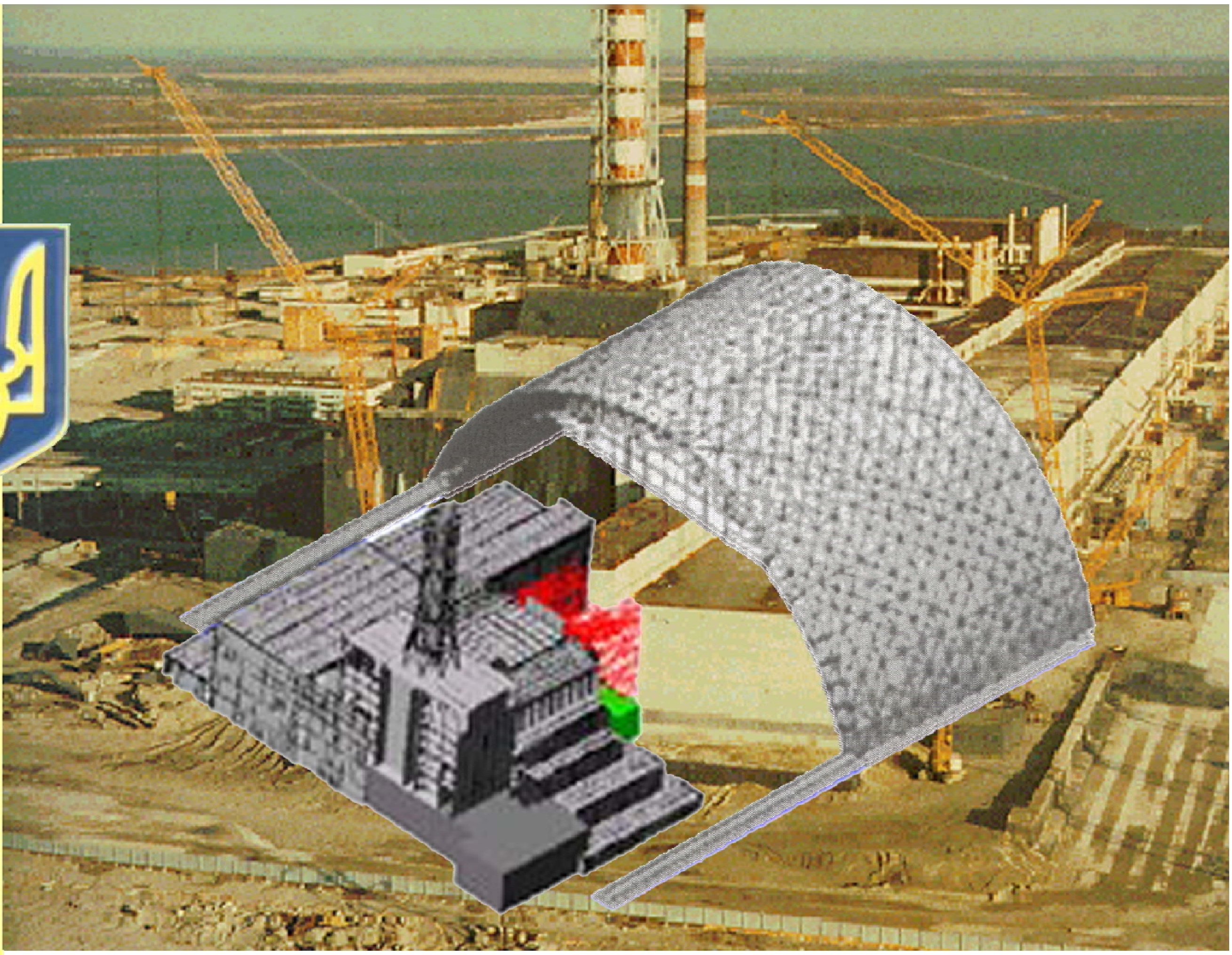

TWENTY YEARS AFTER CHERNOBYL ACCIDENT. FUTURE OUTLOOK

NATIONAL REPORT OF UKRAINE

Ministry of Ukraine of Emergencies and Affairs of population protection
from the consequences of Chornobyl Catastrophe

All-Ukrainian Research Institute of Population and Territories Civil Defense
from Technogenic and Natural Emergencies

20 years
after Chornobyl Catastrophe
FUTURE OUTLOOK

National Report of Ukraine

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LIST OF CONVENTIONAL SIGNS AND ABBREVIATIONS

SSE «Technocentre» – State Specialized Enterprise «Technocentre»
ALARA – As Low As Reasonably Achievable
AMS – Academy of Medical Science
ARS – Acute Radiation Syndrome
ARDIET– All-union Research and Design Institute of Energetic Technology of Minseredmash of USSR
AZF – Active Zone Fragments (Core Fragment)
AC-605 – Administration of Construction № 605 MCM of USSR – specialized building organization set up to make sarcophagus
Bq (kBq, MBq, GBq, TBq, PBq) – Becquerel ($Bq \cdot 10^3$, $Bq \cdot 10^6$, $Bq \cdot 10^9$, $Bq \cdot 10^{12}$, $Bq \cdot 10^{15}$), radioactivity unit
BSRRSU- 2005 – Basic Sanitary Regulations of Radiation Safety of Ukraine
CDC IA «Combinat» – Council of Dosimetric control of Industrial Association «Combinat»
CEC – Commission of European Communities
ChNPP – Chornobyl Nuclear Power Plant
CPRD – Chornobyl Program of Remediation and Developing
CL – Control Level
CMZ – Critical mass zone
CRMEZ – Centre of Radiological Monitoring of Exclusion Zone
CSNFSF – Centralized SNF Storage Facility
ASRCC – Automatic System of Radiation Condition Control
DSS – Dust Suppression System
EBRD – European Bank of Reconstruction and Development
EDC – Exposure Dose Capacity
EPR – Electron paramagnetic resonance
ESCUN – Economical and Social Council of UN
EZ – Exclusion Zone
EZ and ZAR – Exclusion Zone and Zone of Absolute resettlement
FCE – Fuel Containing Elements
FCM – Fuel Containing Materials
FPC – Fuel and Power Complex
FGI – French-German Initiative for Chornobyl
Grey (Gy) – Grey, unit of absorbed dose
HLRW – High level radioactive waste
IAE – I. V. Kurchatov Institute for Atomic Energy
IAEA – International Atomic Energy Agency
ICGNS – International Consultative Group on Nuclear Safety
ICSRWM – Industrial Complex for Solid RW Management
IDD – Iodine Deficiency Diseases
IPHECA – International Program on Health Effects of the Chernobyl Accident
TPL-91 – Temporal Permissible Levels, acted up to 1997.
IRWSU – Interim Radioactive Waste Storage Unit
KIEP – Kyiv Institute «Energy project»
LFCM – Lava-like fuel containing materials
LRWTP – Liquid radioactive wastes treatment plant
LRW – Liquid radioactive wastes
LRW SO – Liquid radioactive wastes SO
LRWSF – Liquid radioactive waste storage facility
ME of Ukraine – Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl catastrophe
MHU – Ministry for Health of Ukraine
Minseredmash (MPEI) – Ministry of Power Engineering Industry of USSR
mR, (R)/hour – Milliroentgen (Roentgen) per hour, exposure radiation dose capacity
NASU – National Academy of Sciences of Ukraine
NCRPU – National Commission on Radiation Protection of population of Ukraine

NNEC «Energoatom» – National nuclear-energetic company «Energoatom»
NPC – Nuclear power complex
NSC – New Safe Confinement
ODRSR – Official Dose Records in State Register of Ukraine
OG – Operations Group
ROW – Recovery operation workers
PC$_a$ – Permissible concentration of substance in air
PL-97 – Permissible Levels of ^{137}Cs and ^{90}Sr radionuclides concentration in food and drinking water, valid at the moment
RADRUE – Realistic Analytical Dose Reconstruction and Uncertainty Analysis
RBMK – Model of Reactor (high power capacity, channel)
RCM – Radio-contaminated materials
RODOS – System of collection and information processing on accident and development of recommendations on decisions making
RIA «Prypiat» – Research-Industrial Association «Prypiat»
RSSU-97 – Radiation Safety Standard of Ukraine-97
RW – Radioactive wastes
RWBU – Radioactive Waste Burial Units
SCRM AMS – Scientific Centre of Radiation Medicine of Academy of medical sciences of Ukraine
SCNR – State committee of nuclear regulation
SCR – Self-sustained Chain Reaction
SCS – State committee of statistics
SFA – Spent fuel assembly
SIP – Shelter Implementation Plan
SNF – Spent Nuclear Fuel
SNF DSF – SNF Dry Storage Facility
SNFSF – Spent Nuclear Fuel Storage Facility
SO – Shelter Object
SR – Safety rods (System of control and safety of reactor)
SRU – State Registry of Ukraine
SRW – Solid radioactive waste
SRWSF – Solid radioactive waste storage facility
SRWTC – Solid Radioactive Waste Treatment Complex
SSE ChNPP – State specialized enterprise «Chornobyl nuclear power plant»
SSSIE «Ecocentre» – State Specialized Scientific – Industrial enterprise «Ecocentre»
Sv (mSv) – Sivert (milisivert), effective dose unit
TC – Thyroid Cancer
TD – Thermoluminescent dosimeter
TF – Transfer factor of radionuclides in natural chains
The USSR – The Union of Soviet Social Republics
TISNO – Technogenic intensified sources of natural origin
TUE – Transuranium elements
Ukr SA «Radon» – Ukrainian state association «Radon»
UN SCNRA – UN Scientific Committee on Nuclear Radiation Activities
UNDP – United Nation Development Program
UIAR – Ukrainian Institute for Agricultural Radiology
URTC – Ukrainian Radiological Training Centre
WHO – World Health Organization
WMR – Water-moderated reactor
WBC – Whole body counter

HISTORIOGRAPHY OF EVENTS

1. CHORNOBYL CATASTROPHE IN UKRAINE

The scale of the Chornobyl catastrophe – the most severe man made nuclear accident in the history of mankind – is well known to both scientists and politicians worldwide. About 3% of the radionuclides that had accumulated in the ChNPP Unit 4 at the time of the accident were released into environment. That was about 300 MCi, or $1.2 \cdot 10^{19}$ Bq of radionuclides [1] and [2].

The accident contaminated over 145,000 km^2 of the territory in Ukraine, the Republic of Belarus, and the Russian Federation with a density of contamination by ^{137}Cs and ^{90}Sr exceeding 37 kBq/m^2. As a result of the Chornobyl accident, about 5 million people were affected; and about 5,000 inhabited settlements in the Republic of Belarus, Ukraine and the Russian Federation were contaminated with radionuclides. In Ukraine alone, 2293 villages and towns with a population of about 2.6 million were contaminated.

Besides the three countries most affected above, the Chornobyl accident also affected many other countries, notably Sweden, Norway, Poland, the United Kingdom, Austria, Germany, Finland and Switzerland.

The accident occurred when tests on utilising turbo generator rundown to ensure in-house power demand during complete de-energising of the NPP were conducted. The objective of the tests was to check the electrical equipment. The impact of such an experiment on the reactor was not analysed in details.

The tests were proposed by the Chief Designer of the Reactor Plant (Scientific-research constructional institute of powertechnic (RDDEEI), Moscow). It is now clear that such experiments should have been classified as integrated unit tests, and their program discussed in details and coordinated with the General Planner, General Designer, and Scientific Supervisor of the NPP RNBK reactors project (I. V. Kurchatov Institute for Atomic Energy (IAE), Moscow) and the State Supervisory Board. This was not done. Moreover, the regulations in effect in the USSR at that time did not require that the management of NPPs coordinate such programs with the above organisations. From the present standpoint, conducting such tests was an illegal action.

The basic causes of the catastrophe were as follows:

1. Conduction an incompletely and incorrectly prepared electrical experiment.
2. The low professional level of operators, and of the NPP management and the officials of the Ministry of Electrification as a whole in the area of NPP safety.
3. Insufficient safety level of the graphite-uranium reactor RBMK-1000.
4. Constructive falts RBMK-1000.
5. Personnel mistakes.

The world community is aware of these facts. However, many other related issues remain unknown not only to the global community, but also (in several cases) to the public of the countries affected. Such issues include the overall scope and extent of activities that had to be performed after the catastrophe; the role of science in addressing the radiation accident problem; the effect of interaction between the government, scientists and political forces during catastrophe recovery work; and the impact of social and psychological factors.

The report describes and reviews the actions of the governments of the USSR, Ukraine, and the Verkhovna Rada of Ukraine; the activities of scientists in elimination of the accident consequences; and elimination of the additional experience gained over the past years. Mistakes made during these activities are highlighted.

Actions during the active phase of the accident

The accident in the ChNPP Unit 4 destroyed barriers and safety systems, which protect the environment from radionuclides contained in the irradiated fuel. The release of activity from the damaged reactor at a level of dozens of millions of Curie daily continued for 10 days from April 26 to May 06 [3]. After this, the level dropped by several thousands fold. In the literature, the initial interval is referred to as the «active accident phase».

Accident recovery work at the ChNPP commenced on 26.04.86 under the supervision of the State Commission of the USSR. The Commission started to work in Chornobyl in the afternoon on April 26, and continued its activities until 1991.

The State Commission identified three basic kinds of hazards from the nuclear fuel of the ruined reactor.

Nuclear hazard. Most alarming was the fact that the reactor could still have contained intact a big cluster of the uranium-graphite inventory. The first estimates carried out in early May 1986 [4] showed that in the absence of water and safety rods (SR) the neutron multiplication factor K_{∞} was ~1.16 at the assumed temperature of about 10,000 °C, and therefore a self-sustained chain reaction could occur. As established later, the temperature in the reactor was actually about 2,000 °C and the neutron multiplication factor K_{∞} was less than unity so a chain reaction would not have occurred.

Thermal hazard. Initial assessments indicated that part of the nuclear fuel could reach the reactors bottom plate. The thermal hazard could be attributed to the possibility of the melted fuel gradually burning through the reactor plate, and subsequently through the partitions of the bottom structure in the reactor room. As a result, radioactivity would penetrate into the bubbler pond, and then further to contaminate the groundwater table. The results of first estimates were alarming in that it seemed that the thermal hazard could become a reality.

Radiation hazard. This hazard was attributed primarily to combustion mainly of the graphite in the reactor leading to the release of radioactivity from the ruined reactor. Hot radioactive plume had risen to an altitude of 1,500 metres, resulting subsequent transport of radionuclides in troposphere.

At its first meeting in the night of April 26, the State Commission made a decision to start dropping certain materials from helicopters into the open reactor cavity to contain the accident. As became evident in 1987, «bombarding» the reactor was ineffective because the materials dropped, failed to fall into the reactor due to inaccurate placement.

Can the decision of the Government Commission to drop special materials into the reactor be considered as mistake? From the standpoint of 2006 – yes, but from that of 1986 – no. In the critical initial conditions, the time factor was crucial. There was no time to determine whether the helicopter pilots were capable of performing the decision of the State Commission.

This example is a demonstration of how important is to develop decision making procedures related to major man made catastrophic events, as well as to work through all the elements of such decisions, before such events happen.

During the active phase, all technical measures were focused on containing the accident and preventing release of radioactive substances from the reactor (cf. [5]). As activities in containing the accident and controlling releases continued, a first model, or more precisely a first description of the active phase was produced [3, 6 and 7] and presented in the report of the Soviet delegation to the IAEA [3].

A complete model of the accident has not been developed even to this day.

One of the conclusions drawn, as a result of resolving Chornobyl's problems, was the need to create an emergency preparedness system, the RODOS system, implemented subsequently by joint efforts of scientists of European and other affected countries. RODOS (and its successor EURANOS) is a joint system comprising both an information acquisition system and software for processing accident information and drawing up recommendations for the government and/or decision makers.

Activities of the Government of Ukraine, the Academy of Sciences, and other state institutions and organisations in 1986–1987

According to the presentation of Y. A. Izrael and L. A. Ilyin, the Government Commission made a decision to create a 30-km exclusion zone around the ChNPP.

On April 27, 1986, the Government of Ukraine initiated evacuation of the residents of the towns of Prypiat and Chornobyl, and regional centre towns and villages in the 30-km zone (roughly 91,000 people).

Let us make a comment here on relocation of the residents of the town of Prypiat. Preparation for their evacuation started as early as it possible on April 26, but it was postponed by a decision of the USSR Government and the Central Committee of the CPSU. Fortunately, this did not entail grave consequences. The town of Prypiat is located 4 km away from the NPP in the north-western direction. The wind on that day was blowing in the direction of the town. The pine forest (which was 1 km away from the NPP roughly in the same direction) was transformed by the radioactive plume into a «red forest». Thus, irradiation dose of 10 Gy or 1,000 rem caused senescence of pine trees in early spring. The lethal radiation exposure 0.5 level for man is 4 Gy or 400 rem. Hence, it is clear that postponing evacuation of Prypiat's residents was certainly an huge mistake.

On May 3, 1986, an Operations Group (OG) on elimination of the ChNPP accident consequences was created. This Group immediately initiated actions both at the plant, and in the affected Oblasts, viz. the Kyivska, Zhytomyrska, and Chernigivska Oblasts, in the City of Kyiv. The OG initiated a range of activities focused on protecting the population from the consequences of the accident. These included the following actions [2]:

• monitoring of level of food contamination with radionuclides,
• organising health recovery and rest of children from May till September,
• setting up monitoring stations in Kyiv for measuring the gamma field level.

