of such processing. The cost of services of foreign specialized enterprises for spent nuclear fuel storage and processing of NPP of Ukraine has increased more than in 2 times within last 15 years.

Besides saving money, which will have a positive effect on restrain of the electricity tariffs growth, the construction of own storage facility in Ukraine will significantly increase the energy safety of Ukraine. In fact, if the SF removal will be suspended for any reason, three existing Nuclear Power Plants of Ukraine, for which storage is assigned, and which currently provide about 25% of electricity production in the country, also will have to stop their operation soon due to nuclear safety requirements.

Therefore, construction in Ukraine of safe SF temporary storage of VVER reactors for its own need completely meet the international practice primarily aimed at provision of energy and nuclear safety of our country and completely meet the National energy program of Ukraine, approved by the Verkhovna Rada of Ukraine dated 15 May 1996, the Presidential Decree of Ukraine dated 27 December 2005 «On NSDC of Ukraine decision dated 9 December 2005 «On the Government of energy safety in Ukraine and the principles of State policy in the sphere of its provision», Energy Strategy of Ukraine till 2030, approved by the Cabinet of Ministers of Ukraine.

The draft law, entitled «On location, design and construction of centralized storage of spent nuclear fuel of VVER type reactors of National Nuclear Power Plants» was developed to implement the above decisions of higher authorities of Ukraine and in accordance with current legislation provisions. The site of the storage location, chosen on the results of multifactor analysis during development of the construction feasibility study, is proposed to allocate within the Chernobyl Exclusion Zone, 10-12 km south-west from Chernobyl.

In accordance with the requirements of Article 5 of the Law of Ukraine, entitled «On the order of decisions making about location, design and construction of nuclear installations and facilities which were designated for radioactive waste handling and which have the national significance», a set of supported materials was developed to the draft law, including the following: feasibility study for investments approved by the Cabinet of Ministers of Ukraine, a positive conclusion of the State ecological expertise, report to inform the contiguous states on the possible effect of SNFTS (Spent Nuclear Fuel Treatment Shop) within a transboundary context and agreement of the Ministry of Emergency of Ukraine to allocate SNFTS within the Exclusive Zone territories contaminated as a result of the Chernobyl accident.

Feasibility study for investments (FSi) for a storage construction had passed a comprehensive State examination, including the following: environmental, sanitary-epidemiological and investment expertise, nuclear and radiation safety expertise, performed by authorized State agencies. In particular, the conclusion of the State ecological expertise indicates that the SNFTS allocation and operation at the site chosen for this purpose is environmentally acceptable. The general conclusion of a comprehensive State expertise of FSi is positive.

According to the design decisions proposed in the FSi, the centralized Spent Nuclear Fuel Storage is proposed to be constructed within the Exclusion Zone territories contaminated by the Chernobyl catastrophe. The sanitary protective zone of the facility as estimated in FSi will not exceed 100 m, and the monitoring zone where the facility’s impact is possible – 1000 m. The above special zones completely belong to the Exclusion Zone, which excludes the impact of SNFTS on population.

The procedure of decision making on location of nuclear installations and facilities within the territory of Exclusion Zone and the zone of unconditional (obligatory) resettlement, designed for radioactive waste handling that are of national significance, was regulated by the amendments to the Law of Ukraine «On making decisions about the design, construction of nuclear installations and facilities designated for radioactive waste that have a national significance» (the Law of Ukraine №

1566-VI, Article 3–1). According to these amendments, the decision on approval of nuclear installations and facilities location within the territory of Exclusion Zone and the zone of unconditional (obligatory) resettlement, designed for radioactive waste handling and have a national significance, is made by the central executive body authorized to solve the issues on legal regime of the territories contaminated by the Chernobyl catastrophe. According to this legislative regulation, location of the SNFTS within the Exclusion Zone was approved by the Ministry of Emergency of Ukraine.

SE «Energoatom» performed a considerable information and explanatory work in order to inform the public of Ukraine on safety issues when the SNFTS construction and operation, including the following:

– publication in the newspaper «Uriadovyi Kyrier» («Governmental Courier») of statements related to intent and environmental consequences of the SNFTS construction, coverage in the media of materials concerning the SNFTS, post on the SE «Energoatom» website of information about the chosen storage technology of the SF storage, the storage construction and operation, information and analytical review of feasibility study for investments of the SNFTS construction, etc.;
– public meetings (briefings, round tables with the public and media representatives), public debate in the settlement of urban type Ivankov (with participation of Polesie district public) and in Slavutich, Kyiv region, informational support of public hearings in Slavutich, held by public participation of the Slavutich, Ivankov and Polesie districts, arrangement of tours for the public members of the above areas to the Zaporozhye NPP where the similar Spent Nuclear Fuel Storage is in operation, coverage of the safety issues of the SNFTS Project;
– process of the measures results, the public issues, and preparation of their responses, coverage of the work results with the public.

The implemented work with the public of Ukraine concerning the SNFTS safety was reflected in the «Report on Public Consultation on the construction of a Centralized Storage for Spent Nuclear Fuel of a VVER type of NPP of Ukraine». The above «Report ...» was included into the SNFTS EIA (Environment Impact Assessment), which held the State ecological expertise.

However, in order to implement the provisions of Article 12 of the Law of Ukraine, entitled «On Nuclear Energy and Radiation Safety» and to ensure the incorporation of the recommendations of the above public hearings concerning the SNFTS issues held in Slavutich, the draft law provides funds in the amount of 10 percent of the total estimated cost related to the storage construction and construction of social facilities in Slavutich, Ivankov and Polesie districts of Kyiv region, which will facilitate the issues solution regarding the social and economic development of these areas and will provide an opportunity to create new working positions. In accordance with Part 8 of Article 12 of the Law of Ukraine, entitled «On Nuclear Energy and Radiation Safety» transferring of these funds will be carried out in proportion to the SNFTS capital investment.

7.3.3. Improvement of the Physical Protection System of the Radioactive Waste Disposal Storage within the Exclusion Zone

Radioactive Waste Disposal Storages and Radwaste Temporary Localization Sites of the Exclusion Zone are included in the management sphere of Ministry of Emergency, which in accordance with the legislation requirements is responsible for programs' development related to improvement of the physical protection system of its subordinate facilities.

However, it should be noted that implementation of the Governmental policy in the area of physical protection of radioactive waste and other sources of ionizing radiation, aiming at protection of the national safety interests, prevention and suspension of the acts of nuclear terrorism and strengthening of the nuclear nonproliferation regime, is not the priority of the Ministry of Emergency, and the Exclusion Zone Administration at present.

Thus, in accordance with the results of comprehensive inspections performed by the SNRCU during 2008–2009–2010, a very poor state of physical protection system of Radioactive Waste Disposal

Storage and Radwaste Temporary Localization Site (RWDS, RWTLS) located within the Chernobyl NPP Exclusion Zone was revealed. .For instance, absence of the technical means of detection and video monitoring systems does not allow effectively performing the functions of security at RWDS «Pidlisnyy», «Buriakivka», «3rd commissioning stage of ChNPP» and RWTLS «Rozsokha. Due to the absence of technical means of illumination of the restricted access zones, the complete security functions are not performed during the night time. Within the certain sections of the restricted access zone of RWTLS «Rozsokha, adjacent to the forest, there is no perimeter fencing and warning signs.

As an example of the negative consequences of non-compliance of physical protection system with the legislation and legal acts requirements – there was a theft of radioactively-contaminated copper-nickel-iron pipes, with the total weight of 6 t. 920 kg from the RWDS «Buriakivka» restricted area in the IV quarter 2009. And in 2010 while attempting to penetrate to the RWDS «Pidlisnyy» territory, an employee of one of the Exclusion Zone enterprises was detained; in the third quarter of the same year a theft of radioactive materials was recorded (products manufactured from depleted uranium) with a total weight of 74.4 kg at facility «3rd commissioning stage of ChNPP».

Based on the results of the implemented inspections, it has been concluded that the system of physical protection of radioactive waste disposal sites of the Exclusion Zone does not completely comply with the legislation requirements on the nuclear physical protection, and is unable to perform the function of a counterwork to potential threats. Arrangement of activities at these facilities does not provide comprehensive solutions of problems associated with provision of the radioactive waste physical protection, which in turn may be defined as the failure of Ukraine to perform the international obligations – namely, the Convention on the Physical Protection of Nuclear Material. Lack of effective internal control creates an atmosphere of impunity and irresponsibility of the industrial personnel.

Also, one of the negative situation factors is the failure to meet Article 27 of the Law of Ukraine, entitled «On the physical protection of nuclear installations, nuclear materials, radioactive waste and other sources of ionizing radiation» related to the funding procedure of the physical protection system of radiation hazard objects. So far the calculations have not been performed considering the need to create an effective system of the RWDS physical protection as it is foreseen by the effective legislation requirements.

7.3.4. General Government Measures for the State Policy Implementation Concerning the Issues of Chernobyl NPP Safe Decommissioning and its Conversion into the Environmentally Safe System and the RAW Handing

The State Nuclear Regulatory Committee within the frames of its powers, implements the State policy on the nuclear energy use, provides for meeting the nuclear and radiation safety requirements, and within its activities related to the Object «Shelter» follows the Laws of Ukraine, decrees and orders of the Cabinet of Ministers of Ukraine, legal acts in the sphere of nuclear energy use.

The Ministry of Environmental Protection and Nuclear Safety of Ukraine approved the «Statement about the policy of nuclear and radiation safety regulation of the Chernobyl NPP Object «Shelter» dated 08 April 1998, No. 49 in order to clarify the State policy of nuclear and radiation safety regulation of the Object «Shelter». It defined the basic principles of nuclear and radiation safety provision when implementing the activities related to the Object «Shelter» in the course of its conversion into environmentally safe system, namely: management principles, prevention of nuclear accidents, radiation protection, radioactive waste handling, and the general technical principles.

In 2001 the State Nuclear Regulatory Committee developed and registered in the Ministry of Justice of Ukraine the «Requirements to the structure and content of the Shelter Implementation Plan safety analysis report». In accordance with requirements of this document, the SSE ChNPP develops the safety analysis report of the designs to be submitted to the State Nuclear Regulatory Committee as part of the documents set in order to obtain a permit to conduct certain activities or operations at the Object «Shelter».

During the 2005–2006, the State Nuclear Regulatory Committee developed the «Basic safety principles of activities within the framework of the Shelter Implementation Plan» and «Guidelines on the application of safety principles when performing regulatory activities within the framework of the Shelter Implementation Plan» with participation of foreign experts.

In October 2010, the Legal Act «Conditions and procedure for issuing written permits for certain types of activities or operations related to conversion of the Object «Shelter» into the environmentally safe system» developed by the State Nuclear Regulatory Committee came into force. This document defines the types of activities or operations to be carried out under the individual permits at the Object «Shelter», sets the conditions and procedure for issuing, amending, refusal to issue, suspension and revocation of permits for certain activities or operations related to conversion of the Object «Shelter» into the environmentally safe system.

For the arrangement of mutually agreed activities of regulatory authorities involved in the Shelter Implementation Plan (SIP) performance, State Nuclear Regulatory Committee, Ministry of Health, Ministry of Natural Resources, Ministry of Regional Development and Construction, State Committee of Ukraine on Industrial Safety, Labor Protection and Mining Supervision, State Fire Safety Department of MES of Ukraine executed a «Protocol between the regulatory authorities of Ukraine related to cooperation and division of competence in respect of Shelter Implementation Plan» in order to avoid duplication of activities, to shorten the designs review terms, and to adopt the coordinated regulatory decisions in 2003.

Coordination of regulatory authorities' activities oriented on the most important issues is conducted through the «Interdepartmental Working Group on Coordination of the regulatory authorities' activity when issuing licenses for activities on the Object «Shelter» and Chernobyl NPP decommission».

«SIP Projects Licensing Plan. Phase 2» was developed in 2003 in order to ensure a clear process of the SIP projects licensing, the determination of interaction between parties involved in the review of these designs. This document defines the scheme of documents concurrence, obtaining the permits from the regulatory and supervisory authorities. The individual licensing processes for the most important projects were developed in the course of this document evolution, namely: implementation of stabilization measures, realization of the New Safe Confinement, realization of the Object «Shelter» Integrated Automated Monitoring System.

In accordance with the National Program of the Chernobyl NPP decommissioning and conversion of the Object «Shelter» into the environmentally safe system, approved by the Law of Ukraine dated 15 January 2009, N 886-VI, measures taken at the Object «Shelter», shall be classified as the measures aimed at the Object «Shelter» conversion into the environmentally safe system.

The Object «Shelter» conversion into the environmentally safe system requires mobilization of significant financial and material resources and international support to solve this wide scale problem.

The International program of the Object «Shelter» conversion into the environmentally safe system – Shelter Implementation Plan (SIP), in Ukrainian: План Здійснення Заходів (ПЗЗ) was developed jointly with the Governments and experts from different countries during 1997.