After the accident the 4th unit became an open source of a highest activity. That's why from the very beginning it was clear for the specialists and Government Commission members that it should be needed to construct an object of «Shelter» type, aimed at covering of the ruined unit. Its designation and construction was completed in 6 months; it was unexampled case in a world practice. The systems of gamma and neutron fields, thermal and seismic controls were established in the object «Shelter». The results of the monitoring, being carried out since the first days during all the years, showed that thanks to the «Shelter», the RW release from the ruined 4th unit into the environment was minimum.

Since April 26, 1986, all activities of the Academy of Sciences of Ukraine and other state institutions and organisations were focused on delivering scientific and technical support to the government on elimination of the consequences of the Chornobyl accident. On May 3, the Academy of Sciences of Ukraine also created an OG on elimination of the consequences of the Chornobyl catastrophe.

The key tasks of research institutes and organisations in 1986 and 1987 were:

1. Acquisition, classification and presentation to the government information on contamination of air, soil, the Dnipro River water, the Dnipro basin rivers and the Polissia lakes on the territories affected.

2. Making recommendations to the government on:
• immediate protection of the population affected by the ChNPP accident;
• a long-term action plan for the Chornobyl exclusion zone (EZ);
• actions at the ruined Unit 4, and in the towns of Prypiat and Chornobyl;
• dust suppression in the EZ roads; and
• actions at the remaining ChNPP units.

The Academy of Sciences, the Ministry of Water Resources, the State Agricultural Department of Ukraine and other agencies set up an analytical centre at the Institute of Cybernetics AS of Ukraine for assessing possible contamination of the Dnipro River along its entire watercourse. The first forecast was presented to the OG and government of Ukraine in autumn 1986. Later, this forecast was confirmed in its entirety. Since that time, and up to 1998, this centre regularly presented forecasts for the government on Dnipro water contamination during autumn and spring floods.

Since 1986, researchers from academic institutions in Ukraine, jointly with the scientific department of IA «Combinat» (in future – SPA «Prypiat»), launched regular research activities on the impact of long-term radiation on the fauna and flora in the EZ.

A characteristic feature of the activities of all official commissions and, primarily, the government Operations Group, during this period was close cooperation with scientists.

Activities in 1989–1998

In 1989, an interdisciplinary commission was set up around the Academy of Sciences of Ukraine to elaborate basic laws on protection of Ukraine's population that was affected during the ChNPP accident. In early 1990, the government received a file of documents, which served as a basis for the Verkhovna Rada of Ukraine to adopt laws on this issue. Adopting laws and regulatory-legal documents considerably relieved the accident associated social and economic stresses amongst recovery workers and the affected population.

The basic principles of laws on protection of population that have been affected by the Chornobyl catastrophe were developed by Ukraine's researchers jointly with their colleagues from Belarus and Russia.

In 1991, Ukraine created a Ministry of Affairs of Population Protecting from the Consequences of the ChNPP accident. One of the first actions of this Ministry was the development, jointly with the Academy of Sciences of Ukraine, a National Program of Scientific and Technical Activities for developing the strategy on elimination of the consequences of the Chornobyl catastrophe. In late 1991, this Program was developed and all activities followed this Program up to 2001.

If in 1986–1987 the political leaders of the country and scientists cooperated closely, in 1990–1992 such cooperation was suspended, and in several cases, there was clear opposition.

One of the key sections in the program of activities on protecting the population from the aftereffects of the Chornobyl accident was developing necessary instrumentation. All countries have technic for measuring neutron and gamma fields in the event of a nuclear war. They are intended for measuring relatively high, low and very low radiation levels. However, during the Chornobyl catastrophe, there was a need for extensive continual measurements (dozens of thousands) of many intermediate-level fields when determining the contamination of food. For determining radiation fields in the imme-

diate vicinity of the reactor, instruments that measure extremely high level fields were necessary. In Ukraine, this problem was resolved in a short time by the development of suitable devices by Ukraine's scientists.

Some mistakes and poor decisions

The Introduction highlighted the high stress of the affected population due to absence of data required for making decisions and the extremely short timescales in which important decisions had to be made. There were mistakes and poor decisions made during the summer and autumn of 1986. Mistakes were also made during another period in 1989–1992

There were further mistakes that are believed to be more critical described below.

Mistakes during 1986–1987

1. Information about the catastrophe was concealed from the public, as a result of a decision of the country's leaders and Minsredmash (Minsredmash – Ministry of Atomic Industry of the USSR). One of the arguments for concealing the catastrophe was to prevent panic among the population. Such opinions were not unfounded. However, the scale of the catastrophe was such that concealing it was impossible. Information on resettling the residents of the towns of Prypiat and Chornobyl (on 27.04.86 and 06.05.86 respectively) immediately spread among the population of Ukraine, Belarus and Russia. At the same time, until mid-May 1986, the physicians of the Ministry of Health, and the mass media were prohibited to inform the population of the USSR about accident recovery work; personal hygiene measures, and on the extent of the accident. Radiation contamination maps and radiation level data were classified until 1989.

Concealing information about the Chornobyl catastrophe resulted in the emergence and spread of different rumours on the possible consequences of the catastrophe. In turn, this caused intense social and psychological stress among the population, and distrust of official information. There is no doubt that concealing information about the Chornobyl catastrophe was an error.

2. The USSR's leaders rejected international cooperation proposals during nuclear accident recovery work. Only in 1989 did the USSR government address IAEA with a request to give an expert appraisal of the ChNPP accident recovery operations. In so doing, the terms of reference drawn up by the USSR leadership specified a territory with ^{137}Cs contamination lower than 15 Ci/km^2. Refusal of international cooperation at an early stage was also mistake.

There were engineering faults due to absence of adequate expertise in 1986–1987.

During another period (1989–1993), one of the critical mistakes was adopted, under pressure from a group of deputies, the radioactive contamination density of a territory rather than the human exposure dose arising from an area as the key radiation hazard criterion. Extremely safe, i. e. they don't require measures on radioactive protection of population, of ^{137}Cs contamination density was taken to be 15 Ci/km^2, which resulted wrong designation, primarily in the Polissia territory where acid peaty soils are widespread.

In such soil, migration of ^{137}Cs in the soil-plant system is significantly higher than in chernozem or clayly soil. This resulted milk and meat contamination that exceeded norm limits on territories that were considered «safe» with regard to contamination. For instance, in the Rivnenska and Volynska Oblasts, the territory contamination density was 10 or less kBq/m^2, whereas the soil-plant-milk migration factor in these regions was fairly high. Unfortunately, these northern regions were only identified as affected areas in 1998, and agricultural countermeasures aimed at reducing food contamination have only been initiated since that time.

From above, it is evident that close cooperation between the government (officials making decisions) and the scientific community of the country is necessary, and it is a key prerequisite for taking effective actions both under standard reactor operating conditions and in the case of accidents.

Nuclear power engineering, as a component of general power engineering, will certainly develop in the future. That is why we are aware of the critical importance of learning all the lessons of the Chornobyl catastrophe.

Conclusions

The text above has been used to outline the following conclusions:

1. The huge natural forces harnessed by nuclear power engineering call for an extremely high professional level of operators. This requirement needs not only excellent knowledge of nuclear equipment and nuclear physics, but also high moral standards of operators.

2. Any country that utilises nuclear power should have an extensive system of training and refresher courses for nuclear power industry personnel.

3. Nuclear power engineering, as an industrial sector of the national economy, requires that the country has both an expert management system in place, and a high level of scientific and engineering cooperation.

4. Undoubtedly, the current safety level of nuclear reactors is higher by an order of magnitude compared to that of RBMK reactors in the 80's. However, even at the modern level of its development, nuclear power engineering still remains a potentially hazardous industry. Due to this, close cooperation of the government (officials making decisions) with the scientific and engineering community of the country is a critical prerequisite for taking effective actions both under standard reactor operating conditions and in the case of accidents.

5. The accident demonstrated the necessity of development and maintaining a high-level national response system to cope with potential man made accidents.

6. The accident demonstrated the hazard of isolating the nuclear power industry from public supervision, and highlighted the necessity of an open and objective dialog with the public in all aspects of safe utilisation of nuclear power.

7. Analysing the experience of responding to the Chornobyl accident provides a unique opportunity for improving the emergency response system, which should include clear action procedures, trainings of personnel, adequate required instrumentation and equipment, *a priori* developed criteria and decision-making procedures, and a system for training a rescue personnel.

2. RADIOACTIVE CONTAMINATION OF THE ENVIRONMENT

2.1. Pre-accident radioactive contamination of the environment

The development of nuclear energy in the 2nd half of the 20th century caused artificial radioactive contamination of the environment. Radioactive contamination has also been caused by nuclear arms tests. Hundreds of atmospheric nuclear explosions were undertaken during 1945–1981, the majority before 1963. These have increased radiation to levels above background, primarily in the Northern hemisphere, with maximum values at 40°–50° North. According to available data, the atmosphere received a total of 949 PBq ^{137}Cs, 578 PBq ^{90}Sr [1] and 5550 PBq ^{131}I [2] during this period.

The annual average concentrations of ^{137}Cs, ^{90}Sr and aggregate beta-activity in the atmosphere surface air above the former USSR (Fig. 2.1.1) shows that from 1963, radionuclide concentrations in the surface air gradually decreased due to natural self-cleaning processes and decay. A renewal of explosions halted this decrease and caused a temporary increase of radionuclides concentration in aerosols. And only form the last atmospheric nuclear explosion in 1981, a decrease of radionuclides concentration in the atmosphere continued until April 1986.

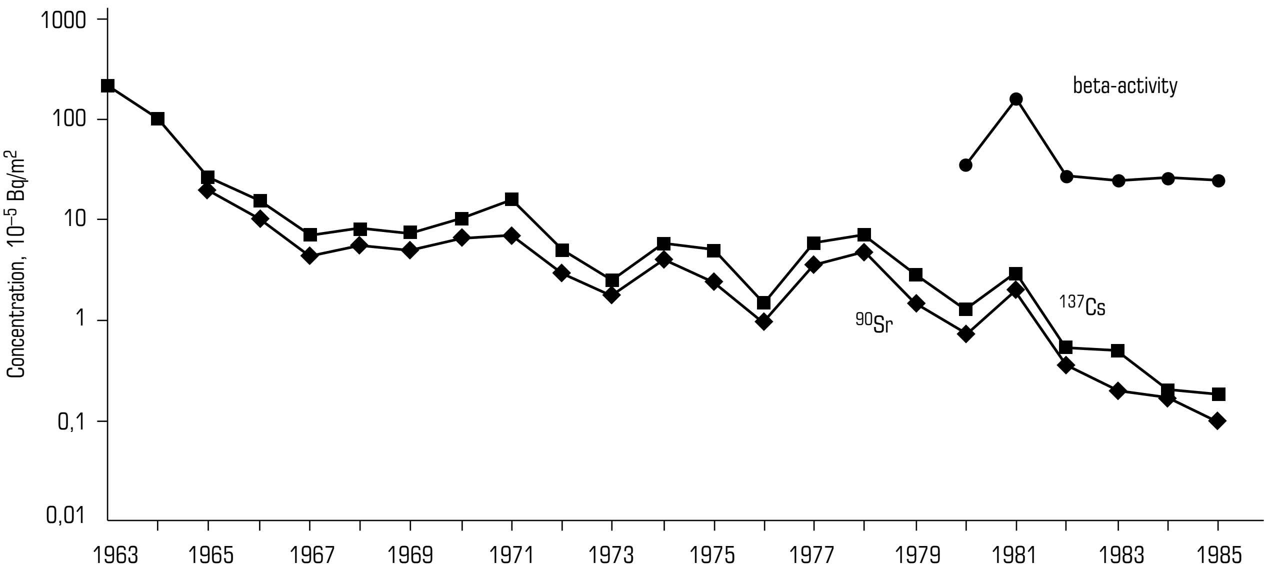

Fig. 2.1.1. Average annual concentrations of ^{137}Cs and ^{90}Sr and integral beta-activity in the atmospheric surface air [3]

Average monthly concentrations of ^{137}Cs and ^{90}Sr in the surface atmospheric air above the territory of Ukraine in 1984–1985 were $0.21 \cdot 10^{-5}$ Bq/m^3 and $0.12 \cdot 10^{-5}$ Bq/m^3 respectively [3], while in Odesa and Baryshivka the concentration of each of those radionuclides in the surface atmospheric air was $0.08 \cdot 10^{-5}$ Bq/m^3 [4].

According to monitoring, concentrations of ^{137}Cs and ^{90}Sr in the soil reached their maximum values in 1967–1968 (Fig. 2.1.2). Before the ChNPP accident, the average contamination levels of soil with ^{137}Cs and ^{90}Sr on the Ukrainian territory was within 0.8–4.0 kBq/m^2 (annual average value of the ratio $^{137}Cs/^{90}Sr$ remained practically stable – nearly 1.6) (Fig. 2.1.3 and Fig. 2.1.4, look inset) [5]. According to selective data collected by local and foreign researchers, the level of contamination with plutonium isotopes in the Northern hemisphere latitudes, typical for Ukraine, was 10–60 Bq/m^2.

Gamma background at an altitude of 1 m above the soil surface was 10–20 μR/hour on average, fluctuating mainly as a function of the natural radionuclides concentration between 4–70 μR/hour. However, in certain places, e.g. near the Azov Sea and Polissia (marshy woodland area of Ukraine) gamma backround was several hundreds of μR/hour, due to the presence of natural minerals which contain high concentrations of natural uranium and thorium.

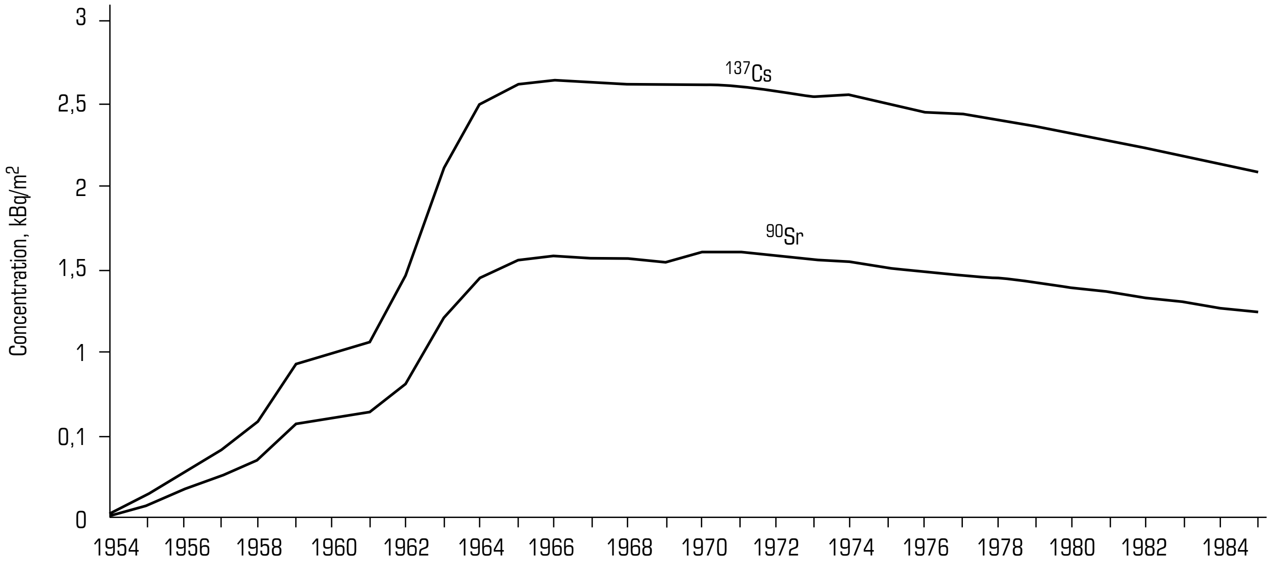

Fig. 2.1.2. The dynamics of ^{137}Cs and ^{90}Sr concentration in soil. Average data for the Northern hemisphere [3]

The dynamics of surface water contamination with the global ^{90}Sr in the pre-accident period are presented in Fig. 2.1.5. ^{90}Sr penetrated the upland surface waters primarily due to its washing-out from the water catchment territories. ^{90}Sr concentration in sea water was not that much different from its concentration in the upland surface waters. In the Black Sea in 1985, the average concentration of ^{90}Sr was equal to 16 Bq/m^3 [3]. Due to technical and technological reasons (i. e. a lack of the needed number of gamma-spectrometers with the required sensitivity and a lack of selective caesium sorbents) monitoring of dissolved in water ^{137}Cs was only carried out occasionally.

Population received a complementary exposure doze due to nuclear tests in the amount of 1 mSv averaged over a 50-year period [3].

The ChNPP accident caused considerable changes in the radiation environment on large territories in many European countries.