The SIP includes 22 tasks aimed at ensuring of the basic safety objectives, namely: reducing the probability of the Object «Shelter» collapse (stabilization of structures), mitigation of the collapse consequences, increasing the nuclear safety, raising the personnel and environment safety, long-term strategy of measures related to the Object «Shelter» conversion into the environmentally safe system.

The State Nuclear Regulatory Committee performs the examination of nuclear and radiation safety (technical evaluation) of designs, technical decisions, design and technical documentation developed in order to carry out certain SIP tasks. Since the beginning of the SIP projects more than 200 such examinations were implemented.

For their performance a number of methodical and regulatory documents was developed, which identify the requirements' system of the Object «Shelter» nuclear and radiation safety and activities within its framework: from the fundamental principles and safety foundation applied to the Object «Shelter», to specific criteria and requirements concerning this facility.

One of the main SIP projects is the construction of the Object «Shelter» New Safe Confinement (NSC).

Confinement is a protective structure that includes a complex of technological equipment for the removal of materials that contain nuclear fuel from destroyed Power Unit 4 of the Chernobyl NPP, radioactive waste handling and other systems designed to implement the measures aimed at conversion of this Unit into the environmentally safe system and the personnel and environment safety provision.

Providing for the licensing process of the Object «Shelter» New Safe Confinement construction is a task of top priority of the State Nuclear Regulatory Committee.

In the course of the NSC construction, the State Nuclear Regulatory Committee closely cooperates with the SSE ChNPP and with the Contractor of the NSC First Commissioning Stage, provides the consultative support and clarifications on the regulations requirements and on approaches to safety justification of the designs, etc. In particular, such support was provided while developing the NSC additional design criteria and requirements, related to the effects caused by the avalanche of snow/ice from the roof of the NSC protective structure, impact of tornado Class 3 on the NSC structures, impacts of wind loads, requirements for material of steel sheets and welded pipes of the NSC protective bearing structures, and the NSC main crane system.

Infrastructure for the ChNPP radioactive waste and spent nuclear fuel handling within the framework of the Chernobyl NPP decommissioning foresees the construction of Spent Nuclear Fuel Storage (**ISF-2**), the Liquid Radioactive Waste Treatment Plant (**LRTP**), the Industrial Complex For Solid Waste Management (**ICSRM**), Complex of production on decontamination, transportation, processing and disposal of radioactive waste from the areas contaminated after the Chernobyl catastrophe (code-named «Vector»).

ISF-2 (Spent Nuclear Fuel Storage).

Terms of license, entitled «Nuclear Installation Construction» Series EO # 000124 dated 13 May 2003, issued by the State Nuclear Regulatory Committee, foresee the activities for the construction of ISF-2 only after approval of the revised Design for the ISF-2 construction in the established order and agreement of the ISF-2 preliminary safety analysis report (PSAR) with the State Nuclear Regulatory Committee.

During 2010, the State Nuclear Regulatory Committee involving the experts from State Scientific and Technical Center of Nuclear and Radiation Safety (SSTC NRS) (Ukraine) and RISKAUDIT (Germany – France) performed the State Expert Review of nuclear and radiation safety of ISF-2 PSAR and other documentation related to completion of the ChNPP ISF-2 construction.

On 19 October 2010, the Decree of Collegium of the State Nuclear Regulatory Committee No. 12 approved the conclusion of the State expert review of PSAR and other documentation associated with the completion of ChNPP ISF-2 construction, as the ones that demonstrate the compliance of the ISF-2 design decisions with nuclear and radiation safety requirements in general.

As of present-day, the Chernobyl NPP takes measures related to approval of ISF-2 design and re-issuance of the license Series EO # 000124 «Nuclear Installation Construction», issued by the State Nuclear Regulatory Committee on 13 May 2003.

LRTP (Liquid Radioactive Waste Treatment Plant).

As of today, the State Nuclear Regulatory Committee plans their activities within the framework of the LRTP licensing on the basis of the «Schedule of the documents development and submission in order to obtain permits for the LRTP commissioning and operation» updated by the ChNPP.

Expert support within licensing activities related to the LRTP project implementation, is being provided under the Contracts awarded in accordance with «Grant Agreement (Chernobyl NPP Nuclear Safety Project) between the European Bank for Reconstruction and Development (as Administrator of grant funds from the Nuclear Safety Account), the Cabinet of Ministers of Ukraine and the State Nuclear Regulation Committee of Ukraine (as the Recipient)» (Grant Agreement dated 07 August 2009, Reference Number 007).

The State Nuclear Regulatory Committee has approved the SEE ChNPP Technical Decision «On revisions of the design of «Liquid Radioactive Waste Treatment Plant». This Technical Decision is an important document of the Operator in the context of the LRTP project completion and commissioning of this facility, as the SSE ChNPP formulates a list of major modifications (revisions) in this document that are to be incorporated to the LRTP design and are significant from the point of view of safety of this facility. To evolve this Technical Decision, the SSE ChNPP shall prepare the working documentation packages on modifications and submit them to a Comprehensive State Expert Review.

Submission of application and the documentation package to obtain the certain written permit of the State Nuclear Regulatory Committee for the LRTP commissioning is scheduled for 4 quarter 2011, and for the operation – 1 quarter of 2012.

ICSRM (Industrial Complex for Solid Waste Management).

Project Composition: Lot 0 – Temporary Storage for interim storing of low and medium active long-lived and highly radioactive waste that is being constructed inside the Liquid and Solid Radioactive Waste Storage Facility (LSWSF); Lot 1 – Installation of Solid Radwaste Removal; Lot 2 – Solid Radwaste Treatment Plant; Lot 3 – Specially Equipped Surface Storage of Solid Radwastes (SESSSR), constructed at the Vector site.

Lot 0.

On 10 December 2010, the State Nuclear Regulation Committee of Ukraine signed a Particular Permit No. 000040/4 on operation of the Temporary storage of solid radwaste of the third group and low and medium active long-lived wastes (hereinafter referred to as TS SRW and LM LLW) which is part of Industrial complex on solid radioactive waste management at the site (hereinafter – ICSRM) of the SSE «Chernobyl NPP».

The grounds for granting such permission are as follows:

1) positive conclusions of the State nuclear and radiation safety expert review;

2) results of inspection survey held by the Commission of State Nuclear Regulatory Committee in September 2010 (Deed dated 17 September 2010, No. 46-24-34П).

Also, the following was taken into consideration: the Plan of measures on eliminating the comments, presented in the Act of inspection survey dated 17 September 2010, No. 46-24-34П, and the comments revealed within the framework of the State nuclear and radiation safety expert examination documentation which justify the safe operation of TS SRW and LM LLW, approved by Mr. A. Bilyk, Technical Director (Chief Engineer) of SSE ChNPP on 26 November 1910, and put into force by the SSE ChNPP Order dated 26 November 2010, No. 757.

In accordance with the terms of this Permit:

- practical works on acceptance of RAW packages and their load into the compartments of TS SRW and LM LLW may be initiated only under the circumstances that the mentioned above «Plan of measures on eliminating the comments ...» is implemented (including the provision of supporting documents);
- Receiving waste packages may be made from processing plant solid waste ICSRM only.

It should be noted that this Permit gives the right to perform the activities related to TS SRW and LM LLW operation and associated with acceptance, and storing of the SRW and LM LLW packages until the storage's compartments are full. In the future, taking into account the speed of the compartments filling of the TS SRW and LM LLW, but not later than in 10 years, the SSE «Chernobyl NPP» is to plan and perform the reevaluation of the storage safety. As part of the storage safety reevaluation, the SSE «Chernobyl NPP» should provide to the State Nuclear Regulatory Committee a revised Safety Analysis Report of the storage and other documents that substantiate the safe storage of radioactive waste packages. Among other things, according to the revaluation results of the TS SRW and LM LLW safety, the period of radioactive waste packages storage should be defined and justified.

Lots 1, 2. On 13 May 2010, the State Nuclear Regulation Committee of Ukraine executed a Particular Permit, ref number 000040/3 for the commissioning of Solid Radwaste Removal Plant (hereinafter – SRRP, Lot 1) and Solid Radwaste Treatment Shop (hereinafter – SRTS, Lot 2) of the Industrial complex for radioactive waste at the SSE «Chernobyl NPP».

According to the granted permission, SSE «Chernobyl NPP» has the right to conduct activities within the framework of the first stage («hot tests») of the SRRP and SRTS commissioning, as provided by documents «ICSRM Commissioning Program» and «Work Program of the ICSRM «hot tests» first stage».

ICSRM Commissioning Program provides for three stages of the SRRP and SRTS commissioning, namely:

Phase 1 – testing with radioactive waste (hereinafter – RAW) that are inside hermetic containers, with the known characteristics beforehand;

Phase 2 – testing with RAW without hermetic containers («open» RAW) with the known characteristics;

Phase 3 – testing with RAW removed from the ChNPP SWSF sections.

In order to obtain a permit to perform work during the second phase («hot tests») of the SRRP and SRTS commissioning, the SSE «Chernobyl NPP» has to provide the State Nuclear Regulatory Committee with the following documents: reports related to achievement of the criteria for the first stage completion, in accordance with the ICSRM Commissioning Program; copies of Deeds of commission for acceptance of the SRRP and SRTS technological equipment and systems after the «hot test»; the Working Program for the second stage of the «hot tests».

Lot 3 – SESSSR. The License Series EO # 000894 dated 07 February 2009 was issued to SSE «Technocenter», with 5 years of validity period. In accordance with the special conditions of this License, SSE «Technocenter» must undertake all necessary measures to ensure and to demonstrate the storage safe operation through the following: revealing and eliminating the causes of water inflow under the storage, providing for the analysis of the storage structures and systems functions foreseen by the design, implementation of modern procedures for safety assessment, implementation of actual analysis of long-term safety of disposal system, and optimization of acceptance criteria. In order to solve the issues on safety assessment of the storage, including seismic analysis, the European Commission provided SSE «Technocenter» with technical support.

7.4. International Scientific and Technical Cooperation Related to Overcoming the Consequences of the Chernobyl Catastrophe

The Chernobyl catastrophe is one of the most tragic events in human history, but is also a vivid example of the unification of the world in the face of a global threat. Now, a quarter of century after the accident, the final resolution of the Chernobyl problem is possible, perhaps now more than ever, thanks to the efforts of the international community, its persistence and consistency. Recent political decisions by the «Group of Eight» leaders and their declaration at the regular summit on nuclear safety issues, held on 11–14 April 2010 in Washington, demonstrate an intent to meet obligations related to the Shelter Implementation Plan (SIP) i.e. conversion of the Object «Shelter» into an environmentally safe system [41]. As is well known, the main task of the Plan (construction of a new protective shell over the destroyed reactor), is still not complete, despite all the efforts of the international community. The construction of the technical infrastructure, needed for safe decommissioning, has been significantly delayed.

Twenty-five years after the Chernobyl catastrophe, its consequences are still a global problem.

An important step in arranging further international cooperation is the international scientific and strategic conference «Twenty-five years after the Chernobyl catastrophe. Safety for the Future», which is scheduled in Kyiv on 20–22 April 2011.

From the first day of the accident, the world's attention was riveted to the Chernobyl NPP, as a source of planetary peril. The main risk was the destroyed reactor and potentially the other reactors of the Chernobyl Plant, which continued their operation.

Taking into account the threat of global environmental radioactive contamination that arose, the economically developed countries – above all the countries of forming the «Group of 7» immediately offered assistance to the USSR to help control the situation as soon as possible. The main condition of the «Group of 7» governments was a requirement related to the prompt final shut-down of all the reactors of Chernobyl NPP as soon as possible. This was not included in the plans of the USSR government, so in 1986 the «Group of 7» agreed to assist only in the field of radiation medicine and not in any technical sphere.

Now, twenty-five years after the accident, looking back at the Chernobyl events and acknowledging the current situation regarding construction of a new safe shell over the «Shelter», it is fair to say no country in the world would be able to solve a problem of this scale alone.

After the collapse of the USSR, international assistance and cooperation with Ukraine has gradually grown, focusing on the following main objectives (since 1992):

- Shelter Implementation Plan (SIP);
- technical assistance to develop the infrastructure needed for the safe decommissioning of Chernobyl NPP and conversion of the Object «Shelter» into an environmentally safe system;
- research projects in the Chernobyl NPP Exclusion Zone and projects to survey the health of individuals affected by radiation;
- projects of humanitarian aid:

a) supplying Ukraine with medical equipment, medicine, clothes and food;

b) the rehabilitation of victims (mostly children) overseas

c) assistance in building local government and promotion of the civil self-help movement (UN Program) [42].

Although it was the technological and radiological aspects that attracted the attention of the international community within the first years after the Chernobyl accident, the scale of the humanitarian aspect of the Chernobyl catastrophe has become clearer since the incident and cannot be overlooked.

According to some assessments, about 2.6 million people living in 2293 settlements were affected as a result of the accident [43]. These communities were affected by direct exposure to radiation and also by the restrictions on economic activity within contaminated areas. In addition, government subsidies gradually depreciated due to inflationary processes and this has intensified people’s apathy and scepticism of the measures. Decreasing subsidies have had a significant negative impact on people’s lives: shortages of available medicine and medical equipment, low education levels of children and teenagers, and a lack of maintenance for engineering and technical infrastructure in the settlements.

Since the early 90’s, contact and communication between Ukrainian non-governmental organizations and individuals of various foreign institutions has become much simpler. This has helped create favorable conditions for the development of a civil movement of support and solidarity with the affected population of Ukraine, Belarus, and Russia. After 1992, in Germany for example, there were over a thousand organizations that provided charitable assistance to residents of the affected areas and evacuees [44]. The Government of Cuba is providing invaluable assistance in the treatment and rehabilitation of children from the resettled villages and towns [45].

Over the past 20 years many non-governmental organizations have provided a wide range of assistance to help overcome the effects of the Chernobyl incident – from the rehousing and rehabilitation of children, the provision of medication and technical support to medical and health institutions, to large-scale social and environmental projects [46]. The establishment of the Unified Chernobyl European Network of non-governmental organizations is a significant step forward in the European charity movement on the eve of 25th anniversary of the Chernobyl accident. In January 2011, Germany planned to publish a book, entitled «25 years after the Chernobyl – a European culture of memory and solidarity». Its main objective is to present a comprehensive history of the involvement of the European charity movement [47].

Bilateral and multilateral, governmental and non-governmental support, which was initially provided to Ukraine in the ‘90s, had a tendency to be focused on short term objectives, dealing with the immediate consequences of the accident. Later on, the international community understood the emphasis needed be move towards longer term development programs.

The need to change the approach to the provision of humanitarian support to victims of the accident was first highlighted in the report «Humanitarian Consequences of the Chernobyl Catastrophe – a Recovery Strategy» [48], which was published in 2002 by the UN Development Program (UNDP), UN Children's Fund (UNICEF) under the support of the United Nations Office for Coordination of Humanitarian Affairs and the World Health Organization (WHO). In late 2002, UNDP and the Government of Ukraine have started a program of restoration and development of areas affected by the Chernobyl catastrophe (RDPCH) [49].

The program paid special attention to three objectives related to assisting the local population. The objectives were:

- restoring a sense of dignity and independence;
- development of initiatives to search for resources and economic opportunities;
- protect the health and wellbeing of inhabitants residing within the contaminated areas.

During 2003–2007 years, UNDP/RDPCH provided funding for approximately 190 social improvement projects. The total budget for these projects is about USD 3.4 million, 30% of which was provided by UNDP/RDPCH [50].

Additional funding for implementation of the RDPCH Program was provided by the Canadian International Development Agency, and the Swiss Agency for Development and Cooperation. Within the UNDP/RDPCH framework, the development projects were completed in the seventeen most contaminated regions of Chernigov, Rivne, Kyiv and Zhytomyr. Through these activities, 279 community organizations in 192 settlements were established involving a total of more than 20000 inhabitants.

Part of the Program was funded by the Government of Japan through the UN Trust Fund for human safety. Financial assistance was provided (grants from USD 20 thousand to 75 thousand) to non-governmental organizations and medical institutions [51].

16 projects were performed with the total cost of USD 717.5 thousand within the framework of this Program between 2002 and 2008.

The official position of the international community regarding future plans and activities within the Chernobyl projects is specified in the 62nd UN Assembly recommendations (October 2007), and consists of rehabilitation and development phases as the next stage in minimizing the effects of the Chernobyl catastrophe. The UN Secretary-General in the report «Optimizing the international efforts on studying and minimizing the consequences of the Chernobyl catastrophe» noted that a return to normal life is a realistic prospect for most people living in areas that have been affected by the Chernobyl catastrophe [52].

According to the experts' conclusions, at present the main problem of the affected areas lies in the non-compliance of social and economic infrastructures, unsatisfactory funding of local authorities and the limited capacity of the local governments. The Chernobyl programs didn't focus on reducing the poverty of the population within the affected areas due to the outdated approaches of the social support system. New 'realities' require the development of new concepts and approaches to social welfare, the main task being to move from humanitarian assistance with its outdated social safety system to the real stimulation of social and economic development in the regions.

The old programs, which developed Chernobyl 'victims', should be decisively replaced with personal and community development initiatives that would encourage the local residents to build their own future, and instilling self-confidence in them.

To this end, the UN experts suggest the main efforts of the international community should focus on stimulation of a steady social and economic development, the creation of new jobs, and attracting investments in order to 'rehabilitate' those territories affected by the Chernobyl catastrophe.

Taking this approach into account, the European Union experts have developed a social and economic strategy for the Chernobyl region and the Exclusion Zone development. For the first time, the EU International Expert Committee has introduced an assessment of business potential for the Chernobyl region, because these areas were being considered only from the point of view of social safety provision. The experts have chosen the following three business-ideas as the top priority ones: brick factory, rape cultivation in Ivankiv region, and dry wood processing in the Exclusion Zone [53].

According to the European Union experts' conclusions, there will be a real danger of fires in the Chernobyl area until radical measures for the utilization of contaminated dry forest are introduced. The European Union experts suggested for Ukraine a project involving 'environmentally clean' wood burning in the Exclusion Zone, implementation of which will cost EUR 2.5 million. Experts have estimated the risks and profitability of the projects. Attracting investors falls is the responsibility of the local administrations. But to start a business on land that's classified as contaminated, one needs a special permission from the Cabinet of Ministers of Ukraine and numerous regulatory authorities and this process discourages potential investors.

Part of implementing the new UN strategy, a practical contribution to the international community, was a series of seminars held in Russia, Ukraine and Belarus during 2009 [54]. For the first time the seminars were co-organized by all four specialized UN organizations: IAEA, UNDP, UNICEF and WHO. The purpose of the seminars was the advanced training of professionals in the distribution of information related to the Chernobyl catastrophe, and training of the local authorities' representatives responsible for decision making and the provision of information to the public.

In Ukraine, this seminar was held during 2–4 June 2009 in Kyiv, at the Radiation Medicine Research Center of Medical Sciences Academy of Ukraine under the support of Ministry of Emergencies and Affairs of Population Protection from Consequences of Chernobyl Catastrophe of Ukraine.

The seminar was within the framework of the Regional project of IAEA technical cooperation RER/3/004 «Radiological rehabilitation support for territories affected by the Chernobyl accident», as well as within the ICRIN project (International draft of the UN organizations), which was devoted to the Chernobyl problems.

Currently the position of the international community remains unchanged concerning the assessment of the current state of the Chernobyl NPP catastrophe – this was presented before the 20th anniversary of the accident in a number of Chernobyl Forum documents: Joint report of the UN, IAEA, WHO «Chernobyl heritage: medical, ecological and social and economic consequences», «Chernobyl: the true scale of the accident», the UNDP and UNICEF reports «Humanitarian Consequences of the Chernobyl accident: a strategy for rehabilitation», Documents from the International Conference «Chernobyl: 20 years later» and the adopted Chernobyl action plan for the period until 2016 by the UN [54].

The main conclusions of the above documents may be summarized as follows:

- degree of the radiation risk to the health of local people (outside the Chernobyl NPP Exclusion Zone) is currently rated as zero.
- restrictions in the economic and commercial sphere caused by radiation stigmatization (i.e. hanging labels, generally isn't justified, for example: in Ukraine, all lands and all agricultural products are radioactively contaminated), hence investment and infrastructure is missing;
- the practice of granting a wide range of benefits in the social sphere formed «dependence syndrome» among the population of the affected regions, and extensive radio phobia which caused passivity and helplessness. These factors are combined within the «Chernobyl victim syndrome» concept;
- the need to change the current policy of humanitarian aid by the international community, implementation of which contributes to strengthening of the consumer frame of mind among the affected population;
- radiological rehabilitation of the population has been completed, the size of contaminated areas is reducing, and its recommended existing international standards are applied for their classification;
- the international scientific community needs greater access and use of the unique scientific 'laboratory', which the Exclusion Zone around the Chernobyl NPP represents.

Analysis of experience gained and the results of years of work demonstrates that international cooperation in Chernobyl does not represent a so-called movement «one-side side». If Ukraine received a large-scale humanitarian and technical aid, the countries that have granted such assistance got an access to a unique «Chernobyl polygon».

To facilitate international research, the U.S. Government and the International Radioecology Laboratory (IRL) sponsored activities within the Exclusion Zone in Ukraine. The IRL has the necessary research base directly at the Exclusion Zone.

Despite the short period of the laboratory's existence, significant scientific findings have been obtained from international projects: the IRL scientists, along with leading scientists from the U.S., UK, Germany, France and several other countries published more than 100 works. Since 2007, the IRL together with the research centers in the U.S. such as the Washington Savannah River Company LLC, Savannah River National Laboratory (later – Savannah River Nuclear Solutions), have moved from the long-term gathering of scientific and theoretical measurements to summarizing the gained knowledge and skills derived in minimizing the consequences of the Chernobyl accident, including the treatment of contaminated areas and the Chernobyl NPP decommissioning. As part of these projects, information has been collated and organized, including: that pertaining to the decommissioning of the Chernobyl NPP and the cooling pond, the construction of the new safe confinement over the Object «Shelter», the radioecological processes that occur in different ecosystems of the Chernobyl Exclusion Zone, approaches to radioecological risks, procedures for environmental researches, and others.

One of the most 'challenging' objects within the Exclusion zone is the Chernobyl NPP Cooling Pond. Its safe handling requires cooperation at an international level. As a result of the accident, the Pond has been contaminated by dispersed nuclear fuel and high-active water discharges from the reactor's primary loop. The handling issues of this object have been periodically reviewed by experts from different countries within the framework of the IAEA Programme at the Chernobyl NPP. One of the last tasks, which took place in October 2009, was devoted to the following: discussing the current state of contamination of Cooling Pond and the surrounding area, the impact of the Pond on the environment, contamination peculiarities of sediments; a forecast of changes to the ecosystem during Pond removal; previous experiences in rehabilitation of radioactively contaminated water bodies.

Establishment of the International Radioecology Laboratory has enriched the treasury of human knowledge in the field of Radiology and Radiation Protection, expanded and strengthened contacts between the scientists of many countries and helped to preserve and increase the scientific potential of Ukraine. The IRL opens a great opportunity for researchers from all around the world to develop and research tools for the estimation of the technogenic environmental contamination consequences and optimal and efficient solutions to overcome these effects.

According to rankings of the most exotic tourist destinations that attract people from many countries, the Chernobyl NPP Exclusion Zone occupies one of the highest positions (according to Forbes magazine). Of course, Chernobyl is not a tourist center. Most people who visit the Exclusion Zone are scientists, journalists, writers, environmentalists and politicians. These are people who have a professional interest in the Chernobyl NPP accident. Ukraine has to attract attention to the accident and its consequences constantly, but foreign tourism to Chernobyl is one way of educating foreigners about this catastrophe. These visits should not be considered as entertainment or vacations, but as a form of public awareness about the scale of the Chernobyl catastrophe and the overcoming of its consequences.

7.5. Scientific Support Measures to Overcome the Consequences of the Chernobyl Catastrophe

Scientific support in all areas of work associated with the Chernobyl accident has been identified as one of the main mechanisms for overcoming the Chernobyl catastrophe consequences.

At the time of the world's largest technogenic catastrophe (at Chernobyl NPP), Ukraine had no specialized scientific institutions in the field of Radiation Medicine, Radiobiology, Radiology, and Agricultural Radiology. Taking into account the scale of the accident, it was decided to establish in Kyiv a number of specialized research institutions to solve the problems caused by the catastrophe. Immediate formation of the scientific support infrastructure enabled the investigation and solution of a wide range of scientific problems resulting from the Chernobyl accident.

7.5.1. Minimization of the Health Consequences of the Catastrophe

Analysis and summarizing of the basic research results for the first 10 years after the accident showed that the health effects of Chernobyl catastrophe were significantly different from the predicted ones. The stochastic effects brought significant contribution to the health decline of all categories of victims in the shape of a wide range of non-tumorous forms of somatic and psychosomatic diseases. In most cases they caused the disability and mortality.

As a result of 15 years observation of different groups of victims in 2001, Ukrainian scientists together with the experts from the WHO, UN SCEAR (Scientific Committee on the Effects of Atomic Radiation), IAEA and other organizations have developed predictions and recommendations concerning minimization of the health consequences for the coming years. It was indicated that within the next 10 years (till 2010), the trends to the number of disease could increase on many forms of disease and possibly cancer, including natural ageing of the affected populations.

The purpose of the «National Program on overcoming the consequences of the Chernobyl catastrophe for 2006–2010» was the health preservation of persons affected by the Chernobyl disaster and their descendants, strengthening and support of radiation safety barriers, radiation protection of population living within radioactively contaminated areas, the maximum possible limitation of the radionuclides spread from the Exclusion Zone, the improvement of social protection of victims of the Chernobyl disaster, and rehabilitation of territories and settlements.