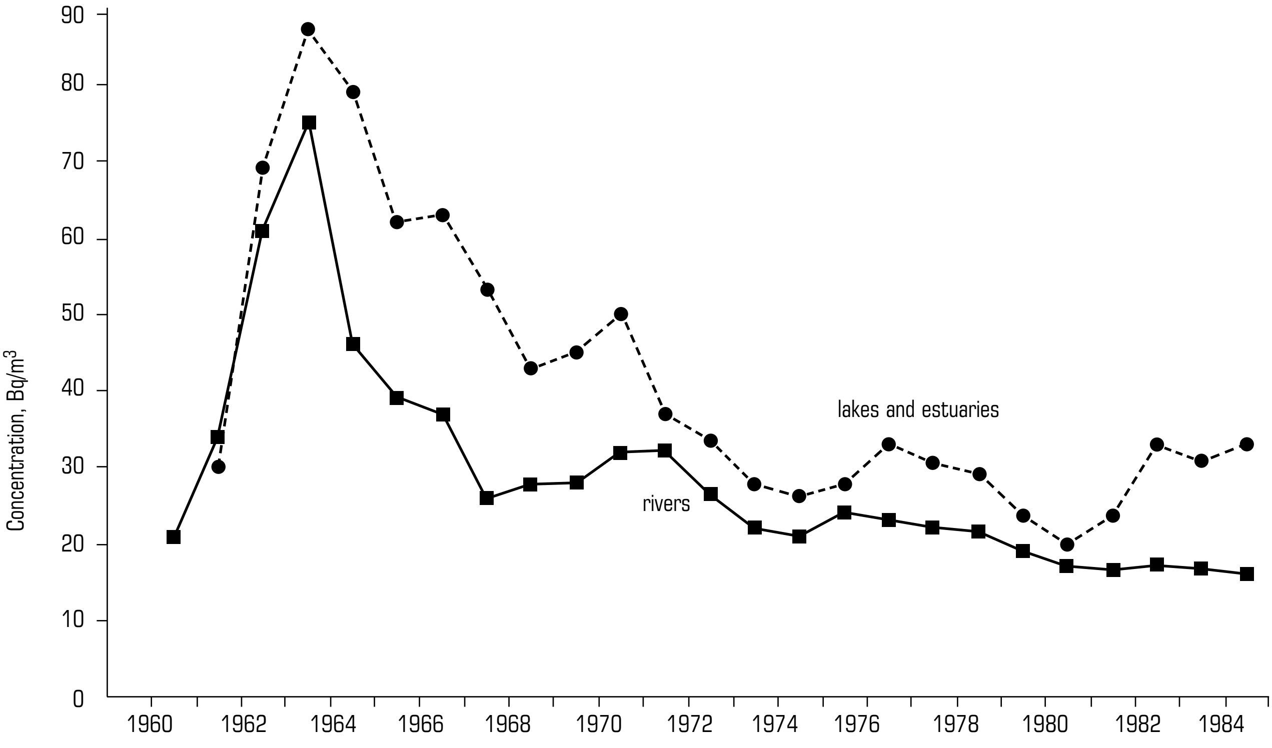

Fig. 2.1.5. Dynamics of surface water contamination with ^{90}Sr [3]

2.2. Features of environmental radioactive contamination after the ChNPP accident

2.2.1. Source of radionuclides

After the explosion on the ChNPP Unit 4 nuclear reactor and the destruction of its containment shells, a powerful emission of radioactive matter into the troposphere occurred. At April 26 in the reactor it was produced more than 210 EBq (10^{18}) of radionuclides. After the protection shield was build around the destroyed reactor (object «Shelter») active emissions into environment practically stopped. According to different authors, environment received at that time about 13 EBq of radionuclides.

Nearly 200 radioactive isotopes of elements in different phases and chemical forms moved in the atmosphere by the complex traces for up to thousands of kilometres from the ChNPP. In May 1986 they were detected in all countries of the Northern hemisphere, and in waters of the Pacific, Atlantic and Arctic Oceans. ^{131}I and ^{137}Cs were the most noticeable of the radionuclides. Ratios between different radionuclides substantially differed depending on the time of emission.

Three main phases of the active emission are conventionally differentiated: «explosive», «emission of low-temperature» and «emission of high-temperature»:

The first phase is characterized by spreading small dispersed particles of nuclear fuel (including fuel fission products which are accumulated during reactor operation and activation) and black lead that was generated during the reactor's powerful explosion, as well as radioactive rare gases and isotopes of iodine and tritium.

The second phase is characterized by a slow decrease of emission of radioactive substances which occurred during the 5 days after April 26. During this period, the total amount released was equal to the 1st day of emission [6]. This period was characterized with a gradual decrease in fuel-containing masses temperature after measures were taken to prevent an uncontrolled chain reaction and to decrease emissions from the destroyed reactor to the atmosphere. The temperature fluctuated from 600–1000 °C and the most volatile elements and their compounds, mainly tellurium, iodine and caesium, fall into the atmosphere.

The third phase was caused by a temperature increase in the fuel-containing mass to 2000 °C, followed by a corresponding increase of emissions of refractory elements including strontium, zirconium, cerium, and plutonium isotopes. The fourth phase, during which periodic increases of emission source activities occurred, was observed until the end of May 1986. However, air contamination during this phase was tens of times less than during the first three phases [7].

According to different authors, 70% [8] – 95% [9] of the fuel concentrated in the active zone remained in the destroyed premises of the ChNPP Unit 4 active zone after the accident. Residua with fission and activation products were emitted beyond the Unit territory. It caused global environmental contamination.

Gradually, the activity of radionuclides released in the environment considerably declined and the trans-uranium elements – ^{137}Cs and ^{90}Sr – are of the main radiological danger (Table 2.2.1).

2.2.2. Physical and chemical forms of released substances and «hot particles»

There is no precise knowledge about the specific physical and chemical processes which occurred in the destroyed reactor during the highest period of radionuclide emission into the environment 26.04.–06.05.86). As a result of a number of explosions on 26.04.86 and a long period of existence of a high-temperature mass of complex contain of the core remnants, radioactive substances were released in the form of large-sized debris of core, including equipment remnants and protective materials which were kept at the industrial site of the ChNPP, through to gas-steam-aerosol mixtures contained particles of micron and sub-micron size which spread globally. To forecast the future of radioecological consequences of the accident, scientists from different fields carefully studied the physical and chemical properties, forms, structures, mineral and chemical composition of the materials which caused radioactive environmental contamination at different distances from the ChNPP [6, 10, 11].

«Chornobyl» emissions are characterized by a wide spectrum of form and composition including radionuclides: gaseous, steam-aerosol, aerosol mixtures, fuel particles, mineral particles-carriers of condensed radionuclides, aggregates of different mineral forms, and organic compounds. The composition of these materials varies from mono-element rare gases and atomic iodine or ruthenium, to poly-element compounds and aggregates, fuel particles, graphite, silicates and other particles with different radionuclide ratios, that were produced during the reactor operations and which depended on their oxidation state [6, 10]. By definition, «a hot particle» is a microscopic mineral formation characterized by increased radioactivity. The predominant number of hot particles formed during the ChNPP accident were fuel particles. Among them there were particles [11] that left their source during different emission phases. In other words, some were released with non-oxidized fuel in the explosive phase, and with different levels of uranium oxidation during the next phases within the reactor active zone.

Table 2.2.1

Evaluation of the activity of radionuclides emitted to the environment after the ChNPP accident at the moment of the accident and 20 years later

Radio nuclide	Half-life	Emission activity, PBq	
		26.04.1986 [7]	26.04.2006
Rare gases			
^{85}Kr	10.72 years	~ 33	~ 9.058000
^{133}Xe	5.25 days	~ 6500	< 0.000000
Volatile elements			
^{129}Te	33.6 days	~ 240*	< 0.000000
^{132}Te	3.26 days	~ 1150	< 0.000000
^{131}I	8.04 days	~ 1760	< 0.000000
^{133}I	20.8 hours	~ 2500	< 0.000000
^{134}Cs	2.06 years	~ 54	< 0.065000
^{136}Cs	13.1 days	~ 36*	< 0.000000
^{137}Cs	30.0 years	~ 85	~ 53.550000
Intermediate volatility elements			
^{89}Sr	50.5 days	~ 115	< 0.000000
^{90}Sr	29.12 years	~ 10	~ 6.210000
^{103}Ru	39.3 days	~ 168	< 0.000000
^{106}Ru	368 days	~ 73	< 0.000077
^{140}Ba	12.7 days	~ 240	< 0.000000
Heavy volatile elements			
^{95}Zr	64.0 days	~ 196	< 0.000000
^{99}Mo	2.75 days	~ 168	< 0.000000
^{141}Ce	32.5 days	~ 196	< 0.000000
^{144}Ce	284 days	~ 116	< 0.000002
^{239}Np	2.35 days	~ 400**	< 0.000000
^{238}Pu	87.74 years	~ 0.035	< 0.030000
^{239}Pu	24 065 years	~ 0.030	< 0.030000
^{240}Pu	6537 years	~ 0.042	< 0.042000
^{241}Pu	14.4 years	~ 6	~ 2.292000
^{242}Pu	376 000 years	~ 0.00004**	~ 0.000040
^{242}Cm	18.1 years	~ 0.9	~ 0.419000
Total contamination		~ 13 935.89593	< 71.696119

The multi-phase process of the nuclear reactor destruction has revealed certain distinctive features of radioactive contamination of territories distant from the ChNPP. Over 90% of ^{90}Sr, $^{141,144}Ce$, isotopes of Pu and ^{241}Am were released in the form of fuel particles with a size of 10 microns and less. 75% of the ^{137}Cs within the exclusion zone can be connected with fuel particles [11]. Fuel particles with relatively constant ratios between radionuclides occur mainly within the exclusion zone. The south-western and northern traces are characterized by high-level fractioning of light volatile radionuclides. However, the southern trace has ratios which are close to the fuel ratios. Condensation particles smaller than the fuel ones, characterised the contamination of territories more distant from the ChNPP, i. e. 40–300 km from Chornobyl. They contain radionuclides which have mainly highly soluble forms [12].

At further distances from the ChNPP, contamination of the territories of the majority of European countries has been caused by steam-aerosol and gaseous mixtures, and particles of sub-micron size, containing $^{103,106}Ru$, $^{131,133}I$, ^{132}Te, $^{134,137}Cs$ and radioactive rare gases. The same isotopes were also

observed in large quantities in the Pacific and Atlantic Oceans, and in fall outs in South America and Asia.

Within the territory of the exclusion zone, ^{90}Sr and $^{134,137}Cs$ were found in non-soluble forms [13] during the initial years after the accident. They were integral to the composition of the «hot particles», but since those particles were later destroyed, ^{90}Sr, along with $^{134,137}Cs$, became more mobile. Whilst ^{90}Sr became more «bioavilable», $^{134,137}Cs$ tended to be fixed through binding with soil clay minerals and became subsequently less-mobile [14].

2.2.3. Specific features of environmental radioactive contamination

Scale of contamination and factors which caused it

Belarus, Russia and Ukraine have experienced the highest contamination from the ChNPP accident. However, air masses, saturated with radioactive substances, moved over the northern parts of the hemisphere during the first few weeks after the accident and contamination occurred almost in all European countries, especially in Scandinavian countries and in Alpine regions. Zones with the highest levels of radioactive contamination were formed in the first 10 days. Their existence at distances more than 50 km from the ChNPP was caused by different factors: emission of contaminated radioactive masses into the air at the altitude 2 000 m; precipitation over territories where contamination occurred; and complex landscapes that determined the direction and altitude of the air masses contaminated with ChNPP emissions.

The altitude of the radioactive substances emission, determined the global character of contamination, while precipitation and landscape resulted differences in character of territory contamination.

In Ukraine, precipitation in Narodytsky and Lugynsky regions of Zhytomyr Oblast, southern part of Kyiv Oblast, in Cherkaska Oblast, Podillia and Near-Carpathian mountains regions resulted the formation of zones with increased contamination density of $^{134,137}Cs$. Rains caused washing-out of radioactive particles, aerosols from the troposphere and creation of radio-contaminated zones on considerable territories of Belarus and Russia as well as in Sweden, Finland, Germany, Austria, Switzerland, Greece, Bulgaria, Romania and Georgia.

At a distance of 800–1400 km from the ChNPP, the distribution of zones with elevated levels of ^{137}Cs showed local maxima which could be explained by the mountains' impact on the shift of air masses, including an increase in precipitation in the foothills (of the Alps and the Balkans) and therefore, an increase in ^{137}Cs fall-out density.

Estimation of ^{137}Cs distribution on the territory of Europe by electronic map of contamination [15], given in the table 2.2.2, shows that:

– the highest density of contamination ($q_{Cs\text{-}137}$) is found within 30-km zone around ChNPP (R_{int}, R_{extern} – distance from ChNPP), levels of contamination exceeding the global blank at the distance up to 3000 km from the accidental place are observed;

– on territories of Ukraine, Belarus and European part of Russia, within the circle of 400 km radius around ChNPP, in the area ($S_{territory}$) equal to 5,5% of the total area of Europe almost 40% of ^{137}Cs ($Q_{Cs\text{-}137}$) fallen outside the industrial plot of ChNPP is found;

– total amount of ^{137}Cs fallen in Europe is 80 PBq, that is conformed to estimate of the total amount of radionuclide withdrawn outside the industrial plot of ChNPP [7].

After the accident, nearly 75% of Ukrainian territory (in 10 Oblasts) had a 2-fold higher contamination level with ^{137}Cs. The total activity of ^{137}Cs located beyond the object «Shelter» boundaries (and excluding the radioactive wastes in the corresponding storage facilities and temporary storage sites) exceeded 13 PBq.

Kyivska and Zhytomyrska Oblasts experienced the greatest contamination in terms of scale (almost 100%) and level (more than 1 MBq/m2). On the territories of Rivnenska, Cherkaska and Chernigivska Oblasts, the levels were two-fold less, although the scale of contamination was almost the same (Fig. 2.2.1 – inset, Table 2.2.3) [5]. Almost 100% of Donetska, Ivano-Frankivska, Luganska, Sumska and Chernivetska Oblasts territories were contaminated with ^{137}Cs at levels more than two times higher than the pre-accident global levels of 1967–1968.

However, high levels of radioactive contamination do not necessarily pose the greatest radioecological problems. For example, areas with comparatively low levels of contamination (40 KBq/m^2) can become unbearable for living when ^{137}Cs become bioavailable in soils. For example, many forest areas, especially in Ukrainian marshy woodlands (Polissia), belong to such territories. In total, more than 80% of the forest area experienced a considerable contamination with ^{137}Cs (Table 2.2.4).

The areas of Ukrainian territory which have been contaminated with ^{90}Sr, and Pu, ^{241}Am isotopes are considerably less than those contaminated with ^{137}Cs (Figs. 2.2.2–2.2.6 (inset), Tables 2.2.5–2.2.6) [5].

Table 2.2.2

Distribution of ^{137}Cs on the territory of Europe

R_{int}, km	R_{extern}, km	$S_{territory}$, %	*$Q_{Cs\text{-}137}$, %	$q_{Cs\text{-}137}$, kBq/sq. m
0	10	0.0034	1.70	5030
10	30	0.0275	4.69	1730
30	100	0.3129	7.19	235
100	400	5.1587	24.11	48
400	800	15.275	16.49	11
800	1400	30.176	25.46	8.6
1400	2000	32.695	15.47	5.7
2000	3000	16.355	4.89	3.1
800	3000	79.226	45.82	6.0
1400	3000	49.05	20.36	4.2

* $Q_{Cs\text{-}137}$ – total amount of ^{137}Cs, consisted of global radiocesium remaining on the territory of Europe and released during the Chornobyl accident (for May, 1986).

These belong to a group of heavy volatile radionuclides that were emitted to the atmosphere primarily during the first phase of the accident after explosions in the active zone on 26.04.86. During the following days, their emission in a flow of steam-aerosol-gaseous mixture was caused by graphite burning, by increases in temperature within the active zone up to 2000 °C, by generation of more volatile poly-element compounds, and by absorption on mineral particles [6, 10].

A special role in the radioactive contamination of the environment was played by radioactive ^{131,132,133,135}I isotopes, which are short-lived radionuclides that belong to a group of light volatile elements. It is worth mentioning here, however, that only isotopes ^{131}I has high radiological value; among other isotopes, only ^{133}I increased substantially the general exposure dose received by the thyroid glands of children from the town of Prypiat and surrounding villages. When the core temperature increased, these iodine isotopes were almost completely released to the atmosphere and they were thus spread with the air masses through almost all the Northern hemisphere. A lack of a necessary monitoring network did not allow to estimate the spread of these radionuclides. However, the results of model calculations based on scanty measurements and determinations of ratios between radioiodine and different radionuclides, especially ^{137}Cs allowed intensive determinations of Ukrainian territory contamination density. Further, direct measurements of the thyroid dose (the gland absorbs 100% of iodine taken in by the human body from the atmosphere and with consumed food products) helped evaluate the scale of ^{131}I spread on the territory of Ukraine (Fig. 2.2.7). For children who were born in 1986, the exposure dose exceeded the permissible level of 50 mGy.

During the 20 years after the ChNPP accident the natural processes of radionuclide decay have substantially altered of the distribution of ^{137}Cs and ^{90}Sr within Ukrainian territories (Figs. 2.2.1–2.2.4 (inset), Tables 2.2.3, 2.2.5), whilst the level and scale of contamination with Pu isotopes have not changed significantly. The activity of ^{241}Am has been gradually increasing at the expense of ^{241}Pu decay, and the scale of its spread is comparable with the scale of the spread of Pu isotopes (Figs. 2.2.5–2.2.6 (inset), Table 2.2.6).

Some specific features of formation of urbanized territory contamination

Contamination of urbanized territories is characterized by specific differences in the contamination of natural, semi-natural landscapes and agricultural lands. First, radioactive contamination occurred due to both dry / wet fall-out and transport vehicles. Second, on urbanized territories, non-penetrating surfaces prevail, which in contrast to agricultural (penetrating) surfaces, are characterized by a specific absorbing capacity, which results unevenness redistribution of contamination. Specific features of contamination on urbanized territories including dotty and linear anomalies formed under water drains, along roads, between curbs, drain grates, under separate trees, and along dams and in places of car washing [15]. Parks can represent large radiation sources and retention of contamination by roof covers (25–90% of ^{137}Cs is retained). However, the level of external exposure on urbanized territories is lower than in rural areas or in forests.

Table 2.2.3

Ukrainian territory contamination with caesium-137 ('000 km²)

Oblast	Oblast Area	Years	Area of territory contamination with ^{137}Cs, kBq/m²									
			< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480
Autonomous Republic of Crimea	27.0	1986	0.29	17.8	8.3	0.61						
		2006	11.94	11.41	3.62	0.03						
Vinnytska	26.5	1986	0.30	3.2	13.7	4.9	2.7	1.7				
		2006	1.8	8.2	11	2.9	2.22	0.38				
Volynska	20.2	1986	0.27	2.4	10.3	4.5	2.5	0.23				
		2006	1.2	7.0	8.2	2.9	0.89	0.01				
Dnipropetrovska	31.9	1986	8.2	8.1	10.8	4.4	0.40					
		2006	14.5	6.7	9.2	1.4	0.1					
Donetska	26.5	1986		0.04	11.57	10.39	3.6	0.9				
		2006		2.5	16.6	5.35	2.0	0.05				
Zhytomyrska	29.9	1986	0.5	2.1	7.4	6.3	2.6	5.4	3.27	1.69	0.51	0.13
		2006	1.6	4.6	8.9	2.7	3.5	5.8	1.39	1.08	0.29	0.04
Zakarpatska	12.8	1986	0.47	4.5	6.53	1.21	0.09					
		2006	2.5	6.98	2.96	0.36						
Zaporizhska	27.2	1986	0.85	12.5	12.1	1.72	0.03					
		2006	8.5	12.35	6.07	0.28						
Ivano-Frankivska	13.9	1986	0.07	1.9	3.2	5.9	2.43	0.4				
		2006	1.1	2.17	5.69	4.0	0.77	0.17				
Kirovogradska	24.6	1986	0.07	1.92	15.91	5.34	1.12	0.24				
		2006	0.58	11.3	10.03	2.21	0.43	0.05				
Kyivska	28.9	1986		0.02	3.49	6.0	8.09	6.17	2.58	1.57	0.49	0.49
		2006		0.8	6.4	8.1	6.7	4.2	1.1	0.9	0.36	0.34
Luhanska	26.7	1986			1.6	20.0	5.1					
		2006		0.1	14.8	11.39	0.41					
Lvivska	21.8	1986	2.2	17.3	2.3							
		2006	14.9	6.7	0.2							
Mykolayivska	24.6	1986		9.5	13.9	1	0.1					
		2006	4.2	16.1	4.1	0.17	0.03					
Odeska	33.3	1986	0.1	8.2	21.5	3.15	0.35					
		2006	2.3	20.34	9.8	0.81	0.05					
Poltavska	28.8	1986		1.1	25.4	2.3						
		2006	0.45	8.25	20.1							
Rivnenska	20.1	1986		0.25	6.2	2.29	3.46	6.18	1.6	0.12		
		2006		3.9	4.2	2.7	4.8	4.19	0.31			
Sumska	23.8	1986	0.07	1.8	14.6	4	2.48	0.75	0.1			
		2006	0.99	6.42	11.44	3.64	0.93	0.38				
Ternopilska	13.8	1986	3.6	4.65	2.5	1.5	1.21	0.34				
		2006	7.3	2.27	2.17	1.38	0.65	0.03				
Kharkivska	31.4	1986		0.08	13.9	16.53	0.89					
		2006	0.03	2.64	24.53	4.2						

Continuation table 2.2.3

Oblast	Oblast Area	Years	Area of territory contamination with ^{137}Cs, kBq/m^2									
			< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480
Khersonska	28.5	1986	0.94	22.72	4.64	0.2						
		2006	17.4	10.0	1.1							
Khmelnytska	20.6	1986	1.68	7.85	6.41	3.34	1.03	0.28	0.01			
		2006	7.4	6.0	4.93	1.83	0.32	0.12				
Cherkaska	20.9	1986		0.72	7.0	4.8	3.4	4.3	0.61	0.17		
		2006	0.17	3.9	7.0	3.3	4.0	2.3	0.22	0.01		
Chernivetska	8.1	1986		0.02	3.8	2.3	1.6	0.33	0.05			
		2006		1.6	3.8	2.11	0.44	0.15				
Chernihivska	31.9	1986	0.56	5.8	10.7	6.2	6.41	1.52	0.56	0.15		
		2006		8.0	11.8	6.9	3.55	1.4	0.25			
Exclusion zone	2.6*	1986					0.01	0.30	0.5	0.93	0.43	0.43
		2006					0.18	0.5	0.54	0.77	0.3	0.31
Total in Ukraine	603.7	1986	20.17	134.47	237.75	118.88	49.59	28.74	8.78	3.7	1.0	0.62
		2006	98.86	170.23	208.64	68.66	58.79	19.23	3.27	1.99	0.65	0.38

* Area of the exclusion zone and absolute resettlement zone located in the territory of Kyivska Oblast.

Table 2.2.4

Radioactive contamination of Ukrainian forests (km^2)

№	Oblast	Density of contamination with Cs-137 [kBq/m^2]										Total forest area
		< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480	
1	Vinnytska	0	45.3	1497.9	471.6	432.4	243.0	0.03				2690.2
2	Volynska	58.2	332.6	3339.5	1592.4	1971.8	146.6					7441.1
3	Dnipropetrovska	42.1	132.1	443.1	76.1							693.4
4	Donetska	0	0	530.8	326.0	186.7	28.6					1072.1
5	Zhytomyrska	23.6	266.9	1619.3	1159.0	872.8	3789.6	2089.2	1419.8	157.5	77.2	11474.9
6	Zakarpatska	555.9	3292.5	3202.4	868.3	106.6						8025.7
7	Zaporizhska	169.1	37.8									206.9
8	Ivano-Frankivska	0	830.5	1916.3	2825.8	1171.9	108.7					6853.2
9	Kyivska	0	0	255.6	964.2	1422.0	2108.2	765.0	733.3	260.8	163.8	6672.9
10	Kirovogradska	0	16.3	773.1	218.6	42.2	4.9					1055.1
11	AR of Crimea	0	268.3	2725.2								2993.5
12	Luhanska	125.1	6629.2	972.4								7726.7
13	Lvivska	0	0	192.5	1232.3	154.4						1579.2
14	Mykolayivska	0	65.4	167.7	17.2	0.6						250.9
15	Odeska	1.8	52.5	729.1	191.2	46.0	0.2					1020.8
16	Poltavska	0	58.0	1911.3	51.4							2020.7
17	Rivnenska	0	2.9	1046.4	777.4	1296.7	4204.3	681.3	18.2			8027.2
18	Sumska	2.8	154.2	2265.4	944.6	533.5	118.6	0.2				4019.3

Continuation table 2.2.4

№	Oblast	Density of contamination with Cs-137 [kBq/m²]										Total forest area
		< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480	
19	Ternopilska	225.9	711.8	516.9	278.9	169.7	65.4	0.5				1969.1
20	Kharkivska	0	0	1949.9	1326.1	54.0						3330.0
21	Khersonska	0	671.6	50.0								721.6
22	Khmelnytska	34.9	532.7	1372.9	472.6	88.7	36.3					2538.1
23	Cherkaska	0	63.0	966.7	732.3	550.0	450.6	48.4	4.8			2815.8
24	Chernivetska	0	0	1007.3	1165.2	655.5	38.1	0.1				2866.2
25	Chernihivska	46.8	708.5	2416.1	1773.4	1073.9	706.1	219.9	13.9			6958.6
	Ukrainian forests	1286.2	14 872.1	31 867.8	17 464.6	10 829.4	12 049.2	3804.6	2190	418.3	241	95 023.2
	Total for Ukraine	20 170	134 470	237 750	118 880	49 590	28 740	8780	3700	1000	620	603 700

Table 2.2.5

Ukrainian territory contamination with Strontium-90 ('000 km²)

Oblast	Oblast area	Years	Area of territory contamination with ^{90}Sr, kBq/m²									
			< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480
Autonomous Republic of Crimea	27.0	1986	21.8	5.2								
		2006	27.0									
Vinnytska	26.5	1986	16.2	7.8	2.43	0.07						
		2006	22.3	3.52	0.68							
Volynska	20.2	1986	19.86	0.32	0.02							
		2006	20.16	0.04								
Dnipropetrovska	31.9	1986	23.8	7.92	0.18							
		2006	30.8	1.1								
Donetska	26.5	1986	18.4	7.68	0.42							
		2006	25.2	1.3								
Zhytomyrska	29.9	1986	10.9	10.1	7.2	1.25	0.35	0.08	0.02			
		2006	18.9	6.5	3.73	0.58	0.13	0.05	0.01			
Zakarpatska	12.8	1986	7.6	5.2								
		2006	12.68	0.12								
Zaporizhska	27.2	1986	26.1	1.1								
		2006	27.2									
Ivano-Frankivska	13.9	1986	5.0	8.48	0.42							
		2006	13.21	0.52	0.17							
Kirovogradska	24.6	1986	14.4	8.82	1.36	0.02						
		2006	22.0	2.35	0.25							
Kyivska	28.9	1986	1.3	5.4	12.9	5.87	1.30	0.67	0.47	0.56	0.22	0.21
		2006	4.8	9.13	9.51	3.13	0.58	0.67	0.43	0.34	0.19	0.12
Luhanska	26.7	1986	13.3	13.0	0.40							
		2006	25.5	1.17	0.03							

Continuation table 2.2.5

Oblast	Oblast area	Years	Area of territory contamination with ^{90}Sr, kBq/m^2									
			< 2	2–4	4–10	10–20	20–40	40–100	100–185	185–555	555–1480	> 1480
Lvivska	21.8	1986	20.82	0.98								
		2006										
Mykolayivska	24.6	1986	23.4	1.2								
		2006	24.56	0.04								
Odeska	33.3	1986	18.2	10.4	4.7							
		2006	26.7	6.6								
Poltavska	28.8	1986	21.6	7.1	0.1							
		2006	28.06	0.74								
Rivnenska	20.1	1986	12.7	6.88	0.47	0.05						
		2006	18.8	1.21	0.07	0.02						
Sumska	23.8	1986	22.25	1.53	0.02							
		2006	23.69	0.11								
Ternopilska	13.8	1986	11.1	2.41	0.29							
		2006	13.1	0.67	0.03							
Kharkivska	31.4	1986	20.4	10.88	0.12							
		2006	30.2	1.2								
Khersonska	28.5	1986	28.5									
		2006	28.5									
Khmelnytska	20.6	1986	16.1	4.1	0.38	0.02						
		2006	20.0	0.46	0.14							
Cherkaska	20.9	1986	8.5	6.1	5.53	0.77						
		2006	12.7	5.5	2.74	0.06						
Chernivetska	8.1	1986	2.3	5.05	0.73	0.02						
		2006	6.0	1.98	0.12							
Chernihivska	31.9	1986	16.2	9.9	4.2	1.47	0.13					
		2006	24.1	5.0	2.3	0.49	0.01					
Exclusion zone	2.6*	1986				0.38	0.26	0.52	0.47	0.56	0.2	0.21
		2006			0.01	0.53	0.35	0.63	0.43	0.34	0.19	0.12
Total for Ukraine	603.7	1986	400.73	147.15	41.87	9.54	1.78	0.75	0.49	0.56	0.22	0.21
		2006	527.96	49.22	19.71	4.28	0.72	0.72	0.44	0.34	0.19	0.12

* Area of the exclusion zone and compulsory resettlement zone located in the territory of Kyivska Oblast.

Table 2.2.6

Ukrainian territory contamination with plutonium isotopes ($^{238+239+240}Pu$) ('000 km^2)

Oblast	Oblast area	Area of territory contamination with $^{238+239+240}Pu$, kBq/m^2									
		< 0,04	0,04–0,1	0,1–0,2	0.2–0.4	0.4–1	1–2	2–4	4–10	10–20	> 20
Autonomous Republic of Crimea	27.0	18.1	8.9								
Vinnytska	26.5	24.5	2.0								
Volynska	20.2	16.8	3.4								
Dnipropetrovska	31.9	31.9									
Donetska	26.5	20.9	5.6								
Zhytomyrska	29.9	16.2	10.2	2.1	0.74	0.5	0.11	0.05			
Zakarpatska	12.8	0.3	11.72	0.78							
Zaporizhska	27.2	22.5	4.7								
Ivano-Frankivska	13.9	5.5	7.3	1.1							
Kyivska	28.9	5.9	11.6	5.1	2.98	1.31	0.48	0.47	0.53	0.21	0.32
Kirovogradska	26.4	23.1	1.45	0.05							
Luhanska	26.7	17.8	8.9								
Lvivska	21.8	17.9	3.88	0.02							
Mykolayivska	24.6	24.5	0.10								
Odeska	33.3	29.4	3.9								
Poltavska	28.8	28.8									
Rivnenska	20.1	17.9	2.05	0.15							
Sumska	23.8	22.96	0.84								
Ternopilska	13.8	11.8	2.0								
Kharkivska	31.4	31.12	0.28								
Khersonska	28.5	25.6	2.9								
Khmelnytska	20.6	20.02	0.58								
Cherkaska	20.9	13.1	6.3	1.48	0.02						
Chernivetska	8.1	6.2	1.87	0.03							
Chernihivska	31.9	21.6	6.7	2.5	0.91	0.19					
Exclusive zone	2.6*				0.38	0.26	0.43	0.47	0.53	0.21	0.32
Total for Ukraine	603.7	474.4	107.17	10.71	4.65	2.0	0.59	0.52	0.53	0.21	0.32

* Area of the exclusion zone and compulsory resettlement zone located in the territory of Kyivska Oblast.

2.2.4. Radioactive contamination of water systems

Contamination of water catchments and water systems

Rivers are the major transport systems for radionuclide transfer. Radioactive contamination of water bodies arises through direct fall-out of radioactive aerosols and through secondary contamination, including those from water catchments (i.e. over time, radionuclides migrate from the surface to deeper layers or are displaced in bulk by surface waters), water arriving from other more contaminated systems, and due to mass exchange between bottom sediments and water. During 1986–2005, the Prypiat river waters carried about 123 TBq ^{137}Cs and 148 TBq ^{90}Sr. The catchment territories of the rivers Prypiat and Dnipro are one of the largest in Europe. According to available estimates [16], 19.6 PBq ^{137}Cs; and 2.3 PBq ^{90}Sr are concentrated in Dnipro and Prypiat river basins. The amount of radionuclides that enter into water is proportional to:

• the value of activity in the upper, so-called effective layer of the soils in the catchments;

• the share of exchangeable forms of radionuclides that can travel to soil solutions (for different landscape types it differentiates by value);

• geo-chemical composition of soils;

• amount of water (flow layer) formed on the contaminated territory.

The highest levels of contamination of surface of water bodies were observed during the period of direct aerosol fall-out on their water surface. During the first post-accident weeks, the rivers Prypiat, Teteriv, Irpin, and Dnipro had contamination levels that exceeded sanitary norms by hundreds and even thousands of times, even at a distance of several hundred kilometres from the ChNPP. The highest contamination levels in water were observed in the Prypiat River near the town Chornobyl where water activity of ^{131}I reached 4 440 Bq/l (Table 2.2.7).

Table 2.2.7

The highest level of water contamination in the river Prypiat identified by monitoring during the first weeks after the ChNPP accident in May 1986 [17]

Radio nuclide	Max. activity, Bq/l	Radionuclide	Max. activity, Bq/l
^{137}Cs	1591	^{106}Ru	271 **
^{134}Cs	827*	^{144}Ce	380
^{131}I	4440	^{141}Ce	400
^{90}Sr	30	^{95}Zr	1554
^{140}Ba	1400	^{95}Nb	420
^{99}Mo	670	^{241}Pu	33 ***
^{103}Ru	814	239+240Pu	0.4

* Determined by the ratio ^{134}Cs/^{137}Cs ~ 0.52.
** ^{103}Ru – determined on the assumption ^{103}Ru/^{106}Ru (~ 3) for aerosols emitted from the destroyed ChNPP Unit 4.
*** Determined by ^{241}Pu/$^{239+240}$Pu (~ 82) in aerosols.