The analysis shows the effectiveness of applied medical countermeasures on minimization of the health consequences of the Chernobyl accident, including measures to reduce exposure of children population in 1986, and the planned rehabilitation of affected children. The system of measures associated with the early diagnosis and treatment of thyroid cancer, which included clinical examination with ultrasound diagnosis, surgery and radioiodine therapy of metastases has become effective. The UN Chernobyl Forum (2006) stated that mortality from thyroid cancer in affected countries did not exceed 1%.

The Chernobyl Forum formulated recommendations related to priority tasks of the health system. They included the following:

- continuation of the monitoring of individuals exposed in childhood;
- when planning the system of measures on the health protection, predictive assessment must be used taking into account the cancer and exposure risks;
- implementation of analytical researches are recommended as those that provide the quantitative assessment of the disease risk within exposed persons and modifying factors. It is important to continue environmental studies for the efficient distribution of scarce financial resources in health care area, to document the geographical and temporal changes in risks under the large number of diseases;
- the cancer registry is an important element of activities, which are characterized by high quality data.

The Chernobyl Forum specified that it is impossible to exclude the possibility of increasing the radiation risks of thyroid cancer after exposure in adulthood. Implementation of the properly planned and analyzed studies has been recommended. The same recommendations were given for research implementation of children exposed during the prenatal development.

The continuation of extensive analytical studies of leukemia and temporal differences in the values of radiation risks was recommended. As for the other forms of cancers, it was concluded that although there were no evidences of the cancer frequency increased apart from the thyroid cancer at the time of the analysis performance; the possibility of the risks increase could not be ignored, especially with the liquidators. If a surplus exists, it will be recorded in one or several decades after the disaster.

It is also recommended to implement the research to verify the role of ionizing radiation in the induction of cardiovascular diseases at liquidators.

The UN SCEAR completed drafting of document «Effects of the Chernobyl accident on human health associated with the action of ionizing radiation» in 2008. In the document, published in 2011, publications before 2006 inclusive were analyzed. The prevailing limitation of the SCEAR document was the analysis implementation only of those effects for which the relation with the radiation was established earlier. Compared to the previous document (Annex J, 2000) leukemia, cataracts at liquidators besides the thyroid cancer were added to the established effects. The necessity of research of cancers, including breast cancer, and cardiovascular disease at liquidators was scientifically justified.

Almost 25 years have passed since the Chernobyl accident. Problems caused by the Chernobyl catastrophe have not disappeared, and their acuity hasn’t decreased. However, the scientific analysis shows the changes in trends of morbidity, which requires the adjustments in planning measures related to minimization of health consequences.

The main problem of recent years is the probable increase of mortality level of liquidators compared with the population of Ukraine. The main causes of death were cancer and death from cardiovascular complications. In accordance with the environmental research, previous assumptions about the increased of thyroid cancer at adults – liquidators and evacuees are being confirmed. Disease incidences of breast cancer exceeded the expected level at female liquidators of 1986-1987 in 1.5 times. The radiation risks of leukemia increase are confirmed, which are similar to those established at the victims of nuclear bombings. The results are confirmed following the research of Russian liquidators group by the UN International Agency for Cancer Research.

At the same time, a tendency of decreasing the number of radiogenic leukemia cases among liquidators has appeared. It was expected and can be explained by temporal trends of changes in radiation risks and high mortality from cardiovascular system and other forms of cancer.

Studies of the health consequences of the Chernobyl catastrophe showed that one of its most adverse effects is an increase of the children’s disease indices of almost all classes of diseases, among which the significant disorders in the immune system and pathology of the gastrointestinal tract are noted. Researches of the last period also show the availability of problems in children – descendants of the exposed parents (children of liquidators and evacuees).

The less urgent problems in terms of medical radiation protection in recent years are the general health condition of the population residing within contaminated territories. This is connected with the decrease of annual doses loads due to natural processes of decay and the migration of radionuclides, migration processes on settling the contaminated territories within younger population who was not exposed with ionizing radiation in primary dose formation period. These processes are positively reflected in the demographic values. At the same time, the problems of radiation protection of population residing within the contaminated territories with abnormally high levels of incorporation of radionuclides are still crucial.

Dynamics and forecast of the medical consequences of the Chernobyl disaster showed that increase of the medical assistance efficiency to persons who have undergone radiation impact does not only preserves its actuality, but also it becomes the most priority in the coming years. According to the existing structure of morbidity there is a need for additional or specialized care for all categories of victims. The system of medical care to residents of contaminated territories remains effective owing to the principle of consistency between all institutions that provide such assistance.

The requirement and the basis for the development of Government programs and system of measures aimed at preserving the health of victims, scientific and social research implementation is the support and proper functioning of the State Register of Ukraine (SRU) and the National Cancer Registry of Ukraine. The SRU level does not meet modern requirements in connection with the obsolescence of equipment and software, insufficient quality of data entered at the SRU local levels, the availability of exposure doses only at 38% and the technical impossibility to include the retrospective data of individual dosimetry, and others. Coordination and exchange of data between the three existing systems of accounting – the SRU of persons affected by the Chernobyl disaster, the official statistics of the annual clinical examination and specialized departmental sub registers are required. All affected persons are to be included into the SRU.

Analysis of health consequences for 25 years after the Chernobyl accident shows that in general, they correspond to the consequences among those who suffered from atomic bombing. Considering the determined patterns of radiation effects at victims, the following is expected in the coming years:

- Increase of the cancer frequency at liquidators, including:
  - maintaining the high incidence of thyroid cancer, urinary tract, increased incidence of breast and lung cancers;
  - reduction of radiation-induced leukemia incidence with increasing incidence of multiple myeloma and myelodysplastic syndrome.
- Increased morbidity and mortality of liquidators from non-tumorous diseases, in the first place – cardiovascular pathology.
- Maintenance of the increased incidence of radiation cataracts.
- Increased incidence of non-tumoral and some forms of cancer in the population affected with radioactive iodine during pre-natal development, in childhood and adulthood (evacuated);
- Increased frequency of congenital and hereditary pathology, and possibly other classes of diseases at children born of parents-liquidators and those evacuated in childhood from Pripyat and the 30-km zone.

Contingents of priority observation during the third after disaster decade are still the people who have suffered acute radiation sickness, liquidators with radiation dose above 250 mSv, evacuees from the 30-kilometer zone, persons with high-dose exposure of the thyroid, pregnant women and children living within contaminated areas and born of parents who received high radiation doses.

Development of measures aimed at preservation of the health and working abilities of the SSE Chernobyl Nuclear Power Plant (SSE ChNPP) and the Object «Shelter» (OS) personnel during the shut down and conversion of the OS into radiation safe system is one of the most topical problems of modern radiation safety and Radiation Medicine, a testing for medical radiation protection system, including on the ability to assimilate the past lessons and conclusions from the mistakes. Analysis of results shows that effective health protection is only possible when using rigid standards of medical professional selection, constant current control of dose loads and the introduction of behavior culture of workers within the exposure area. Proper application of these known criteria reduces the radiation-induced effects risks to acceptable ones.

The following should be considered as the most significant problems on minimization of the consequences of the Chernobyl disaster in the future:

- need of government support for the work implementation related to minimization of the disaster effects and approval of the Government program for 2012–2016;
- introduction of effective diagnosis of remote cancer and non-tumor effects of irradiation and their treatment;
- clinical examination of victims with timely transfer of personalized data to the SRU;
- continuation of scientific analytical, environmental, epidemiological and basic research related to study of the medical consequences of the Chernobyl disaster in the remote period in the priority observation groups;

- medical rehabilitation of the affected population, development of preventive measures aimed at early diagnosis of cancer incidence;
- continuation of national and international programs associated with the population awareness, continuation of participation in the WHO «ICRIN» Program;
- continuation of dosimetry certification of the contaminated areas where the abnormally high levels of incorporated radionuclides are observed within the population; provision of local health institutions with the modern dosimetric equipment instead of equipment that have depleted their resources;
- improvement of medical and sanitary base of specialized hospitals, which are constantly providing medical care to the victims.

At the national and international levels, there is a necessity in development and expansion of scientific research programs taking into consideration the long-term objectives. It is reasonable to continue improving the system of health provision and social protection of population affected by the Chernobyl accident, focusing on medical monitoring of the priority contingent. Introduction of balanced and scientifically based approach to measures aimed at eliminating the consequences of disasters and works to convert the Object «Shelter» into the radiological safe system can ensure their relevance and high efficiency.

7.5.2. Radiological Investigation, Radiological Protection of Population and Improvement of Environmental Health of the Radioactively Contaminated Territories

The Ukrainian Scientific and Research Institute of Agricultural Radiology (UIAR) established in 1986 is the main and coordinating institution in the field of agricultural radiology, radiological investigations, and rehabilitation of contaminated territories in Ukraine, which elaborates the issue of agriculture within the affected territories.

During the first post-accident years, a large amount of practical work was performed to assess the radiological situation within contaminated territories and within the different areas of agriculture, namely: the sampling and analysis of tens of thousands of samples of soil, vegetation, animal products, summarizing of the obtained results. In the course of investigation, the critical farms were found within the contaminated regions of Ukraine where the content of ^{90}Sr in cereals exceeded acceptable levels; countermeasures in all areas of agriculture were elaborated and implemented. Also, the special technologies and the Program of contaminated land recultivation were developed.

In that period the following had been developed:

- express method to assess the contamination level of agricultural land, which allowed to examine them at the entire territory of Ukraine in no time, to map the agricultural contamination territories and to remove the most contaminated areas from the agricultural usage;
- conversion program of the farms which are located in the contaminated territories;
- radiological certificate of an agricultural enterprise;
- methods of farmlands decontamination and technological projects of the differential countermeasures application in the collective and individual farms.

Implementation of all these scientific developments has allowed stabilizing the radiological situation in the agricultural industry of Ukraine and practically providing the Public Sector with production of agricultural products, in which the concentration of radionuclides did not exceed the acceptable levels.

The Law of Ukraine «On the Government program for overcoming the consequences of the Chernobyl catastrophe for 2006–2010» dated 14 March 2006, # 3522-IV was adopted in 2006 in order to determine the priorities during the long stage of minimization of the consequences of the Chernobyl catastrophe.

One of the key objectives of Governmental policy on minimization of the consequences of the Chernobyl catastrophe is the implementation of a set of measures oriented on the comprehensive protection of population, creation of safe living conditions within the contaminated territories. A basis for these activities planning is an objective assessment of radiological living conditions and development of the respective Programs related to the radiological revival of the territories

The subjects of investigations related to radiological protection of population and environmental health improvement of the territories that suffered radioactive contamination, were the following: the territories contaminated due to the Chernobyl catastrophe; social and economic development of those territories and places of the citizens compact resettlement; critical settlements that belong to the second contamination zone in accordance with Article 2 of the Law of Ukraine «On legal regime of the territories contaminated in the aftermath of the Chernobyl catastrophe» and in accordance with the radiation situation can be removed outside the second zone boundaries.

Based on the comprehensive radiation and hygienic analysis of the radiation situation in the settlements within the contaminated territories referred to the second zone of radioactive contamination, the radiation situation as of 01 January 2008 was described, the settlements were defined, which in accordance with radiological parameters can be removed outside the second zone boundaries, critical agricultural lands were identified, the effectiveness of existing countermeasures and procedures for optimization of these settlements application were assessed.

In this regard, the analysis was performed concerning the modern radiation and environment condition of the Exclusion Zone, the prospects of the Chernobyl NPP decommissioning and conversion the Object Shelter into environmentally safe system, and development of proposals related to the territories within the short, medium and long period of application.

When developing the issues concerning the further strategy of liquidation of the consequences of the Chernobyl catastrophe, the following was performed: generalization of available information; review of approaches to planning; establishment of priorities in the countermeasures’ implementation and assessment of their effectiveness in order to assess the radiation protection strategies, and the effectiveness of protective measures undertaken in the post-accident years within the affected territories. The most critical settlements were defined and the amount of necessary funding was calculated, the activities were continued related to the assessment of course and intensiveness of radionuclides penetration into the human body on the basis of the developed criteria for assessing the effectiveness of radiological countermeasures. The obtained materials became the basis for the National Program’s objectives and measures draft developed for overcoming the consequences of the Chernobyl catastrophe for 2010–2014.

For post-accident period the Institute’s scientists published more than thousand research papers, including more than 100 methods, recommendations, proposals focused on the organization of agricultural production within the territories contaminated by radioactive substances. These research papers guide the Departments of Ministry of Agrarian Policy of Ukraine, the workers of radiological services in the regions, districts, and farms. The concept of agricultural production within contaminated areas of Ukraine till 2010, and the Rehabilitation programs of the contaminated territories were developed. Technical projects were developed ensuring obtaining the production that meets the sanitary standards in Ukraine for the most critical of settlements. The UIAR specialists as the highly qualified experts are invited by a number of national (NCCR, SNRC, National Security Council, Ministry of Emergency, Ministry of Agrarian Policy, etc.) and international organizations (IAEA, OSCE, NATO, etc) for the significant scientific and industrial tasks solution.