Since contamination exceeded the highest level of permissible concentrations of drinking water, this caused panic among the local population. Further uncertainty was caused since countermeasures to stop further spread of radioactivity with water flows failed. During the first few weeks, aerosol fall-out ceased which occurred as surface water contamination levels were also declining due to the physical fission of short-lived radionuclides and fixation of radionuclides in water catchment soils and water reservoirs bottom sediments. With time, ^{137}Cs and ^{90}Sr became the major components of water ecosystems contamination. However, their concentration in the Dnipro water system was relatively low, with short-term increases in the rivers during spring floods and rainfalls. Contaminated territories of the river Prypiat floodlands in the exclusive zone of ChNPP and filtration drains from the water reservoirs and waterlogged territories became the main sources of secondary contamination, primarily with ^{90}Sr, that was brought to the Dnipro water system. Thus, these sources became the major items for radiation control and water protection measures that were performed to greater or lesser extents during the period after the accident.

Problem of radionuclide drain and river contamination

The processes of radioactivity leaching into rivers with lateral flow in the water catchment territories was thought to be an important factor determining contamination spread over large areas beyond the ChNPP exclusion zone. However, amounts of radionuclides naturally washed-out from the surface of contaminated soil are low, reaching the level within several 1/10 to 1% of the overall amount of radioactivity in the rivers' basins. the majority of Ukrainian catchments, where soils are composed mainly of mineral particles, wash-out ratios for ^{137}Cs were $1–5 \cdot 10^{-2}$ m^{-1}. The wash-out ratio for ^{90}Sr on the same territories were in 3–5 times higher than for ^{137}Cs, but also did not exceed the upper limit of 10^{-1} m^{-1} [18, 19].

For these reasons, the processes of natural snow melting and rainfalls have not contributed significantly to a decline in the total amount of radionuclides in the catchments over nearly 20 years, and they also did not cause any noticeable secondary contamination of the water systems. The rate of decrease of water contamination with ^{137}Cs in the river Prypiat was higher than for ^{90}Sr. Considerable increase of contamination levels in the exclusion zone rivers, including also the river Prypiat, was observed only in periods of high floods and water logging of the contaminated floodlands (Fig. 2.2.8).

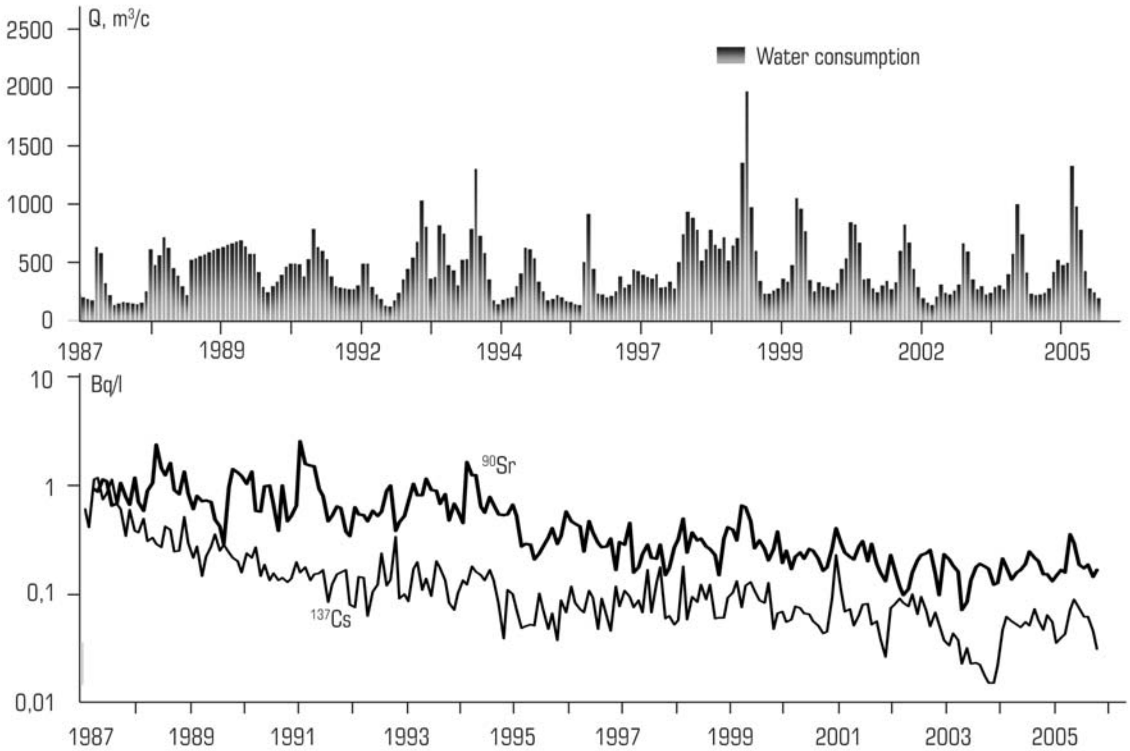

Fig. 2.2.8. The level of ^{90}Sr and ^{137}Cs in the river Prypiat, near Chornobyl town, taken from monitoring data (average monthly data)

During the years after the accident (except 1986, when contamination was formed at the expense of direct radioactivity fall-out on the surface of the water body), the ^{137}Cs water drain was formed primarily beyond the exclusion zone of the ChNPP on the territory of Belarus, and after 1992 its contribution to the formation of the Dnipro water system contamination was insignificant. That was an important reflection of the self-rehabilitation effect of contaminated water catchments and the processes of fixing ^{137}Cs in the soils (Fig. 2.2.9).

At the same time, during all the years after the accident, radio-strontium drain into the Dnipro water reservoirs was formed primarily in the ChNPP exclusion zone at the expense of mainly filtration drain from the reservoirs, drainage from water logged polder lands and water logging of the rivers' floodlands.

Considerable decrease of radioactive drain into the river at the expense of implemented specific water protection measures after 1993 in the flood lands and reclamation systems in the vicinity of the ChNPP also influenced the formation of the modern sufficiently stable trend of contamination decrease in the river Prypiat. In the recent decade, the biggest levels of Dnipro water contamination with ^{90}Sr were observed in 1999 and were caused by water logging processes in the contaminated floodlands of the river Prypiat in the zone near ChNPP because of the non-finished second water protection anti-flood dam on the right bank of the river Prypiat [20]. After full completion of its construction in 2003, the probability of water logging of the most contaminated territories of the ChNPP zone has considerably decreased.

Radioactive contamination of lakes and water reservoirs

Initial contamination of lakes and water reservoirs was primarily due to aerosol fall-out and migration of radionuclides from adjacent territories through slope drainage. Radionuclide concentrations in the lakes and water reservoirs decreased at a high rate during the first year after the fall-out, but this varied considerably depending on the water balance of the system. In some cases, the level of radioactive contamination remained high during the entire post-accident period. This is illustrated by the behaviour of ^{137}Cs in closed reservoirs when it interacts with the organic soil of water catchments and bottom sediments. In the closed reservoirs of the ChNPP exclusion zone elevated levels of contamination with ^{90}Sr due to its leaching into the water from fine particles of nuclear fuel have been observed over the past decade. Moreover, the process of radionuclides turnover in closed reservoirs formed seasonal fluctuations of radionuclide migration in the system [21 and 22].

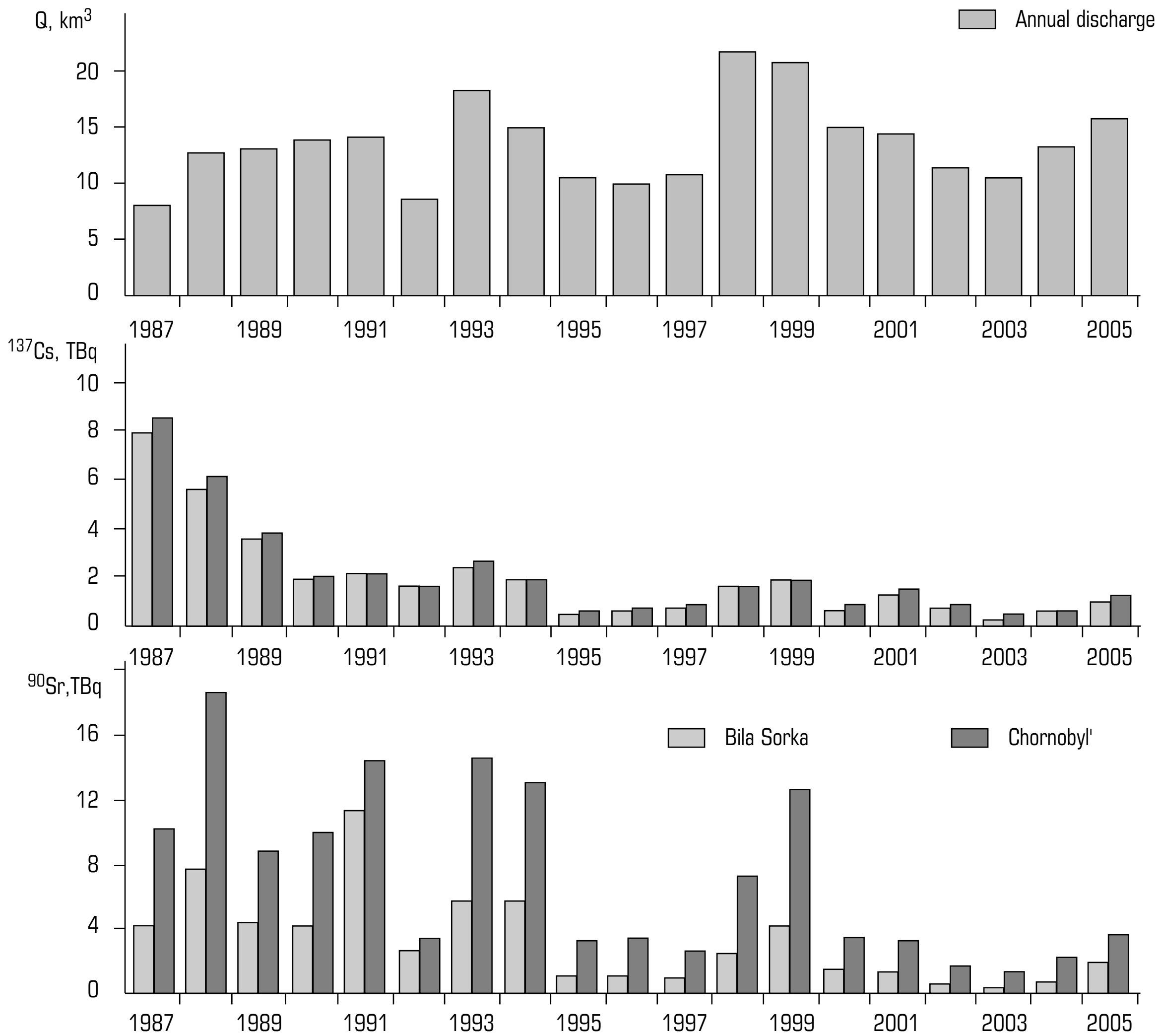

Fig. 2.2.9. Balance of ^{137}Cs and ^{90}Sr in water drains formed in the water catchments of the ChNPP exclusion zone

Closed water reservoirs in contaminated floodlands, the ChNPP cooling pond and artificial water reservoirs were created during the construction of hydro-technical installations or due to inefficient drainage systems in waterlogged areas, are the most contaminated lakes of the exclusion zone. Lake Hlyboke, the ChNPP cooling pond and artificial reservoirs of water logged areas in the basins of the rivers Sahan, tract Rodvino, etc. are typical examples of such water bodies in the exclusion zone.

The lake Hlyboke is a special water system. It is located at the most contaminated site of the left-bank floodland of the river Prypiat at a distance of several kilometres from the ChNPP. A considerable amount of the destroyed reactor fuel particles have been preserved in the lake catchment and in the bottom sediments even 20 years after the accident. Destruction and filtration of radionuclides from nuclear fuel particles are the main source of lake high level radioactive contamination with ^{90}Sr in the range of 100–200 Bq/l, which has not decreased, but increased over the past years.

The ChNPP cooling pond is the biggest of the closed reservoirs with the area of more than 22 km^2 and water volume up to 149 million m^3, which was contaminated with radioactive fall-out during the accident as well as discharges from the ChNPP industrial site. According to the experimental studies in 2005, the reservoir had accumulated nearly 288 TBq ^{137}Cs, 42.5 TBq ^{90}Sr and 0.74 TBq ^{239}Pu + ^{240}Pu (mainly in the bottom sediments). As of today, the major part of the activity has been accumulated in the deep-water of the reservoir (Fig. 2.2.10).

Annual transfer of ^{90}Sr into the river Prypiat from the reservoir is only a little percentage of this radionuclide drain with the river flow in the recent years. The present concentration of ^{137}Cs in the reservoir water mass is driven by seasonal phytoplankton biomass fluctuations in the reservoir [23].

If the pumping station prevents the regular replenishment of water lost due to filtration and evaporation, the water levels in the reservoir will gradually drop and reach the same levels as in the river

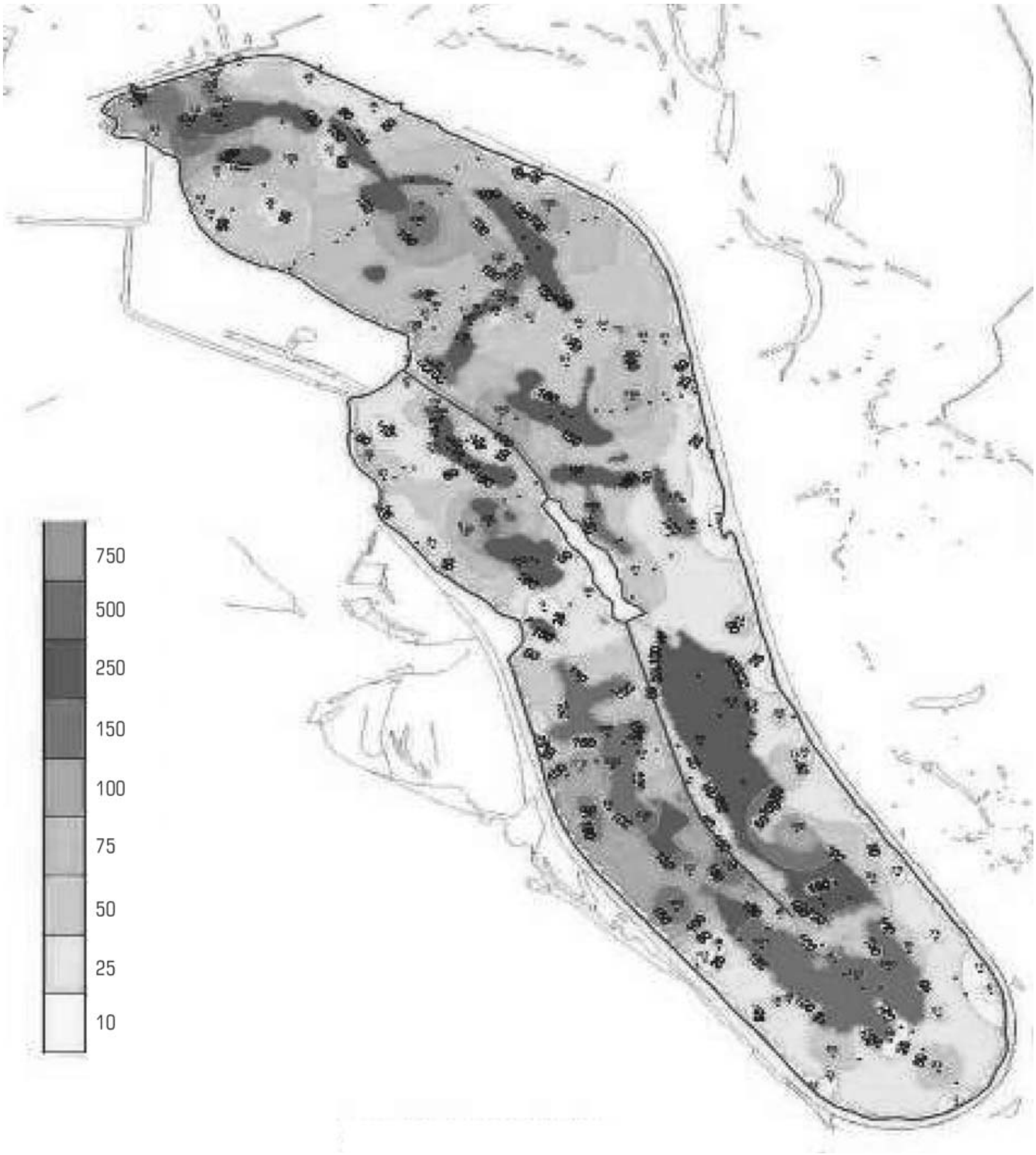

Fig. 2.2.10. Aerial distribution of ^{137}Cs (kBq/kg) in the bottom sediments of the ChNPP cooling pond as of 2003

Prypiat. In 3–5 years after the water pumping is stopped, infiltration from the reservoir will stop and the contaminated bottom of the reservoir will be exposed to possible wind lift and wind transfer. As the reservoir is emptied it will therefore get transformed into a system of separated reservoirs, in which the water levels will vary depending on the season and weather conditions. Although the uncovered beds, including areas with high levels of contamination will experience wind erosion, the latest research indicates that neighbouring territories will be only minimally affected when sediments will be quickly covered with plantations. Thus, even if no further preventive measures are taken, the former ChNPP cooling pond separated by a protection dam, will not contaminate adjacent territories [24].

The present state of reservoir, the implementation of different strategies in discharging water from the ChNPP, and the implementation of different rehabilitation measures have been considered by a number of international projects. The results of these projects will be used to plan the optimal and safe management of this reservoir in the ChNPP exclusion zone.

Dnipro reservoirs. Reservoirs of the Dnipro hydro project were initially contaminated by radioac-

tive aerosols that settled on the water surface, and also by the river flow. During transference, radionuclides travelling with the river flow get redistributed in the system between the water and the bed through sedimentation. The process of ^{137}Cs leaching and its geochemical fixing, are the major factors of water system purification. Leaching also explains why minimal ^{137}Cs reached the Black Sea. ^{90}Sr became the dominant radionuclide in the reservoir of water masses, and ^{137}Cs is prevailing in the bottom sediments. A quantitative estimation of contamination of the reservoir beds was carried out nearly 10 years ago and, we can assume that these indicators have not really changed. This is because of the decrease of radionuclide quantity in the reservoirs due to their physical decay and washing away to the Black Sea has been partially compensated by radionuclides incoming with the river flow from the basin water catchment [20 and 25]. Due to active sedimentation, only a small amount of ^{137}Cs which come into the water masses, reaches the reservoirs of the Dnipro lower stream. For example the contamination levels of the Kakhovsky reservoir in 2004–2005 had almost returned to the pre-accident levels of 1986. From the other side, ^{90}Sr decreases in 30–40% along the Dnipro water system with increasing distance from the ChNPP. This is primarily due to dilution with clean tributaries. ^{90}Sr reaches the Black Sea without considerable accumulation in the bed sediments (Fig. 2.2.11).

Radionuclides in marine ecosystems

The total amount of ^{137}Cs in atmospheric precipitation on the Black and the Azov seas water surface are estimated to be 2.8 PBq for the whole sea surface. This is the double amount of ^{137}Cs that entered the water surface because global nuclear fall-out from nuclear explosions (3.1 PBq) [26–28].

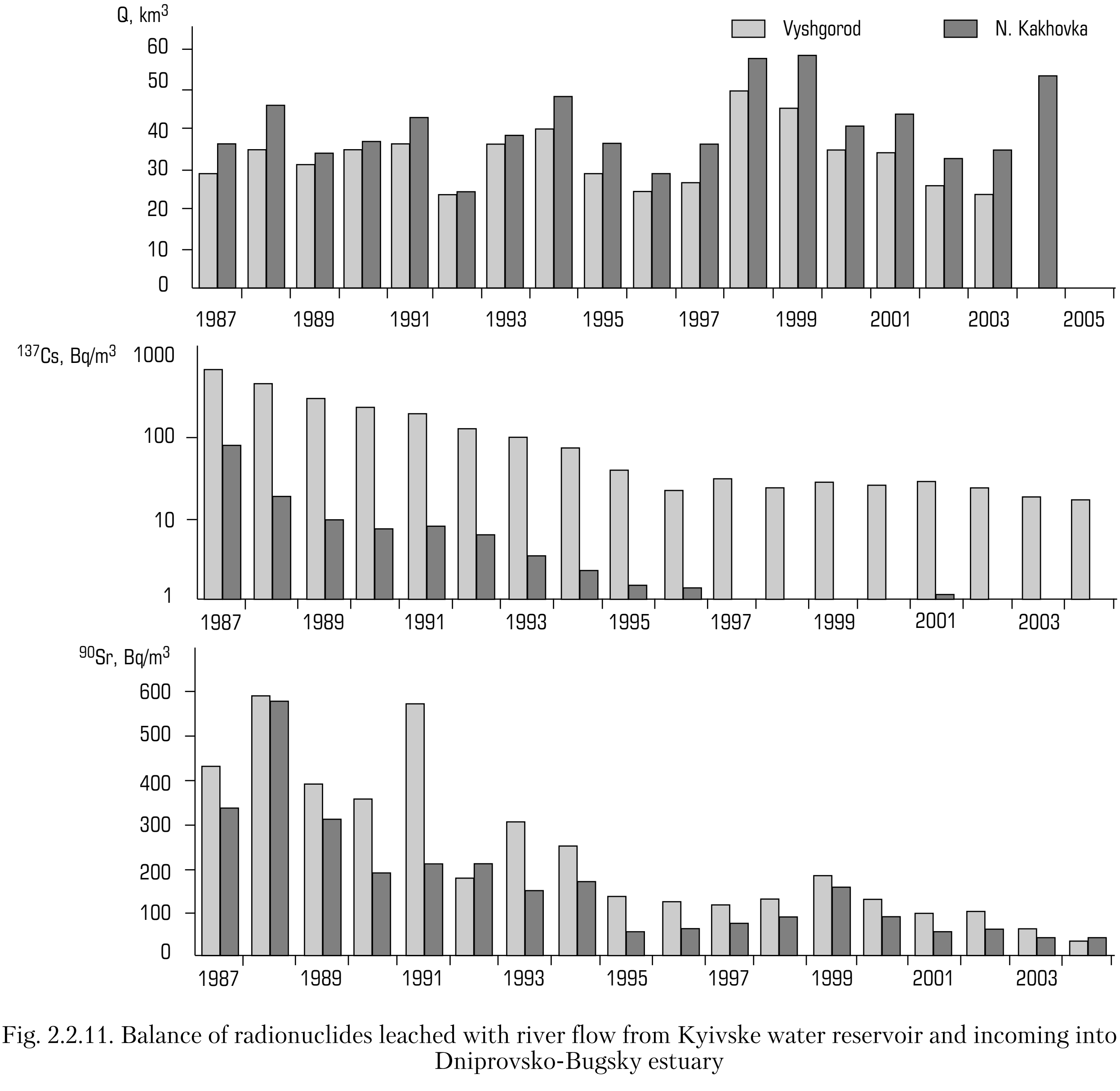

Fig. 2.2.11. Balance of radionuclides leached with river flow from Kyivske water reservoir and incoming into the Dniprovsko-Bugsky estuary

According to extensive Ukrainian and international research, it has been found that sea contamination peaked during early May 1986 in the range of 15–500 Bq/m^3. In autumn 1986 the dynamic processes of water mass movements had balanced this range to 40–70 Bq/m^3 [27]. In 15 years, the present levels of sea contamination have been shown to decrease to 20–35 Bq/m^3 [28].

By comparing the dynamics of Chornobyl-derived radionuclide accumulation in the sea basin from 1950–60s (on the basis of Ukrainian monitoring data), the concentrations of ^{137}Cs in the deep water sediments of the Black Sea can be traced up to 2000 m in depth (Fig. 2.2.12). In the cover layer of soil 0.8–1.0 cm in depth, the peak of the Chornobyl-derived radionuclide can be seen whilst in the layers 1.5–2.5 cm in depth, the contamination traces can be attributed to the nuclear weapons tests.

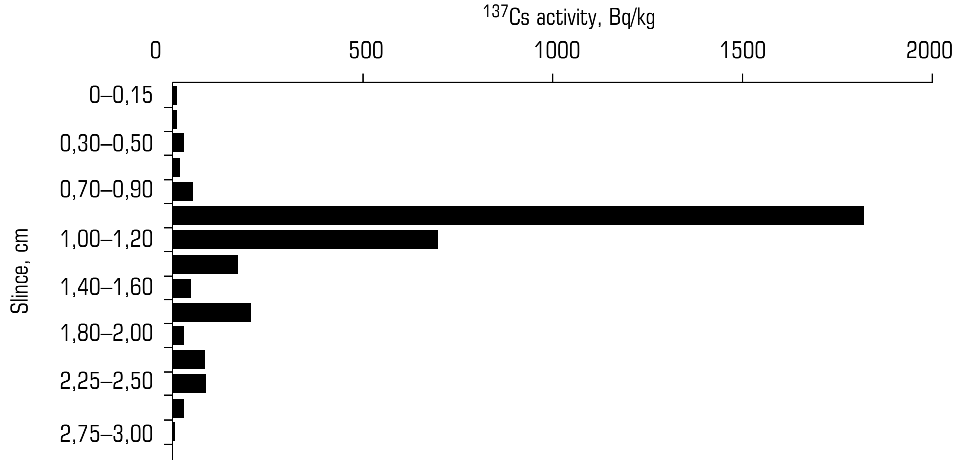

Fig. 2.2.12. Vertical profile of ^{137}Cs in the bottom sediments of the central part (from the depth of 1650 m) of the Black Sea

After the ChNPP accident, additional movement of radionuclides with river waters was insignificant compared to the initial contamination due to fall-out and atmospheric precipitation [25].

In addition to atmospheric precipitation, addition of aerosols containing ^{90}Sr and its transfer to the sea with river waters increased the amount of accumulated ^{90}Sr in the sea by 19% after the period of nuclear weapons tests to reach 1760 TBq [27 and 28]. Today, the amount of radionuclides in the sea continues to decrease due to physical decay of radionuclides and due to the partial transfer of radioactivity into sea deep zones. However, according to the Institute of Biology of Southern Seas at NASU, a great amount of radioactivity is still concentrated in the upper layer of the Black Sea (0–100 m in depth). In the Azov Sea, radionuclides tend to be distributed uniformly over the water surface and accumulated in the bottom sediments in concentrations which are slightly higher than the pre-accident levels.

Bioaccumulation of Chornobyl-derived radionuclides in the Black Sea hydro-bionts was negligible in comparison with the freshwater systems due to higher concentrations of competing ions in the sea water. Typical levels of radionuclide accumulation in the molluscs were 1–2 Bq/kg for ^{137}Cs, ^{90}Sr and $1.6–2.5 \cdot 10^{-3}$ Bq/kg for $^{239,240}Pu$. The levels of the Black Sea anchovy contamination during 1999–2003 in different zones of the sea coast did not exceed 1–3 Bq/kg for ^{137}Cs and 0.1–0.7 Bq/kg for ^{90}Sr. No biological effects of contamination have been recorded [28].

Radionuclides in ground water

The largest network to monitor the status of ground water was built in the ChNPP exclusion zone. Areas monitored included those near to stationary and interim storage facilities for radioactive waste and to objects of special hydro-technical construction. Further areas included the ChNPP industrial site, in places of temporary accommodation of the staff working in the ChNPP exclusion zone and at sites where radiation background was already being monitored [29]. According to the monitoring results, ground water contamination levels, in general, are relatively low, they range from 0.1 (and less) – 1.0 Bq/l for ^{137}Cs and 1–10 Bq/l for ^{90}Sr at the most contaminated areas, excluding those areas where radioactive storage facilities are located and where drains from the contaminated reservoirs and from the ChNPP industrial zone flow are filtered. The speed of contaminated ground water spread in the direction of their discharge pathways into rivers is slow, even for ^{90}Sr [30].

In general, ground water contamination has not became a severe problem in the vicinity of the exclusion zone and in adjacent territories, as was expected from the most conservative forecasts in the

first years after the accident. Expert reviews have indicated that even if local population return to their former villages in the exclusion zone and use the wells and contaminated places to get drinking water, the exposure doses are low in comparison with external radiation factors and with the doses received after eating local food[31].

The cumulative drains of radionuclides into the rivers of the exclusion zone together with ground water discharges are, and will remain in the future, relatively low in comparison with radionuclides contained in surface run-off from contaminated territories. Thus, ground water discharges do not present any substantial radiation risk for the Ukrainian population residing beyond the ChNPP exclusion zone [30 and 31].

In recent years, relatively high levels of water contamination – sometimes exceeding the MAC for drinking water up to even hundreds of times have been observed only in the vicinity of radioactive wastes storage facilities that have been constructed without special anti-filtration geo-chemical or other engineering barriers. In some boreholes along the ground water flow of the «Red Forest» area, levels of ^{90}Sr in contaminated water were 100 and even up to 1000 Bq/l in 2004–2005. Some specific areas of the territory with highly reflected depressive morphological relief forms are the exclusion.

According to the forecasts, the ground water front with the highest rate of contamination, which has been integrated in the ChNPP exclusion zone, will start to discharge into the river Prypiat no earlier than in 50 years period (Fig. 2.2.13).

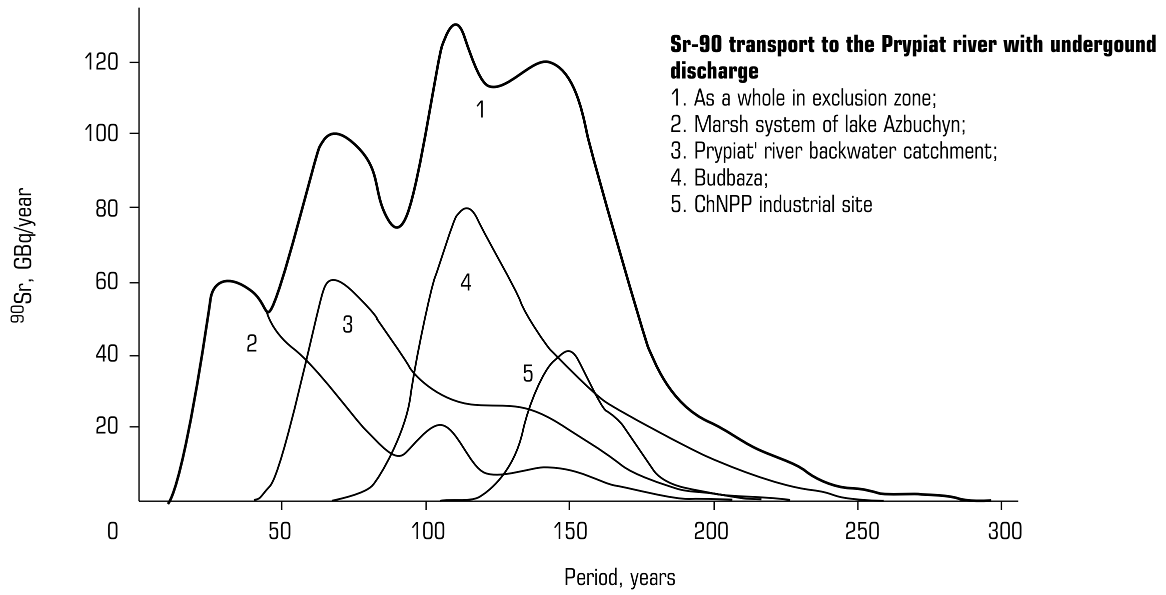

Fig. 2.2.13. Forecasts of ^{90}Sr carry-over with the ground water flow formed within the boundaries of the ChNPP exclusion zone [29]

During the next years, the maximum discharge should amount to 100–120 GBq (3.0–3.5 Ci). In comparison with the expected flow of surface water contaminated with 90Sr, its carry-over with the ground water would not be higher than 10–15%.

After the cooling pond is emptied, which is expected to commence approximately between 2007 and 2010, the flow of contaminated water from the ChNPP industrial area will be moderated, and there could be a slight contamination of the Dnipro water system with radionuclides that have been accumulated under the ChNPP destroyed reactor #4 and in the ground water nearby. Model calculations carried out by M. Zheleznyak and S. Kiva, indicate that the ground water flow from the zone of the present-day object «Shelter» is highly unlikely to reach the river Prypiat, because even in a 100-year period, the front of ^{90}Sr will not spread by more than 600 m.

2.3. Radiation monitoring

Currently, the radiation monitoring network is concentrated under the auspices of Ukrainian Ministry of Emergencies, which, using the capabilities of State Hydro meteorological Service, carries out monitoring of the entire Ukrainian territory. In the exclusion zone, monitoring is done by company «Ecocenter». Besides, subunits of the company «Energoatom» carry out scheduled regulated surveys around the nuclear power engineering facilities.

Since the ChNPP accident, the system of radiation monitoring in Ukraine has not yet received

proper legislative, regulatory and therefore efficient financial support. In December 2004, the Ukrainian Cabinet of Ministers approved the Concept of the Environmental Monitoring Program, but the Program of Monitoring Implementation, including radiation monitoring, has not become a legislative act, therefore, in the next two years it will be financed by the residual principle.

The system of monitoring especially, control of the quality of products which are manufactured on the contaminated lands, is more developed, but a large reduction of financial support in the past decade has effectively ruined the developed network of radiation monitoring on contaminated territories, especially in the agricultural sphere. The remained funds do not consider the changes in ownership forms occurring in the agricultural sector (Section 6 will provide a more detailed description about it).

2.3.1. Gamma-radiation exposure rate (ER)

Determination of gamma-radiation ER on the Ukrainian territory is carried out daily at 179 stations of the state Hydrometeorological radiometry network (in 1986, there were 205 stations), 10 of which are on the territory of radioactive contaminated zones. The gamma-background on the most of the Ukrainian territory is within 5–22 μR/year, which is close to natural levels. At monitoring stations on the contaminated areas with ChNPP emissions, the gamma background has been 6–31 μR/year, whilst the maximum levels outside the exclusion zone have been registered in the town of Korosten (31 μR/year). Present-day values of ER are as follows: the ChNPP industrial site 300–25 000 μR/year, Chornobyl town 20–50 μR/year, «Dytyatky» company 20 μR/year.

Against a background of declining ERs, seasonal variations occur, including a decrease in ER during the cold season. Local minima correspond to periods when the snow cover is at the highest level. In zones within 100 km of other nuclear power plants, the gamma-radiation ER was: Zaporizhska NPP – 5–19 μR/year, South-Ukrainian NPP – 7–19 μR/year, Rivnenska NPP – 8–18 μR/year, and Khmelnytska NPP – 7–18 μR/year.