In 2007–2008, new edition of «Recommendations for the agricultural production on radioactively contaminated territories as a result of the Chernobyl accident for 2007–2010» and «Recommendations for the forest management within radioactively contaminated territories» were developed and published.

The informational materials were updated to meet the most urgent problems related to ensuring the victims’ safe residing within the territories affected by the Chernobyl catastrophe. The materials were analyzed with a view of their perception by youth and school audience and with the following publication of a poster with the respective content. As the results of this work, a new model poster was created associated with the radionuclides penetration into the body and methods to reduce the possibility of their penetration.

7.5.3. Preservation of Cultural Heritage

Ukrainian Polesie, which preserves many unique archaic features of traditional folk culture, is the part of Slavs ancestors' fatherland in accordance with one of the scientific hypothesis.

The territory of the Exclusion Zone and the zone of unconditional (mandatory) resettlement ceased to exist as a whole ethno cultural area for ever due to the Chernobyl catastrophe. There is a real danger to lose irreversibly the monuments of material and spiritual culture of the Polesie inhabitants. The destructive processes in the sphere of social and cultural traditions are observed in the area of guaranteed voluntary resettlement (835 towns and villages with population about 650 thousand people), which still retain the status of increased risk area.

Thus, the Ukrainian science and society faces the problem of urgent issue to save and preserve for posterity all the ethnic heritage complex of the contaminated region.

Therefore, the comprehensive integral systematic fixation of endangered ethno cultural complex is an optimal way to preserve the cultural heritage from the destructive consequences of the Chernobyl catastrophe. The purpose of such fixation lies in creating a multi-regional research fund as a comprehensive information source for the further development of historical science, social and cultural rehabilitation of affected population.

Historical and Cultural Expedition of Ministry of Chernobyl of Ukraine was established in accordance with the Verkhovna Rada Decree «On urgent measures to protect the citizens of Ukraine from the Chernobyl catastrophe consequences» (1990), which in 1992 arranged for development a perspective comprehensive program (which was included into a separate section to the National Program on minimization of the consequences of the Chernobyl catastrophe). The Expedition also attracted a number of temporary creative groups, formed on the basis of relevant academic institutes, universities, museums and public organizations in Ukraine to implement the Program.

On 16 October 2007, the State Scientific Center for protection of the cultural heritage from technogenic catastrophes was established on the basis of Historical and Cultural Expedition following the policy of Ministry of Emergency. This Center was financed by the Government.

The scientific activities of the State Scientific Center for protection of the cultural heritage from technogenic catastrophes (hereinafter referred to as the State Scientific Center) are focused on implementation of the tasks defined by the National Program on overcoming the consequences of the Chernobyl catastrophe for 2006–2010.

Within this time, 7 historical and ethnographic and 3 archaeological expeditions took place, during which the following was implemented:

investigation of the affected settlements oriented to the following identification and observation of the monuments of material and spiritual culture located within the affected territory of Ukrainian Polesie;

archaeological excavations within the territory of medieval Chernobyl town (total area of 80 square meters.), where the cultural layers of XI, XII, XVII and XVIII centuries had been discovered;

continuation of archaeological investigation of the monument's complex near Velykyi Dyvlyn village (Luhyny district). As a result of excavation, 623 objects had been found and a new archeological monument was discovered – an old village dated IX-X centuries, that was called «Velykiy Dyvlyn – 2».

The following was arranged within the implementation plan of the cultural circulation of the collected museum and archival funds:

on the occasion of 22nd anniversary of Chernobyl catastrophe, the historical and ethnographic exhibition «Memories about the Paternal land», which was held from 21 April through 10 May 2008 in the National Museum of Literature of Ukraine, the following expositions of the permanent exhibition were renewed: «Memories about the Paternal land» in Chernobyl, archeological exposition «Medieval Chernobyl Settlement» (from 25 April through 25 May 2008) at the National University of Kyiv-Mohyla Academy;

participation in arrangement and performance of the exhibition «Child in the customs of the Ukrainian people» (since 6 September though 1 November 2008);

historical and ethnographic, and archaeological exhibitions: «Weaving at the Polesie region» (in Kyiv), «Memories about the Paternal land» (in Chernobyl), «Archaeological investigations of the affected regions of Ukrainian Polesie» (in Kyiv).

The following is an important part of the research works results introduction by the State Scientific Center: issuance of the scientific publications «National clothing of the right-bank Polesie inhabitants in the middle of XIX–XX centuries. (Historic and Ethnographic atlas. Dictionary)» and preparation of research manuscripts «Calendar of customs and traditions of the Rivne Polisie inhabitants: Local peculiarities. Transformation (XX – beginning XIX century.)», «Illustrated Dictionary of the Middle Polesie building vocabulary», «Musical folklore Kyiv Polesie. Volume 1». Also, the monitoring of scientific and research activities of institutions is being implemented in the sphere of cultural heritage preservation against the emergencies.

Today the State Research Center for protection of the cultural heritage from technogenic catastrophes is the leading and practically the only institution of such kind. It is still the basic founder of museum and archive complex funds of the affected Polesie areas. The main objective of the Centre related to the further implementation of the National Target Program on overcoming the consequences of the Chernobyl catastrophe is foundation of a Museum-archive of ethnic and cultural heritage of the affected areas of Ukrainian Polesie. The further implementation of these important public objectives requires appropriate maintenance and preservation of museum and archives funds, as well as systematic rescue activities.

It should be taken into account that the future Museum-archive, as the place to be visited by the international tourists, shall be located in an accessible place with the convenient system of transport communication.

7.5.4. Radioactive Waste Handling

The Ministry of Emergency, as a body of government administration in the sphere of radioactive waste handling, arranges for realization the government policy on radioactive waste handling, including those formed as a result of Chernobyl catastrophe. In accordance with the Law of Ukraine «On Radioactive Waste Handling», the Ministry has developed the Law of Ukraine «On the National Target Environmental Program of Radioactive Waste Handling», which was approved by the Verkhovna Rada of Ukraine dated 17 September 2008, # 516-IV. Implementation of the program will allow achieving a high level of nuclear and radiation safety through the following measurers:

creation of unified system of radioactive waste handing;

introduction of unified technical policy for radioactive waste handing and physical protection;

reduction of the risks related to radioactive waste penetration into the unauthorized circulation.

To implement the strategic directions and objectives defined in the Energy Strategy of Ukraine till 2030, the Ministry of Emergency develops National strategy for radioactive waste handling in Ukraine. The above Strategy takes into account the experience gained in the field of radioactive waste handling in Ukraine, Soviet Union, the European Union, and fully corresponds to the principles and requirements of European legislation and recommendations of international organizations such as the IAEA, European Atomic Energy Community, etc.

One of the main objectives of governmental policy on radioactive waste management is summarized and highlighted in the published book «Radioactive waste Storages». This objective reduces the duration of temporary waste storage at the areas of their formation (production), and intensification of their processing with their following storage in the central storage facilities for long and / or permanent storage (disposal).

Minimization the consequences of the Chernobyl catastrophe – is not a temporary activity, but designed for long period of time purposeful Government activity to be carried out during the long historical period, which requires the full and effective support from the central and local executive authorities, local governments, enterprises, institutions and organizations regardless of ownership in the issues of life facilitation of the affected population. It is clear that the implemented activities and measures were insufficient to meet the needs of victims of the Chernobyl catastrophe and to minimize the consequences of it. Therefore everything possible must be done to maximize the implementation of the Laws of Ukraine on overcoming the consequences of the Chernobyl catastrophe so that each Chernobyl inhabitant feels that the central and local governments' activities, the efforts of scientists, physicians, and community organizations are focused on the final positive result for his/her welfare.

Within this context the adoption of terms of the National Program of overcoming the consequences of the Chernobyl catastrophe for 2012–2016 years seems reasonable. This Program shall provide for implementation of the measures focused on the further social, medical and psychological rehabilitation and radiation protection of the population; completion of economic regeneration of settlements; development of the radioactively contaminated territories, preservation of their cultural and historical heritage, scientific support of all aspects of overcoming the consequences of the Chernobyl catastrophe.

The main scientific support objectives for the following period are:

continuation of examination of the impact of the Chernobyl catastrophe consequences on health and environment;

improvement of the radioecological and dosimetrical system of monitoring within the territories that were contaminated due to the Chernobyl catastrophe;

improvement of measures aimed at stimulation of the manufacture of clean production, economic development of the radioactively contaminated territories;

provision of scientifically reasonable usage of funds for implementation of measures on social protection of persons affected by the Chernobyl catastrophe, and overcoming its consequences;

wide application of work results on overcoming the consequences of the Chernobyl catastrophe into practice to prevent other emergencies and liquidation of its consequences, emergency response to radiation accidents;

coordination of international research related to the Chernobyl catastrophe consequences, focused on the Program's objective implementation.

A sharp decrease in financing of the research studies related to overcoming the consequences of the Chernobyl catastrophe (scientific support of all the Program's activities and objectives) in 2009–2010 (UAH 2739.2 thousand against UAH 10000.0 thousand provided by the National Program), significantly reduces possibilities of rational use of scientific potential for solving the issues on minimization the consequences of the Chernobyl catastrophe, and therefore leads to administrative decision making and execution of their work without sufficient scientific evidences.

8. LESSONS LEARNED FROM CHERNOBYL. SAFETY OF THE FUTURE

8.1. Lessons learned from Chernobyl with a view to nuclear power safety

The accident has stricken huge impact to nuclear power throughout the world and slowed down its development for many years. Responsibility for the national nuclear power safety grows into the responsibility to the world community. And it refers not only to designers of a nuclear facility and its operators , but also to national regulatory authorities and the highest state authorities.

The Chernobyl accident has given another lesson: a necessity to maintain efficient international nuclear safety system. This lesson has been learned by the world community rather quickly, as confirmed by the IAEA activities, adoption of a series of important international conventions, and the convention on nuclear safety first of all.

The most important lesson is a necessity of independent state and public control over nuclear safety. Only society has the right to decide about nuclear power development, and it must be clearly formalized in legislation. However, public should be accordingly prepared to make such a responsible decision. The public should know what is an NPP, what are its potential hazards, what has been done for the hazards to become as small as possible . A routine, systematic interface with public shall be ensured.

Availability of an independent and competent state regulatory body is an indicator of a country's nuclear safety culture. Absence of such a body or financial resources and manpower required for implementation of its functions, lack of actual independence during safety-important decision-making indicates lack of nuclear safety culture in a state and infringement of the international safety system.

Equally important lesson of the Chernobyl accident is an obligatory existence of a professionally strong operator able to address problems dealing with nuclear engineering and possessing the potential to assess and manage safety of operating nuclear facilities.

Finally, one more lesson is a continuous NPP safety analysis, identification and elimination of safety deficiencies. The following components shall be referred to this end: investigation of the factors impacting an NPP safety; continuous improvement of regulatory framework; creation of special, safety-oriented, psychological climate in operators' community; continuous upgrades of personnel qualifications and a sense of responsibility for a safe operation of nuclear power units.

Analysis of the events that took place on 26 April 1986 at the Chernobyl NPP is not a goal in itself and it should not be focused on the past. The main thing is to digest the nuclear safety lesson today and in the future, prevent the very possibility for reoccurrence of an accident involving serious radioecological consequences. All those, who in one way or another are involved with nuclear safety assurance, whose decisions may directly or indirectly affect nuclear safety, should understand why it was possible to operate the facility that has not met safety requirements, why the known shortfalls that have resulted into the accident producing catastrophic aftermath have not been eliminated for years. It should be realized.

8.2. Lessons learned from Chornobyl and response efficiency

State-of-the-art technologies provide an opportunity to establish comfortable living conditions for people, i.e. extensive use of electric power, development and introduction of new materials in various branches of economy. However, they also impose additional risks attributed to using hazardous materials and technologies. Nowadays, some states produce over 80% of electricity at NPPs, radioactive materials are widely used in medicine, industry, transport, war and other areas of human activities. Under the conditions of normal operation of nuclear and isotope installations , their contribution to human exposure is less than one tenth of a percent. However, the accident that happened at Unit 4 of the Chernobyl NPP in 1986 shook up the entire world. About 3 million people were subject to additional exposure. The accident demonstrated that if we wish to further use nuclear energy, we should make every possible effort to prevent nuclear accidents and minimize their consequences. Our principal task is to protect people from high doses of radiation in case of radiation and nuclear accidents by means of appropriate and efficient response system. Studying the experience of emergency response during the Chernobyl accident provides a unique opportunity to enhance efficiency of emergency management at all nuclear and other hazardous facilities.