In Kyiv, the gamma-radiation ER fluctuates in the course of a year within 7–17 μR/year, with a 12 μR/year annual average, i. e. it is within the natural background limits.

2.3.2. Radioactive contamination of the atmospheric near-surface layer

Secondary uplift of radioactive elements from earth's surface by wind is currently the main way in which radionuclides come into the atmosphere all over Ukraine.

According to recent monitoring data, the total beta-activity of atmospheric aerosols at the majority of monitoring stations was 0.075–0.179 mBq/m^3. Spatial activity of ^{137}Cs in the air over the country territory has exceeded 0.006–0.007 mBq/m^3 (excluding 2002 when the rather dry and hot summer and beginning of autumn provided growth of air overall radioactivity).

Near-surface radiation monitoring indicates that outside the boundaries of the object «Shelter» there is an increase in the amount of inhalation particles formed there during the process of dust formation.

The presence of longstanding fogs decreased radionuclide concentrations in the near-surface atmospheric layer as was illustrated in November 2000 when all monitoring stations simultaneously registered a similar minimal value of ^{137}Cs in comparison with the data for the whole period of monitoring, regardless of the surface contamination density.

In recent years, air ^{137}Cs concentrations remained considerably lower (by several orders) than the admissible levels set by NRBU-97 for persons of Category «B» (0.8 Bq/m^3).

The concentration of ^{90}Sr in atmospheric aerosols (by date of the Hidrometeorological monitoring network) is, on average, an order of magnitude lower than ^{137}Cs. In recent years, the concentration of ^{90}Sr across wide territories has been 0.0001–0.0012 mBq/m^3, which is comparable with pre-accident levels[1], but in the ChNPP exclusion zone the air ^{90}Sr concentrations are nearly three times higher than the pre-accident value, on average, 0.0021 mBq/m^3 per year. A maximum concentration of ^{90}Sr of 0.0031 mBq/m^3 was observed in Chornobyl. Overall for the country, ^{90}Sr concentration in the atmospheric air is also considerably lower than MAC air, set by NRBU-97 (0.2 Bq/m^3).

2.3.3. Radioactive contamination of atmospheric precipitation

Annual anthropogenic radionuclide fall-out from atmosphere is registered at the majority of monitoring stations and indicators did not fluctuate greatly in comparison with recent years. The average

[1] Annual concentration of ^{90}Sr in 1985 was 0.0008 mBq/m^3.

amount of ^{137}Cs fall-out in recent years in Ukraine is 5–6 Bq/m^2 per year; for ^{90}Sr, the average value is 2.2–2.3 Bq/m^2.

Annual density of ^{137}Cs fall-out on the great part of Ukrainian territory changed within 1.8–13.2 Bq/m^2; at the monitoring stations, located in the contaminated zones, where the density of soil contamination with cesium-137 is i 5 Ci/km^2 (Korosten and Chornobyl), the concentration of ^{137}Cs in the fall-out exceeded the average national level by more than 4-fold and was equal to nearly 24 Bq/m^2 per year.

The density of ^{137}Cs and ^{90}Sr fall-out in Kyiv remains higher than at the rest of the monitoring stations (except in the contaminated zone). In Kyiv, there are specific conditions, whereby technogenic contamination sources typical for a large industrial centre are combined with natural processes of secondary wind migration of radionuclides against a background of post-Chornobyl soil contamination (^{137}Cs 0.63 Ci/km^2, ^{90}Sr 0.32 Ci/km^2). The lowest ^{137}Cs density in fall-out has been registered in the southern part of Ukraine (on average, 0.15 Bq/m^2 per month).

Overall for Ukraine, the concentration of ^{137}Cs in atmospheric precipitations still remains higher than during the last pre-accident year[1]. The ratio of total ^{137}Cs annual fall-out to values of 1985 at the majority of monitoring stations is about 1.3–9.2. In the contaminated zone this ratio exceeds 15.

The current radiometric network covers the entire Ukrainian territory and helps monitor major factors that influence the radioactive contamination of atmospheric precipitations. A large number of monitoring stations is located in zones of influence of operating NPP along borders with neighbouring countries, and in the zone contaminated by the ChNPP accident. The other sampling points are located in big industrial cities.

2.3.4. Staff training for the radiation monitoring system

One of the most important problems during any radiological accident is the availability of specialists and their readiness to activate the system of environmental radiation monitoring and radiation control over agricultural and forest products. Extension courses are one of the most effective measures to train radioecologists and radiometry operators. A special faculty set up in 1987 at Kyiv State University was one of the first educational institutions of such type. This institution trained more than 600 radioecologists annually, and it ensured strict radiation controls over agricultural products produced on the territories contaminated because of the ChNPP accident. Before 1999, that educational institution also provided a facility for retraining specialists through the award of a Diploma in the second higher education in the specialty «Radioecology». Nearly 20 specialists were trained there.

Also in 1987, a separate department and later – a radiological centre within the Institute for Skill Upgrading at the Ukrainian State Committee on the Food Processing Industry was set up. Before 1990, the Radiological Centre mainly trained dosimetrists, radiometry operators and laboratory assistants.

Extension courses for managers and specialists from different ministries, departments and executive committees of the local Councils who worked in the sphere of radiation monitoring, was carried out in accordance with the Ukrainian Law «On Education» and the Cabinet of Ministries Decree № 156-r of 16.03.1992.

In 1994, the former Ministry of Ukraine of Emergencies and Affair of Population Protection from the ChNPP Accident consequences set up a Ukrainian Radiological Training Centre (URTC). By Ministry of Emergencies order, specialists from different enterprises: Ucoopspilka, Ministry of Ecology and Natural Resources, State Committee on Geology, State Committee on Forests, State Committee on Water Resources, State Committee on Food Processing Industry, State Committee on Standards, etc., extended their skills.

At the URTC, lectures from leading scientists and specialists from NASU, Kyiv National University, Ukrainian Research Institute of Agricultural Radiology, Ministry of Health, etc., were presented to students who attended classes on the topics: physical foundations of radioactivity, interaction of radiation exposure with matter, methods of registering ionizing exposure, biological actions of ionizing exposure, basics of radioecology, radiation monitoring, appliances and methods of environmental radioactivity measuring, radiation protection and norms of radiation safety, etc.

During the 12 years of the Centre's existence, more than 1000 specialists from the radiation control branch have thus extended their skills. Nearly 70 specialists went through retraining courses (receiving a Diploma in second higher education in the specialty «Radioecology»), who were mainly students of Taras Shevchenko Kyiv National University. Sixty of these are now working in their new specialty. On average, nearly 200 specialists are trained and get certification annually.

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[1] Annual total fall-out of ^{137}Cs and ^{90}Sr concentrations on the territory of Ukraine, Northern Caucasus and Moldova in 1985 was 1.43 Bq/m^2 and 9.02 Bq/m^2, correspondingly [11].

For today, Ukraine has many educational educational institutions where one can receive necessary training in the area of radioecology and radiometry in a short period of time. Some higher educational establishments have launched training courses for ecologists which give only general knowledge on radioecology, and do not focus on radiometry. Together with URTC and Ukrainian State Committee on Food Processing Industry, other higher educational institutions, NASU institutions, branches of departmental educational establishments train radioecologists.

In the National Agrarian University of Ukraine there is a Department of Agricultural Radiology, and students of biology specialties receive a course of radiobiology. In the State Agro-Ecologic University of Ukraine (city of Zhytomyr), beginning from 1991, training of students in the programs «Radiobiology», «Radioecology» and «Radiology» has started, and beginning from 1999, a new specialty has been introduced there – «Radioecology».

Radioecologists of the highest level (D. Sc., PhDs) are trained at the National Agrarian University of Ukraine, State Agro-ecological University of Ukraine (Zhytomyr) and at the Ukrainian Research Institute of Agricultural Radiology of the Ukrainian Agrarian University.

3. EXPOSURE DOSES TO UKRAINE'S POPULATION RESULTING FROM THE CHORNOBYL ACCIDENT

Four main cohorts, exposed as a consequence of the Chornobyl accident, can be identified:

– Recovery workers (civilian and military) who, in 1986 and 1987, were involved in clean-up operations at the ChNPP, its industrial site and within the 30-km zone;

– Population who, in May 1986, were evacuated from the towns of Prypiat and Chornobyl, and other settlements in the 30-km zone;

– Population who are living in contaminated territories; and

– Children and adolescents who received high thyroid doses in 1986.

We consider the reconstructed doses received by the ChNPP clean-up workers (also known as «liquidators») and evacuees, as well as internal and external doses to population living in contaminated territories.

Exposure doses to population are based on the data of dosimetric monitoring of ^{131}I activity in thyroid gland (over 150,000 direct measurements) and ^{137,134}Cs content in residents' organism (near 30,000 WBC measurements) carried out in 1986, and data of large-scale ecologic and dosimetric monitoring since 1987 to 2005: over 800,000 WBC measurements and over 300,000 measurements of ^{137,134}Cs content in cow milk produced in private farms have been done.

3.1. ROW exposure doses

The clean-up workers at the ChNPP (also known as «liquidators») are one of the most numerous and exposed cohorts. However, the situation with ROW exposure remained vague for a long time. Thus, among the ROW of 1986-1990, who were included in the State Registry of Ukraine of the Persons Affected by Chornobyl Accident (SRU), only about half of them have individual dose records. The validity of available dosimetry records as well as the evaluation of overall success, or failure, of the radiation protection system during accident recovery operations remains unclear [1].

Over the last five years, a large number of activities were concieved and implemented. These activities were focused on clarification of the actual exposures of liquidators as well as making retrospective evaluation of the results of dosimetric control at the time of recovery operations (RO).

3.1.1. Status of information on doses to liquidators

From the viewpoint of quality and level of coverage of cohorts by dosimetry monitoring, five periods can be distinguished (Table 3.1.1).

Table 3.1.1

Periods of RO dosimetry

Period	Time interval	Characteristic
Pre-accident	1978–26.04.1986	Normal functioning of the ChNPP dosimetry service in compliance with radiation safety regulations NRB-76
Initial	26.04.1986 – about 10.05.1986	Failure of ChNPP dosimetry service; using wartime approaches to dosimetry monitoring of troops
Interim	About 10.05.1986 – 01.06.1986	Simultaneous functioning of ChNPP and military dosimetry services; introducing an individual exposure limit (250 mGy); setting up AC-605 with its own dosimetry service
Main	June-October 1986	Functioning of dosimetry services of ChNPP, AC-605 and Ministry of Defence (MD) units based on different approaches
Routine	After November 1986	Simultaneous functioning of dosimetry services of ChNPP, AC-605, IA «Combinat» and MD units. Gradual return to normal operation, and decreasing dose limits (1987–1988)

These dosimetry services started to work at different times after the accident, covered different cohorts and, above all, used fundamentally different approaches to evaluating ROW exposure. Therefore, the completeness, quality and validity of their dosimetry data differ significantly (Table 3.1.2).

The best organised was dosimetry monitoring of personnel from Administration of Construction № 605 (AC-605) of the USSR. Ministry of Medium Machinery (MMM), a specialised construction organisation set up for erecting the sarcophagus (Shelter Object). The result of its well organized activ-

ities was 100% coverage with individual TLD monitoring of over 20,000 AC-605 employees, the majority of whom were sent by MMM enterprises located in Russia.

Table 3.1.2

Major dosimetry services, which performed ROW dosimetry monitoring

	Service	Subordinate to	Activity period	ROW coverage	Data quality
1.	ChNPP dosimetry monitoring service	Ministry of Power Engineering and Electrification of the USSR; since July 1986 p.– Ministry of Atomic Energy of the USSR	May 1986 – till present	ChNPP staff and personnel temporary assigned to ChNPP	Fair to high (depending on post-accident period)
2.	MD units	Ministry of Defence of the USSR	May 1986 – late 1990	Military liquidators	Low
3.	AC-605 dosimetry monitoring department	Ministry of Medium Machinery of the USSR	June 1986 – 1987	Civilian and military construction workers of AC-605	High
4.	IA «Combinat» dosimetry monitoring department and its successors	Ministry of Atomic Energy of the USSR	November 1986 – till present	Civilians who worked in the 30-km zone beyond the ChNPP industrial site	Satisfactory

Dosimetry monitoring performed by the ChNPP radiation safety service during the early post-accident weeks can be characterised as a failure (when standard dosimetry instruments turned out to be unfit for measuring high dose levels), followed by gradual restoring of a quality dosimetry monitoring (in June-July 1986). An adverse impact of ChNPP's standard dosimetry monitoring service failure to adapt rapidly to accident conditions was that the exposure doses of «early liquidators» – evidently, are the highest among all liquidators - remained unknown. As a result, completeness of ChNPP personnel dosimetry data was insufficient (including monitoring data coverage for each liquidator during the entire recovery operations period). This was the prime reason of the urgent need in reconstructing individual exposure doses. On the whole, during 1986–1996, the ADR estimate method was used to evaluate 1,600 individual doses of ChNPP staff and persons provisionally assigned to the plant. Since July 1986, dosimetry monitoring and recording individual doses was conducted duly at ChNPP, and this dosimetry information is characterised by high quality and completeness.

Dosimetry monitoring of civilian personnel (permanent and temporally assigned) who worked in the 30-km zone was largely not conducted during 1986 and part of 1987 due to organisational problems until this function was gradually taken over by the Administration of Dosimetric Control of IA «Combinat» / RIA «Prypiat'». Hence, data on doses of this cohort (especially in 1986–1987) are characterised by incompleteness and low quality at times.

The largest liquidator cohort are military liquidators: professional servicemen, conscripts (at the initial stage) and, the majority, persons enlisted to the army from the reserve. The significance of this cohort is important because about 95% of official dose records (ODR) in the SRU belong specifically to military liquidators. Such a situation with coverage of military liquidators with ODR is a result of both 100% coverage of this cohort with dosimetry monitoring and the features of registering dosimetry information in the SRU – by dose certificates (for servicemen – an insert into the military service card), which all servicemen had on hand, but very little civilian liquidators had. At the same time, along with exemplary coverage, dosimetry monitoring of military liquidators was characterized by the lowest accuracy of individual exposure doses because of crude and inaccurate methods of evaluating doses. For military liquidators, the dosimetry monitoring methods used most often was group based (i. e. one dosimeter per group) and group estimates (i. e. the dose for all group members was estimated beforehand based on the dosimetry situation and scheduled work period). During retrospective analysis of accuracy and deviations of dose estimates for military liquidators, it was found that, on the average, the doses preliminarily estimated by these methods exceed real exposure levels by 2-fold, and the geometric standard deviation is very high and equal to about 2.2. No evidence was found to support the widespread interpretation of the anomalous distribution of individual doses of military liquidators as proof of adulterating dosimetry information to make reports on servicemens exposure levels match current dose limits (250, 100 or 50 mSv). Statistical evaluations suggest that the probable contribution of invalid (adulterated) dose records does not exceed 10% of the total number, whereas the distributions of untypical forms (the scant left part and an abrupt drop at doses exceeding the limit) match the fairly uncommon practice of managing doses [3] when persons who received the maximum admissible dose were dismissed, and they were replaced with new reservists.

On the whole, dosimetry monitoring applied to different groups of liquidators and the system of radiation protection of cohorts involved in ChNPP recovery operations allowed compliance with existing exposure dose standards and limits. Wide-scale overexposure of liquidators was characteristic only for the initial stage of the accident and had involved a fairly limited group of so-called «early» liquidators. Later on (since late May 1986), dosimetry monitoring ensured, on the whole, adequate radiation protection of many thousands, whereas cases of exceeding established exposure dose limits (250 mSv in 1986 and differentiated limits 100 and 50 mSv later on) were rare and occurred, as a rule, as indicated in existing SRS-76 specifications.

3.1.2. Retrospective reconstruction and verification of individual ROW exposure doses

Insufficient coverage of liquidators with dosimetry monitoring as well as incompleteness and inaccuracy of current dose records make it critical to perform a retrospective estimate of individual exposure doses received by liquidators.

To date, the most accurate and unbiased method of retrospective dosimetry is EPR (electron paramagnetic resonance) dosimetry with tooth enamel. The metrological parameters of the SCRM EPR-dosimetry protocol (sensitivity threshold – 50 mGy, error +25 mGy at low doses or 10% at doses exceeding 250 mGy) are, apparently, the best among all methods of retrospective estimate of individual doses [4 and 5]. Such an advantage in accuracy and objectivity of the EPR method allows using it as the so-called «golden standard», i. e. as a reference against which other retrospective dosimetry methods can be checked [6].