The response efficiency 100% depends on establishment and efficient functioning of a national emergency management system, high-grade planning of the activities to be performed by government agencies and response staff, their ability to make every effort to protect people and eliminate accidents and their consequences based on the beforehand developed plans. If a response system with clearly defined decision-making levels is available, all potential accident scenarios are foreseen, qualified experts are ready to respond, public is accordingly prepared and informed, then an impact of an accident itself and its consequences on people shall be considerably minimized. The Chernobyl accident is a unique example of the case when notwithstanding a heroic effort of accident liquidators, planning shortages have resulted in such large-scale and long-term effects.

8.2.1. Assessment of planning and countermeasures

At the time of the Soviet Union, the Chernobyl NPP on-site and off-site emergency plans have been developed. However, implementation of the plans during the accident response revealed their imperfection and formed a basis for emergency planning development throughout the world.

One of the main drawbacks in the plans was lack of provisions regarding accidents of such scale. Nobody admitted that an accident involving complete damage of a reactor core may occur at RBMK reactors. Since such a severe accident has not been provided for, corresponding consequences have not been planned also.

Consequently, the plant suffered from a lack of necessary dosimetry and radiometry equipment ensuring real time assessment of radiation conditions. Thus, there was a delay in evaluating the accident scales and, correspondingly, in initiation of appropriate protective actions. In addition, due to underestimation of potential accident scales, no protective equipment was available for fire fighters, who were suppressing the fire at Unit 4, and for the plant personnel as well; and as a result 28 people perished from exposure. Absence of vehicles to ensure appropriate radiation protection on the site led to additional exposure of personnel and emergency staff. Due to an absence of protective confinement in this type of reactor, it was impossible to promptly establish control over the wrecked reactor and ensure effective implementation of protective actions. Only erection of the Shelter Object enabled restore the control over the accident source.

8.2.2. Assessment of the public protection measures

The major task of response is to protect people and the environment from hazardous impacts. In ICRP Publication 63, the International Commission on Radiological Protection has established that exposure dose in particular is an index of the hazard imposed by deterministic and stochastic effects of radiation. The International Basic Safety Standards (BSS) [18] were developed with due regard for the ICRP Publication 63 recommendations on estimation of the threshold doses, which form a decision-making basis with regard to radiation protection of public. The intervention levels in Ukraine are stipulated by the national legislation and differ from BSS [10, 13].

According to Article 8 of the Law of Ukraine ‘On Human Protection Against Ionizing Radiation Impact’ – ‘The intervention conditioned by a necessity to protect human life and health shall be performed in such a way as for the minimization of harm, which was caused by ionizing radiation effects by way of exposure dose reduction, to be sufficient for justification of both intervention relevance and intervention-caused losses.

Sheltering of people shall be applied in case during the first two post-accident weeks an anticipated cumulative effective exposure dose may possibly exceed 5 millisieverts. A short-term evacuation of people shall be carried out in case during the first two post-accident weeks an effective exposure dose may possibly achieve a level of 50 millisieverts.

In accordance with the regulations established by the Ministry of Health of Ukraine', the iodine prophylaxis shall be implemented in the case an anticipated absorbed thyroid gland exposure dose caused by radioactive iodine accumulated in the thyroid gland may possibly exceed 50 milliGreys for children or 200 milliGreys for adults.

Intervention levels are established by the Law in the units that cannot be measured during an accident by field instruments, but are to be estimated or determined in laboratory conditions. Hence, the intervention levels stipulated by the Law cannot be used as a basis for making decisions on implementation of protective actions during an early phase of accident. According to the international recommendations (TECDOC-955 [19]), the operational intervention levels (OIL), which quantities are directly measured by field instruments (for instance, dose rate), shall be calculated prior to an accident. In case of an accident, the OILs shall be used to make prompt decisions on the protective actions necessity. For instance, a dose rate value exceeding 1 mSv/hour indicates a necessity to evacuate public. OILs are an effective instrument of response, especially during early phases of a release, when little is known about a nature of hazards, however a need to take decisions is urgent. The OILs to be put into actual practice basing on BSS recommendations were calculated in TECDOC-955 [19 restore the control]. They are based on various assumptions concerning characteristics of an accident. These default OILs were developed to be applied during the first several hours or days after a nuclear reactor accident. The OILs shall be revised once composition of a release and actual contamination of the environment are known. In most cases, a need in the default OILs recalculation is related to changes in isotopic composition and distribution of radionuclides. TECDOC 955 includes OIL values for all types of protective actions and methods to adjust the values with due regard for subsequently obtained information about actual contamination. Since intrusion levels in Ukraine differ from the ones stated in BSS, the levels calculated in TECDOC-955 shall not be directly applied in Ukraine under the effective legislation. As a result, currently Ukraine has no OILs required for urgent implementation of protective actions in case of a nuclear accident.

8.2.3. Preparedness to implementation of iodine prophylaxis

An important feature of NPP or other nuclear radiation accidents is presence, alongside with other alpha-, beta-, and gamma-emitters, of radioactive iodine isotopes (iodine-131, iodine-132, iodine-133, iodine-135) in a radionuclide release to the environment. These isotopes impose the most severe radiation danger during the first month after an accident. Iodine-131, the most long-lived among them, has a half-life of about 8 days. Radioactive iodine isotopes may penetrate into a body through digestive system, respiratory apparatus, injured or burnt surfaces.

During an initial period of an accident, the most dangerous is inhalation intake of radioactive iodine isotopes by an organism, since they penetrate into blood quicker than in case of peroral intake; as early as in the first days large quantities of the isotopes are accumulated by the thyroid gland. Selective and rapid concentration of iodine radioisotopes in the thyroid gland stipulates its high exposure doses. The radioactive iodine accumulation depends on age. For instance, in children, due to a small size and functional hyperactivity of the thyroid gland, absorbed doses are formed several times as high as in adults. In newborns and infants the absorbed doses per a unit of absorbed activity are 25 times as high as in adults. Inhalation of radioactive iodine is particularly dangerous for newborns due to the higher respiratory rate and smaller mass of the thyroid gland.

Radioactive iodine has the same chemical and biological properties as naturally occurring stable iodine contained in food and used in medicine. Therefore, there exists a simple easy-to-implement method of public protection against the thyroid gland exposure to radioactive iodine. During taking a necessary dose of stable iodine, for instance in a form of potassium iodide (KI) pills, the thyroid gland shall be saturated with iodine, and radioactive iodine absorption by the thyroid gland shall be blocked, thus preventing its irradiation (the so-called iodine blocking or iodine prophylaxis). Table 8.1 presents the stable iodine intake doses for different age groups pursuant to 1999 recommendations of the World Health Organization [15].

Table 8.1.

Stable iodine intake doses for different age groups

Age group	Iodine mass (mg)	KI mass (mg)	A part of 100 mg pill
Adults and teens (over 12 years)	100	130	1
Children (3-12 years)	50	65	½
Infants (between 1 month and 3 years)	25	32	¼
Newborns (under 1 month)	12.5	16	⅛

The highest protective effect is achieved when stable iodine in form of a medicine is taken 3-6 hours prior to radioactive iodine intake.

The method preserves a great extent of its efficiency even in case of a delayed start: in 2 hours the protection rate is 80%, in 8 hours it amounts to 40%; an in 24 hours it is approximately 7% [16]. However, a delay in implementation of iodine prophylaxis exceeding 6 hours after radioactive fallout shall significantly reduce its efficiency, and in a day its appropriateness seems doubtful at all.

Iodine prophylaxis shall be implemented to mitigate consequences of not only inhalation intake of radioactive iodine, but also its penetration together with food, water, especially with milk and dairy products, contaminated by radionuclides. Furthermore, a risk of such products and water intake may hold true for several days (up to 2–3 weeks).

For the benefit of iodine prophylaxis efficiency, it is necessary that people potentially affected by a nuclear accident shall be early informed about the method, provided with iodine medicines and recommendations on their use [17]. The iodine medicines shall be renewed on a timely basis and be readily available to a facility's personnel and to the public, particularly children, wherever they are at the moment of an announcement about a necessity to implement iodine prophylaxis. The essence of iodine prophylaxis and mechanism of its effects shall be explained to public in understandable and any-time-accessible manner: on relevant Internet websites, in a form of brochures, posters, and in other forms obtainable by public.

Secrecy of emergency plans and non-availability of a decision-making system in the time of Chernobyl, particularly at local and regional levels, have resulted in a delay in implementation of iodine prophylaxis and other protective actions. The actual iodine prophylaxis in Pripyat was started much later, in 8–10 hours after the first release (and in some population centres still later), and only direction of the wind during the first release has rescued the citizens from a significant exposure of the thyroid gland. Iodine prophylaxis is the easiest, cheapest, though efficient measure of public protection; its timely implementation has a tremendous psychological effect, an individual shall feel protected at the very beginning of an emergency.

8.2.4. Assessment of the accident consequences modelling

In case of accidents involving a significant air release of radionuclides to the environment, the first phase of assessing potential consequences shall include modelling ensured by means of the programs for radionuclide transport, dissemination, and fallout.

As a result of the Chernobyl accident, availability of a heavily contaminated area including about 3000 km^2 caused a necessity to evacuate people. However, it was clear only on 6 May 1986, when the first maps with dose rates isopleths were made available (average doses of gamma-radiation on open ground were used for the zoning basing on external exposure; the doses were adjusted by 10 May 1986, when a relatively full and reliable information on dose rates in the centres of population was obtained [20]). Tremendous resources of the Soviet Union were involved to develop the maps; aircrafts equipped with high-sensitivity gamma spectrometers. Those large-scale activities would have been considerably more efficient, if it were for the computer modelling with involvement of the radionuclide transport, dissemination, and fallout modelling . However, effective modelling requires a considerable preparatory effort ensuring timely information support with regard to characteristics of a release, detailed meteorological data adjusted for local conditions, regional landscape characteristics [21].

Unfortunately, no such modelling system is currently available in Ukraine.

8.2.5. Assessment of monitoring

The main goal of emergency monitoring is to ensure timely provision of the information, basing on which the first decision on the types of protective actions (based on accidents classification) shall be confirmed or revised.

To this end, presence of radioactive fallouts, their localization and composition shall be determined. Ensuring prompt monitoring shall be the most important for an efficient emergency response.

In case of a radiation accident, a decision on evacuation or resettlement of people shall be made based on the exposure dose rate and environmental contamination monitoring data.

A monitoring system for the environment radiation contamination (sampling and measurement of radioactivity in soil, water, vegetation, food samples) was actually not available; no required equipment, certified sampling and measurement procedures, trained personnel were in place.

An aerial survey by means of aircrafts and helicopters shall be applied in case of a large-scale accident; mobile laboratories shall be used to get more details on dose rates and radionuclide composition of fallouts. Crucially important is that measurement procedures are tested in advance, have a metrological basis, and are unified for the different laboratories planned to be involved in case of a severe accident. The controls shall be calibrated and personnel shall have already received an appropriate training.

8.2.6. Population warning

Timely notification of public of a threat, situation resulting from accident , as well as informing of procedure and rules of conduct in case of an emergency are one of the major population protection measures.

The warning process includes timely, in the shortest possible time, notification of control agencies, administrative officials and response forces, as well as workers (personnel) of an operating shift and inhabitants of corresponding territory of set in advance signals, orders and information of executive bodies and local public authorities regarding threats and rules of conduct under the circumstances.

It should be stressed that delayed use of a warning system considerably reduces efficiency of protective measures and may lead to unjustified victims and population losses similarly to the first day of the Chernobyl tragedy of 1986.

The process of population warning is necessarily supported by arrangement of warning of management bodies and responsible designated persons who will take decisions on particular population protection, emergency and rescue, and other urgent actions be taken within regions of emergency.

Heads of executive power of the corresponding level bear responsibility for warning arrangement and exercise.

The unified state civil defence system of Ukraine first envisages warning of population at any nature of a threat, activation of an electrical siren, buzzer of which means only the signal of hazard ‘Attention all!’ Having heard this sound (signal) people have to switch on any available verbal information receivers –

wired-radio outlets, radio receivers and TV sets in order to get information massage on the nature and scope of the threat, and recommendations on the most reasonable conduct in the existing situation.

Verbal information must be brief, clear, and instructive enough to make clear what happened and what should be done.

For warning targets to be met at each level of the unified state civil defence system, special centralised warning systems (CWS) of the state, regional, local and facility level are established.

Regional, local and facility levels are the major ones.

Warning system of any level presents an administrative and technical formation of on-line and emergency departments of civil defence control agencies, special control and warning equipment, communication channels (lines) ensuring transmittal of control commands and verbal information in case of en emergency. Decision of warning system activation shall be taken by head of a state administration, local public authority.

Regional centralised warning system is the major link within the entire warning system. This is the level that serves as a basis for planning of centralised warning arrangement.

The task of a regional CWS is warning of administrative officials and population residing on the territory covered by CWS of this level. Information communicated to control agencies and administrative officials is an on-line one, and population gets information on the nature and scale of the threat and actions considering the existing situation.

Local centralised warning system (town, rural region) ensures warning of administrative officials of this level, as well as control agencies of the facility level, and also residing on the territory covered by warning system of this level.

Local CWS is controlled directly by on-line and emergency department of the Ministry for Emergencies in a town or via a communication centre shift employee on duty.

Arrangement of a rural region warning system is much more complicated as against a town warning system. It is associated with a number of reasons:

– rural telephone networks are less advanced as compared to urban ones;
– rural region covers a vaster area than a town;
– a region has quite a number of populated localities;
– though insignificant, but a part of rural settlements do not telephone communication;
– telephone connections of rural settlements are arranged via one or two long distance communication channels;
– bulk of rural settlements do not have a three-phase power supply network that limits power supply networks utilisation.

All the above referenced restricts utilisation of the existing control and warning equipment, requires involvement of considerable financial and material resources. Accordingly, local CWS cover only regional centres, and population of other rural settlements is mainly warned via radio and television, rural telephone network, portable sound amplifiers of civil defence forces, internal affairs departments and household rounds.

Facility warning systems are divided into local, arranged at high-hazard facilities (nuclear power plants, chemical-dangerous facilities, hydraulic works, etc.), and warning systems arranged at different facilities of economic activities that are not regarded as potentially hazardous.

Area of local warning system coverage (LWS) at a nuclear power plant is set within a radius of 5km around it; a nearest settlements must be necessarily covered by it. Direct control of a LWS is arranged starting from a shift supervisor, as a rule, power unit one shift supervisor. In the event of an accident, consequences of which can go beyond its area, shift supervisor by himself or with an assistance of NPP communication centre shift personnel on duty remotely activates warning means for administrative officials and plant personnel, population of plant settlement and populated localities within the 5-km zone. Shift supervisor uses direct dial to warn corresponding MEU control agency via its duty officer.

In view of importance of the issue of timely warning and notification of population of a danger actualisation or threat of danger actualisation, executive bodies or local public authorities, MEU control agencies at all levels shall take measures on warning system arrangement (upgrade) using modern technical means ensuring the most complete warning of population, maintenance of the systems in the constant-ready status. While the attention should be paid to the fact that equipment of the most of local CWS has been in operation twenty-four-hours during 20–25 years, and some of it even more, and it is worn out and outdated, and requires urgent replacement by the state-of-the-art one.

8.2.7. Provision of information to public

Delayed and lacking objectivity informing of public of the accident at the Chernobyl NPP by state control bodies created precondition for development of a social and psychological stress in the society.

In the course and after the Chernobyl accident, as well as any other emergency in the world, the prevailing human responses were fear, despair, depression, hopelessness, etc., their intensity increases at absence of reliable information. This suggests the conclusion to be followed in future: information must be timely, clear, its completeness should not leave a room for ambiguous interpretations.

Consequently, civil defence information shall consist of data on emergencies that are forecasted or have occurred, with their classification, propagation limits, means and methods of protection.

The unified state civil defence system control agencies shall via mass media provide public with on-line and reliable information regarding civil defence, in particular: of threat and occurrence of any emergencies, and their activities in the mentioned area.

Heads of entities operating potentially hazardous facilities have an obligation to provide information on such facilities.

Information should be provided as follows:

- publication in official printed sources or dissemination by information departments of corresponding state authorities and institutions;
- publication in printed mass media or public announcement via audio and audiovisual mass media;

Information must contain:

- data on the party providing the information, field of its activities;
- hazardous substances available at the facility, their hazardous properties;
- potential risk nature in case of accidents, including effect on public and environment;
- way of public notification in case of a threat of actualisation or occurrence of an accident, and rules of conduct to be followed;
- evidences of reporting to control agencies on compliance with safety requirements, proper agreements concluded with response and rescue departments.

Heads of entities operating potentially hazardous facilities, in particular, radiation-hazardous ones, shall list data that shall be provided to population of the surveillance area around such facility in the event of a threat of occurrence or occurrence of an accident at it associated with hazardous substances release, in particular, radioactive. A list of such data shall be approved by the specially authorised central executive body for civil defence.

8.3. National emergency response system

8.3.1. Unified state civil defence system

At the present development stage of our country, a problem of ensuring and improving the level of its public and area safety in case of emergency appears to be among the most important social, economic, and ecological issues.

Civil defence is a state function aimed at protection of public, territories, natural environment, and property from emergencies by way of emergency prevention and elimination as well as provision of assistance to affected individuals.

Civil defence shall be ensured within the entire Ukraine’s territory in times of peace and during special periods and shall be applied to its entire population, government authorities, other government bodies, the Council of Ministers of the Autonomous Republic of Crimea, local government authorities and enterprises, as well as other legal entities.

Civil defence of people and territories from emergencies acquires a priority in the activities of all administrative agencies.

With the objective to ensure and improve safety in the society, maintain successful control over natural hazards and man-caused, natural, and ecological disasters, a targeted national policy is required along with establishment of its major implementation instrument, i.e. an emergency response system.

The national policy in the area of civil defence in Ukraine is governed by the corresponding legislation.

The basic Laws of Ukraine that govern its national policy in the area of civil defence, ensure its implementation in times of peace and war, stipulate legal relations and organizational principles for the subjects of activities in the domain are as follows:

‘On Civil Defence of Ukraine’ adopted in 1993;

‘On Protection of Public and Territories against Man-Caused and Natural Emergencies’ adopted in 2000;

‘On Legal Principles of Civil Defence’ adopted in 2004;

‘On Emergency and Rescue Services’ adopted in 1999;

‘On Fire Safety’ adopted in 1993.

All these laws have been developed in the course of 15 years and at different times; due to the absence of law subjects, to which the documents might be applied, some of them have lost their applicability, scopes of some documents envisage a common legal regulation subject, some contain numerous duplications and inconsistencies, and in some instances they do not correspond to the international humanitarian law standards.

To confirm incompleteness of the civil defence laws, the national legal system currently, **de jure,** envisages the following three national emergency response systems, namely:

civil defence system (established in 1993 pursuant to the Law of Ukraine ‘On Civil Defence in Ukraine’);

unified state system for prevention of and response to man-caused and natural emergencies (established in 2000 pursuant to the Law of Ukraine ‘On Protection of Public and Territories Against Man-Caused and Natural Emergencies’);

unified state system for civil defence of public and territories (established in 2004 pursuant to the Law of Ukraine ‘On Legal Principles of Civil Defence’).

However, in practice, **de facto**, Ukraine has only one state system that is functioning to address civil defence issues, because the system has the same components, including government agencies, civil defence staff, supporting means i.e. material and financial reserves for a case of emergency, monitoring systems, training of experts, training of public to act in case of emergency.

Therefore, pursuant to the decision of the National Security and Defence Council of Ukraine ‘On Functioning Status of the Unified State System for Prevention of and Response to Man-Caused and Natural Emergencies’ dated 16 May 2008 and enacted by Decree of the President of Ukraine No. 590/2008 of 26 June 2008, the Civil Defence Code of Ukraine was determined to be developed as a uniform systematized legislative instrument for the issues of civil defence.

As of 1 April 2011, the draft Civil Defence Code of Ukraine has been developed and is currently subject to the procedure of agreement and further submission to the Cabinet of Ministers of Ukraine for a review.

Currently, functioning of the unified state system for civil defence is formalized in the Law of Ukraine ‘On Legal Principles of Civil Defence’. The Civil Defence Code of Ukraine envisages improvement and development of the system, specifies its components, establishes objectives and functions of the components.

The unified state civil defence system has been developed and is functioning with the objective to integrate the activities of central and local executive authorities, local government authorities, enterprises, institutions and bodies, their subordinate staff in order to ensure civil defence in Ukraine.

The unified state civil defence system constitutes a complex of its administrative bodies, their subordinate civil defence staff, as well as enterprises, institutions, and organizations ensuring implementation of functions related to civil defence, including but not limited to the following:

enterprises maintaining the funds of financial, material, technical, and medical resources, including reserves envisaged for emergencies;

subjects supporting the public urgent assistance system via a uniform phone number 112;

enterprises under the system of communication (including the special one), notification, and information support;

institutions and organizations that constitute the network of emergency monitoring and forecasting system;

educational and scientific institutions that conduct trainings on and ensure scientific support to civil defence issues.

Organizational structure of the unified state civil defence system includes functional and territorial subsystems of national, regional, local, and object levels operating on permanent basis.

The functional subsystems of the unified state civil defence system shall be established by the central executive authorities in corresponding public sectors.

The functional subsystem elements shall be established at local and object levels, particularly at enterprises, in institutions and organizations of corresponding public sectors.

An official of a government body or at an enterprise, who has established a subsystem, element, shall be directly responsible for the management of the functional subsystem, element under the unified state civil defence system.

The territorial subsystems of the unified state civil defence system shall be established by the Council of Ministers of the Autonomous Republic of Crimea and by local executive authorities in the Autonomous Republic of Crimea, in oblasts (provinces), in the cities of Kyiv and Sevastopol, correspondingly

Elements of the unified state civil defence system’s territorial subsystem shall be established by a local executive authority in the rayons (districts) of the Crimea Autonomous Republic, oblasts (provinces), the cities of Kyiv and Sevastopol; and executive authorities of city councils shall establish them in oblast centres, in the cities of oblast and rayon levels.

An official directing the body, which has established a subsystem or element, shall be directly responsible for the management of the territorial subsystem or element under the unified state civil defence system.

The Council of Ministers of Crimea Autonomous Republic shall be directly responsible for the management of the Crimea Autonomous Republic territorial subsystem under the unified state civil defence system.

Depending on scale and characteristics of a forecasted or existing emergency, the unified state civil defence system shall operate in the following modes: routine operation, high alert, emergency situation, emergency status, special period.

8.3.2. Functional subsystem ‘Safety of Nuclear Facilities’

Pursuant to the civil defence legislation and basing on Resolution of the Cabinet of Ministers of Ukraine ‘On the Unified State System for Prevention of and Response to Nuclear and Natural

Emergencies' No. 1198 dated 3 August 1998, the State Nuclear Regulatory Committee (according to Decree No. 1085 issued by the President of Ukraine on 09 December 2010, the State Nuclear Regulatory Committee of Ukraine was renamed into the State Nuclear Regulatory Inspectorate of Ukraine) has established the functional subsystem 'Safety of Nuclear Facilities' and is currently maintaining its activities under the unified state civil defence system.

The functional subsystem 'Safety of Nuclear Facilities' is operating at national, regional, and object levels.

Object-level activities of the subsystem are ensured by the State Nuclear Safety Inspections at nuclear power plants, and its operations of regional level are maintained by the Regional State Nuclear and Radiation Safety Inspections.

The Information and Crisis Centre (hereinafter referred to as ICC) under the State Nuclear Regulatory Inspectorate is a key element of the subsystem at the national level. The most highly experienced experts of the State Nuclear Regulatory Inspectorate and its subordinate organizations are involved into ICC operations.

During 2010, the ICC was functioning exclusively in routine operation mode, thus ensuring a 24-hour duty, operational communications with the nuclear power plants of Ukraine, analysis and recording of information on the events at the nuclear power plants of Ukraine into a computer-controlled database. Summary information on Ukraine's power units status, messages about failures in Ukraine's nuclear power plants operation are placed on the State Nuclear Regulatory Inspectorate's web-site at www.snrcu.gov.ua.

The following are the ICC basic systems:

reliable power supply system;

telephone conversations recording system;

system of personnel automatic notification;

system for on-line transmission and display of nuclear power plants' data via the main crisis centre of the State Enterprise National Nuclear Energy Generating Company 'Energoatom' (hereinafter referred to as SE NNEGC 'Energoatom').

8.3.3. Crisis centres of SE NNEGC 'Energoatom'

The emergency preparedness and response system of SE NNEGC 'Energoatom' is an integral part of the functional subsystem under the USS for emergencies entitled 'Nuclear Engineering and Fuel and Energy Complex' and subordinate to the Ministry of Fuel and Energy of Ukraine (according to Decree No. 1085 issued by the President of Ukraine on 09 December 2010, the Ministry of Fuel and Energy of Ukraine was reorganized into the Ministry of Energy and Coal Mining Industry of Ukraine). The abovementioned system has been established and is currently operating basing on the principles stipulated by the legislation of Ukraine that covers the issues of nuclear energy uses and radiation safety, as well as civil defence issues.

The functional subsystem includes the following technical constituents: main and backup crisis centres of the SE NNEGC 'Energoatom'; the nuclear power plant assistance centre under the Emergency and Technical Centre, being a SE NNEGC 'Energoatom' separated subdivision and located in the village of Bilohorodka in Kyiv Oblast.

The SE NNEGC 'Energoatom' main crisis centre is located in the building of SE NNEGC 'Energoatom' Directorate in Kyiv; the backup crisis centre was established and is currently operating as a part of the separated subdivision 'Atomremontservice' in the village of Dniprovske in Chernihiv Oblast.

Apart from the abovementioned backup and main crisis centres of the SE NNEGC 'Energoatom', the effective regulations envisage establishment of on-site (on an NPP site) and off-site (within a surveillance area) crisis centres at each nuclear power plant.

A nuclear power plant on-site crisis centre shall ensure the functions of a control centre for localization of an accident and elimination of its consequences on an NPP site and within a sanitary control area. A nuclear power plant off-site crisis centre is envisaged to be used in case of accidents, when operation of a corresponding on-site crisis centre is impossible.

In case of a nuclear power plant accident, whenever necessary, the entire network of the SE NNEGC ‘Energoatom’ crisis centres shall be involved into the activities, including crisis centres at other nuclear power plants that shall operate in a routine mode, at the level of engineering and technical support groups.

With the objective to ensure a reliable video communication in case of emergency, a satellite communication system is installed at the SE NNEGC ‘Energoatom’. The system covers the main and backup crisis centres of SE NNEGC ‘Energoatom’, the nuclear power plant assistance centre under the subdivision ‘Emergency and Technical Centre’, on-site and off-site crisis centres of the following separated subdivisions: ‘Rivne NPP’, ‘Zaporizhzhia NPP’, ‘Khmelnytskyi NPP’, and ‘South Ukrainian NPP’. The data transmission system ensures display of required information to describe an emergency situation on the crisis centres’ monitors.

In case of emergency at a nuclear power plant, staff and facilities of the separated subdivisions ‘Emergency and Technical Centre’ and ‘Atomremontservice’ shall be detached and directed to an emergency object, where they shall be under operational control of an on-site emergency manager, who controls activities for elimination of a nuclear power plant accident and its consequences. Using, whenever necessary, robots and other unique equipment, the emergency personnel of the separated subdivisions ‘Emergency and Technical Centre’ and ‘Atomremontservice’ shall assist personnel of an emergency facility to perform radiation and engineering survey; collection and localization of radioactive waste; decontamination; repairs of equipment in reactor, turbine, and electrical shops at a nuclear power plant, etc.

8.3.4. System of emergency preparedness and response to nuclear accidents

The central task of the SE NNEGC ‘Energoatom’ emergency preparedness and response system (hereinafter referred to as ERS) is further full-scale development, improvement, and implementation the system itself; its emergency, technical, and repairs subdivisions; emergency and technical subdivisions at the operating NPPs with the objective to form a complementary complex of technical means and resources; organizational, technical, radiation, and sanitary measures oriented towards attainment of the emergency response aim, i.e. prevention or mitigation of radiation effects for personnel, public, and natural environment in case of an NPP accident or an accident-caused emergency.

The top-priority and long-range objectives of ERS functioning and development include improvement of actual preparedness in terms of emergency response to any nuclear or radiation emergency in accordance with the IAEA requirements (№GS-R-2).

The following are the basic top-priority tasks of the above direction:

standardization and unification of organizational and technical decisions during operation of on-site and off-site crisis centres at NPPs, main and backup crisis centres of the SE NNEGC ‘Energoatom’ directorate;

maintaining operational condition and improvement of the systems for collection, processing, documenting, storage, display, and transmission of data from NPP power units monitoring and control systems, notification and communication systems;

development and improvement of the legal and regulatory environment covering emergency preparedness and response; establishment and maintaining relevancy of the library stock including regulatory, organizational, and administrative documentation concerning emergency preparedness and response, as well as of the reserve stock including design, engineering, process, production, and technical documentation of NPPs, to the extent required to ensure comprehensive support to counter-emergency activities and liquidation works;

adjustment of some discrepancies between the legislation in the area of civil defence and the one in the area of nuclear energy uses and radiation safety;

technical upgrades and modernisation of emergency response facilities, equipment, and means; renewal and augmentation of stocks of backup materials and emergency kits for prevention and elimination of man-caused and natural emergencies;

establishment of a focus group rendering expert support to decision-making in case of emergencies and ensuring its instant functioning, including software development and optimization of managerial decisions and solutions concerning the activities for personnel and public protection in case of an NPP radiation accident;

methodological, material, and technical improvement of the system and process for emergency personnel training and counter-emergency drills at various levels.

The midrange and long-range tasks are:

establishment of a unified information and analytical system for emergency preparedness and response of a nuclear facilities operator, its emergency and technical subdivisions and operating NPPs, integration of the system into a single information and analytical space of the governmental regulatory authorities for nuclear and radiation safety, state administration agencies for nuclear energy uses and civil defence, as well as nuclear design organizations and institutions ensuing their scientific and technical support, other nuclear operators, etc.;

addressing issues of social protection of and extra motivation for emergency personnel;

further capacity building of staff and facilities ensuring emergency response, supply of emergency response means with state-of-the-art materials and equipment and provision of cutting edge hardware and software;

adaptation of the emergency preparedness plans and tasks to the conditions of nuclear and industrial branch corporatisation and energy-saving efforts within the fuel and energy complex of Ukraine;

involvement and implementation of investment programs into the initiatives for further development of emergency preparedness and response system at different levels.

With the objective to implement the abovementioned and other tasks on a step-by-step basis, the SE NNEGC ‘Energoatom’ has adopted ‘Development Program for the SE NNEGC ‘Energoatom’ Emergency Preparedness and Response System for the Period till 2015’, PM-D.0.03.396-10. Implementation of the Program under an appropriate financing pattern shall ensure support and further development of the currently existing high (as per assessments made by international experts of various levels) level of preparedness to emergency activities in case of a radiation emergency.

8.3.5. Emergency planning

Appropriate emergency response plans shall be developed to ensure an organized performance of actions ensuring response to a radiation accident.

The Radiation Accidents Response Plan has been developed at the national level. It was approved by the joint decree of the State Nuclear Regulatory Committee of Ukraine and the Ministry for Emergencies and Affairs in Protection of Population from the Consequences of the Chernobyl Disaster No. 87/211, dated 17 May 2004 and registered in the Ministry of Justice of Ukraine on 10 June 2004 under reference No. 720/9319.

The Radiation Accident Response Plan was reviewed in March 2010. The Plan review was accomplished by a working group that included experts of the State Nuclear Regulatory Committee, Ministry for Emergencies, Ministry of Fuel and Energy, Ministry of Health, and Ministry for Ecology and Natural Resources. The working group was established to implement resolution No. 11 issued by the Board of the State Nuclear Regulatory Committee on 20 March 2008 and entitled ‘On Implementation of IAEA Recommendations Regarding Emergency Preparedness and Response with Due Consideration of the Experience in Conduction of Emergency Trainings’.

Amendments to the Plan were approved by administrative order ‘On Approval of Amendments to the Radiation Accident Response Plan’ No.24/126 issued by the State Nuclear Regulatory Committee and Ministry for Emergencies on 02 March 2010 and registered in the Ministry of Justice of Ukraine on 25 March 2010 under reference No. 250/17545.

The Radiation Accident Response Plan (hereinafter referred to as Plan) was developed to ensure a coordinated immediate response of administrative agencies, staff and resources of functional and territorial subsystems of the unified state civil defence system in case of a radiation accident (hereinafter referred to as RA) or a threat of it.

The Plan was developed with due regard to the requirements stated in the Laws of Ukraine ‘On Nuclear Energy Uses and Radiation Safety’, ‘On Protection of Public and Territories During Man-caused and Natural Emergencies’, ‘On Legal Principles of Civil Defence’, ‘On Protection of People from ionizing Radiation Effects’, the National Emergency Response Plan approved by resolution of the Cabinet of Ministers of Ukraine No. 1567 dated 16 November 2001, as it refers to RA, as well as pursuant to recommendations of the International Atomic Energy Agency.

The following were the Plan development objectives:

legal regulation of the actions implemented by functional and territorial subsystems of the unified civil defence system with due regard to a specific character of emergency planning and RA response;

harmonisation of legal and regulatory environment in the area of emergency response that is in effect in Ukraine and the effective legal and regulatory environment in the countries of the European Union.

The RA response Plan establishes the following:

categories of radiation hazard for the facilities and activities that may produce a RA;

breakdown for the classes of radiation accidents and other hazardous events, including but not limited to: municipal accident, site-level accident, industrial accident, emergency preparedness, loss of control over a source;

allocation of RA response responsibilities among an enterprise, central and local executive authorities;

procedure of emergency response including but not limited to: implementation of plans, organization of crisis centres’ activities, etc.

financial provision of the activities envisaged in the Plan;

organization and conduction of emergency training.

With the objective to ensure timely response to RA and undertake effective measures for protection of public and territories, the following RA response plans shall be developed in addition to the Plan:

emergency plans of the facilities, where practical activities related to radiation or radiation-nuclear technologies are performed;

response plans of the territorial subsystems’ links under the unified civil defence system, local-level ones;

response plans of the territorial subsystems under the unified civil defence system, regional-level ones;

response plans of the functional subsystems under the unified civil defence system.

Emergency response plans for the facilities, which may occur within radioactive contamination zones, shall envisage, as a separate section, relevant RA response activities.

Top managers of the enterprises acting as operators of the facilities performing practical activities related to radiation or radiation-nuclear technologies shall be responsible for the development, approval, and implementation of measures envisaged in the response plans.

Top managers of the enterprises ensuring transport of radioactive materials shall be responsible for the development, approval, and implementation of action plans for eliminating consequences of the accidents that may occur during transportation of radioactive materials, pursuant to Provisions for Planning Measures and Actions in Case of Accidents during Radioactive Materials Transportation, approved by Order of State Nuclear Regulatory Committee of Ukraine on 07 April 2005 No.38, and registered in the Ministry of Justice on 22 April 2005 under reference No. 431/10711.

Emergency plans that are developed at the facilities, where practical activities related to radiation or radiation-nuclear technologies are performed, shall identify a facility's radiation hazard category. The radiation hazard category shall be identified based on a facility's radiation safety analysis with due regard to an estimated classification of objects and types of activity by radiation hazard categories.

Emergency plans for the facilities of radiation hazard category I shall be developed based on the Typical Emergency Plan for Ukrainian NPPs; the Ministry of Fuel and Energy of Ukraine shall be responsible for its development and agreement with other involved Ministries.

Requirements to RA response plans for the territorial subsystems of local and regional levels under the unified civil defence system shall be developed by the ME with the participation of the MH and Ministry for Ecology and Natural Resources, in accordance with a radiation hazard category of the facilities and types of activities that may possibly affect a subsystems' territory in case of RA.

Response plans for the territorial subsystems under the unified civil defence system, which area entirely or partially refers to an observation zone of the facilities pertaining to radiation hazard category I-II (but not less than a thirty-kilometre zone for an NPP with a capacity up to 4 GW, a fifty-kilometre zone for an NPP with a capacity exceeding 4 GW) shall be developed as separate documents.

Response plans for the territorial subsystems under the unified civil defence system, within which areas the facilities of radiation hazard category III are located or the activities of radiation hazard categories IV-V are performed, may be included as separate sections into the response plans developed for the emergencies most probable to occur within a territory and are developed to fulfil resolution of the Cabinet of Ministers of Ukraine dated 16 November 2001 No. 1567 'On Approval of the National Emergency Response Plan'.

Response plans for the territorial subsystems under the unified civil defence system, which area entirely or partially refers to an observation zone of the facilities pertaining to radiation hazard category I-II, shall be developed based on source information provided by the enterprises, which operate the facilities pertaining to radiation hazard category I-II, and shall be agreed by top managers of the enterprises.

Response plans for the territorial subsystems under the unified civil defence system, which area entirely or partially refers to an observation zone of the facilities pertaining to radiation hazard category I, shall be developed based on the Model RA Response Plan for territorial subsystems under the unified civil defence system, approved by the ME order, and agreed with the Ministry of Fuel and Energy, MH, and Ministry for Ecology and Natural Resources.

All response plans for the territorial subsystems shall be mutually consistent.

Response plans of the functional and territorial subsystems under the unified civil defence system shall establish the following:

procedure for information exchange with other RA responders;

recommendations on form and content of press releases to be prepared to inform public and media, depending on an existing or forecasted situation at various stages of an RA development.

Conclusion

Modern society cannot abandon using nuclear energy. However, people should always remember the Chernobyl disaster, keeping in mind the necessity to take due responsibility when using hazardous technologies. It is the sum and substance of safety culture. Nuclear energy should not be used without scientific and engineering support, competent experts training system, multilevel decision-making and responsibility system.

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Chapter 2

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Chapter 3

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Chapter 8

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Національна доповідь підбиває підсумки роботи з подолання наслідків Чорнобильської катастрофи за 25 років, а також містить рекомендації та висновки щодо безпеки ядерної енергетики на майбутнє.

Офіційне видання

«Двадцять п’ять років Чорнобильської катастрофи. Безпека майбутнього»

Національна доповідь України

(англ. мовою)

Видавець та виготівник “Видавництво КІМ”
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