The key factor that places limits on using EPR-dosimetry is lack of samples for analysis – teeth extracted from liquidators. To overcome this obstacle, Ukraine has developed an efficiently functioning system of collecting teeth[1], which are extracted from liquidators for medical reasons. The teeth are collected and stored in the Central Bank of Biosamples for dosimetry applications. As of late 2005, a total 7,544 teeth of liquidators had been collected and are being stored. The teeth collection network covers seven Oblasts of Ukraine (Dnipropetrovska, Zaporizhska, Poltavska, Kharkivska, Cherkaska, Chernihivska and Kyivska). 314 dentists and 167 dentistry establishments are participating in collecting teeth. Fig. 3.1.1 shows the time pattern of collecting teeth in Ukraine as a whole with a breakdown

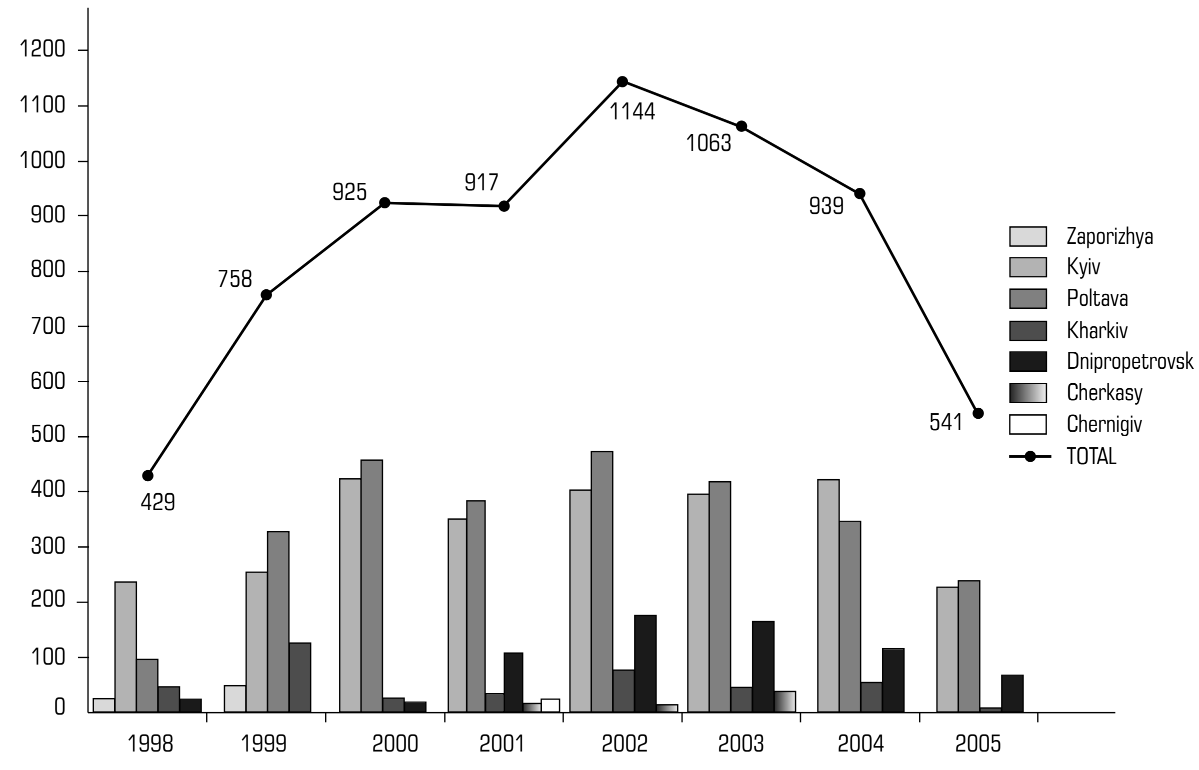


Fig. 3.1.1. Time chart of collecting ROW teeth and depositing them with the Central Bank of Biosamples for dosimetry applications

[1] This system has no analogs in the world and, in addition, it is functioning practically without any budget expenditures (it had been supported by international projects, in particular, the French-German Initiative «Chernobyl» and the Ukrinian-American project on studying leukemia among liquidators).

for each Oblast. The rate of collecting teeth has declined over recent years because the International «French-German Initiatives» Project has been completed and funding of this activity has been suspended.

Another method of individual retrospective dosimetry, which was developed in recent years, and is being employed with success for reconstruction of individual doses of liquidators, is RADRUE (Realistic Analytical Dose Reconstruction and Uncertainty Analysis) – an time-and-motion method developed jointly by experts from Ukraine (SCRM and ChNPP), Russia (Institute for Biophysics), the USA. (National Cancer Institute), and France (International Agency for Cancer Studies).

A distinctive feature of this method, which is based on interviewing liquidators, is analyses of the validity of answers by a dosimetry expert, and using extensive databases on the radiation situation in recovery operation sites, is that it can be applied without exception to any liquidator, including deceased persons (by interviewing proxies - colleagues and relatives). In total, this method was applied to reconstruct doses for 1,010 liquidators. The range of liquidators' exposure doses in 1986–1990 was from «about zero» to 3.2 Gy, the mean arithmetic dose being 90 mGy (the geometric mean was 12 mGy). Such a wide range of doses reflects the fact that the liquidator cohort is exceptionally heterogeneous and includes, along with persons who were exposed significantly in the first post-accident days, also personal services staff or persons who visited the 30-km zone during short-time assignments. The exposure dose to separate occupational categories among liquidators somewhat differ (Table 3.1.3). Thus, the Ministry of Internal Affairs employees (who had fewer chances to effectively influence exposure levels) and nuclear energy professionals (NPP personnel and AC-605 workers) received relatively higher exposure doses. It should be emphasised that the latter group (nuclear energy professionals) also includes the so-called «early liquidators», i. e. persons among ChNPP personnel who were exposed at the initial accident stage when no effective radiation protection and dosimetry monitoring system was yet in place.

Table 3.1.3

Results of reconstructing individual doses by the RADRUE method for separate professional liquidator categories (data of Ukrainian-American study of leucaemia among liquidators)

Category	Number	Average dose (mGy)	Median dose (mGy)	Geometric standard deviation
Military (total)	218	76	54	2.1
Breakdown by years of participating in RO				
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
Nuclear energy professionals	35	381	277	1.78
MIA personnel	27	203	173	1.86
Assigned persons	340	70	48	1.95
Drivers	213	64	41	1.99

These findings are in good accord with results of an independent review of official dose records and qualitative considerations regarding the features of dosimetry monitoring of servicemen during RO.

The behaviour of irradiation doses to servicemen-liquidators over years (Table 3.1.3) adequately reflects the evolution of the radiation situation in the 30-km zone and steady decline in doses during 1987–1988. It should also be stressed that, on the average, the doses of military liquidators are significantly lower than the values officially registered and common in public opinion.

3.1.3. Lens irradiation

During recovery operations, the doses of remote beta-irradiation were virtually unmonitored (due to a limited available technological and methodical base). However, the Chornobyl' mix of radionuclides comprised a wide gamut of hard beta-radiators (^{144}Pr, ^{106}Rh, and ^{90}Y), which could form significant doses of remote beta-irradiation of open skin areas and the lens. The large scale dose reconstruc-

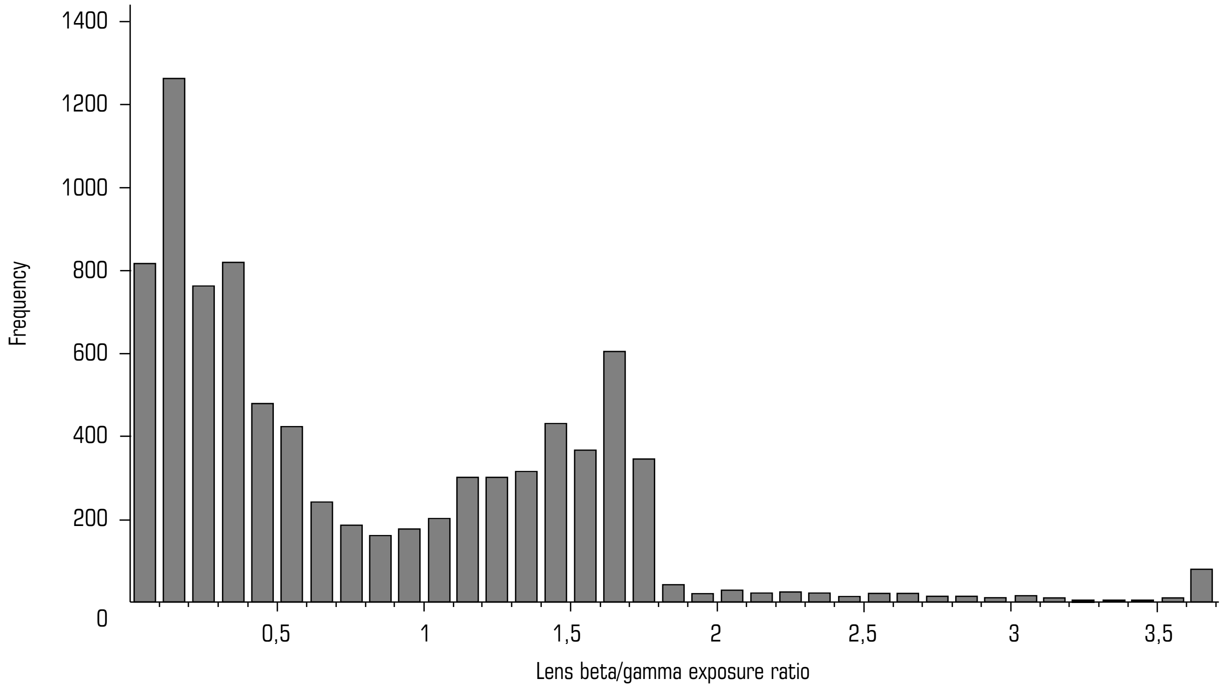


Fig. 3.1.2. Distribution of beta irradiation dose and gamma irradiation dose ratio for 8607 subjects of the Ukrainian-American Chornobyl Ocular Study (UACOS)

tion study of individual beta-doses to lenses of 8,607 liquidators [6] was performed in the framework of Ukrainian-American Chornobyl Ocular Study (UACOS) by the researches of Scientific Center for Radiation Medicine AMS Ukraine in collaboration of the Institute of Occupational Medicine AMS Ukraine (principal contractor of UACOS). Although the final goal was estimation of total (beta+gamma) lens doses, the relation between gamma and beta doses is quite informative (Fig. 3.1.2). It was found that, in about 32% of monitored subjects, the beta exposure doses were higher than respective gamma-doses (i. e. the integral lens exposure dose was more than twice higher than the estimated gamma-dose alone) [6]. At the same time, in about 53% of subjects, the beta irradiation doses do not exceed one-half of the respective gamma irradiation dose (Fig. 3.1.2). The so-called «early liquidators» received the highest exposure doses.

3.2. Evacuees' doses

3.2.1. External doses to persons evacuated from settlements in the 30-km zone

Individual effective doses of external exposure were reconstructed and analysed for representative groups of evacuees from the 30-km zone: 12 632 Prypiat' residents and 14 084 residents from the settlements in the 30-km zone. These evacuees represent 104 settlements in the 30-km zone, including the towns of Prypiat' and Chornobyl'; 223 residents from the Belarus part of the 30-km zone, who lived in 40 settlements, were also polled and included in the total number of surveyed persons. The high level of coverage of evacuees with this stochastic modelling technique (individual doses were assessed for 25% of Prypiat' residents and 35% of residents in remaining settlements in the 30-km zone) allows making substantiated inferences on irradiation parameters, in particular, average and collective doses to respective cohorts, and also to evaluate the maximum probable exposure doses by means of 95 percentile dose distributions.

The average effective dose to Prypiat's residents, which was accumulated by the time of evacuation, was 10.1 mSv. The estimated collective external exposure dose to this cohort was 500 man-Sv. The doses to about 4% of evacuees from Prypiat' (534 persons of those 12 632 surveyed) exceeded 25 mSv, and only 18 persons (from this group) received doses higher than 50 mSv. The maximum value of the effective dose for this group of Prypiat' residents was 75 mSv.

Individual doses were also estimated for 14 084 persons who were evacuated from settlements in the 30-km zone. The estimate covered the period from the beginning of the accident and till the time of evacuation beyond the 30-km zone. The average value of the effective dose for this group (about 35% of all evacuees) was 15.9 mSv. The estimated collective external exposure dose for all the population in the 30-km zone (excluding Prypiat') was 640 man-Sv. Among the study group, doses to 1260 persons

(9%) exceeded 50 mSv. For 120 (0.85%) persons, the effective doses were higher than 100 mSv, and only for one person of the dose exceeded 200 mSv (214 mSv).

3.2.2. Internal exposure doses

Conservative estimates of the internal exposure component have shown that, by inhalation (town of Prypiat'), the total effective exposure dose to evacuees (without account of thyroid exposure) is less than or can be equal to the external exposure component (i.e. the integral dose can be 2 times higher than the external component). In those places where evacuation was delayed for 10–15 days (villages in the 30-km zone), and a significant contribution was made by oral intake of Chornobyl radionuclides, internal exposure could have exceeded the external one by 2 to 4-fold.

3.2.3. Exposure doses received along evacuation routes

The exposure doses to the majority of Prypiat's residents received in course of evacuation turned out to be within 11–19 mSv, which is comparable with pre-evacuation exposure of the population. On the average, the evacuees received 52±19% of the dose during evacuation. At this, the standard evacuation route in the direction of Polis'ke, which was provided for by emergence preparedness plans, was not optimal. For instance, if Prypiat's residents were evacuated in the direction of Bila Soroka (Belarus direction), the evacuation doses would contribute to only 6% of the integral dose.

Hence, accounting for the dose received along the evacuation route has a fairly strong impact on the overall pattern of evacuees' exposure, and the selection of the evacuation route had a decisive influence on additional exposure doses to evacuees.

3.3. Exposure doses to population in radiocontaminated territories

3.3.1. External exposure doses to population in radiocontaminated territories

A density of ^{137}Cs fallout from Chornobyl, which exceeds 37 kBq/m^2, has been registered in about 48 400 km^2 of contaminated territory in Ukraine where more than 1.45 mln people live mostly in rural settlements (further referred to as RS) (Fig. 3.3.1).

The average external exposure doses for different territories have been estimated in the range of 1.4–15 mSv for 1986; 3.8–40 mSv for the first 20 years following the accident; and 5.2–55 mSv for the 70-year post-accident period.

The exposure doses to residents of territories with a high fallout level (exceeding 555 kBq/m^2)

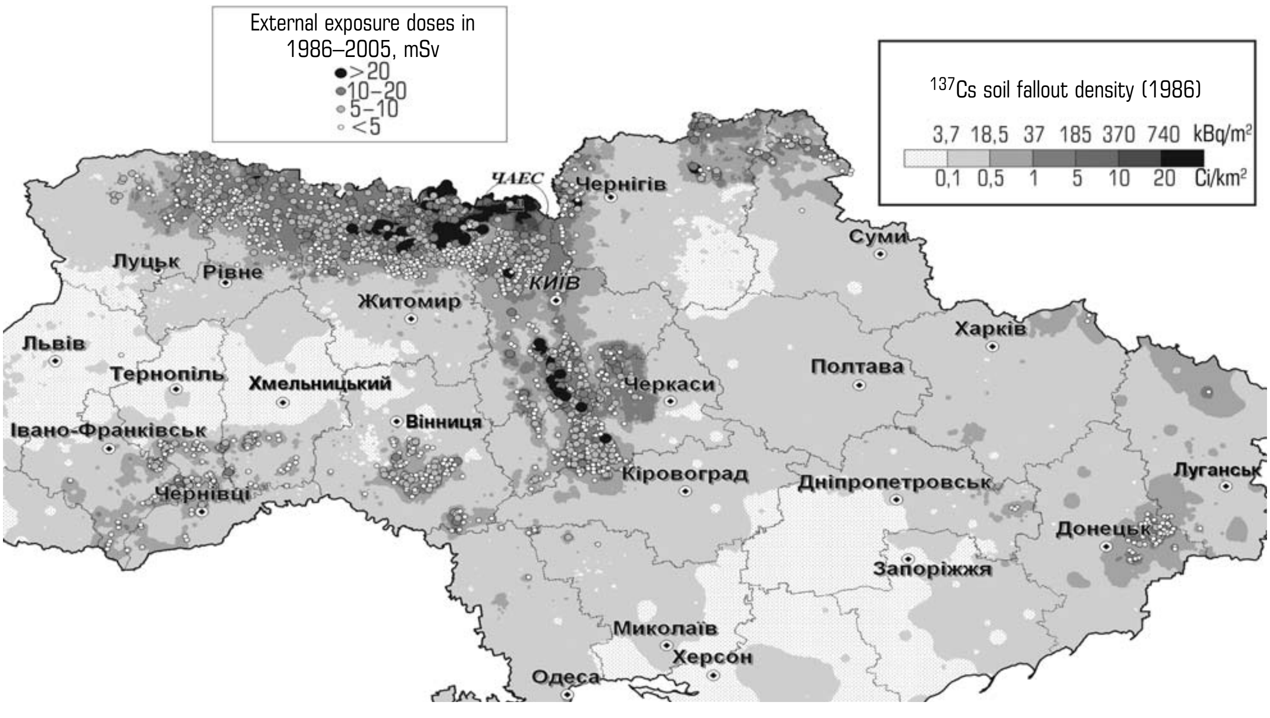


Fig. 3.3.1. RS areas with different average external exposure doses to population that have been accumulated over 20 years (1986–2005) in territories where ^{137}Cs soil fallout density exceeds 37 kBq/m^2

exceed the average exposure doses to inhabitants of territories with low (< 37 kBq/m^2) ^{137}Cs soil deposition by more than 50-fold [7–10].

Population breakdown by intervals of average external exposure doses

The average external exposure doses to inhabitants of RS where the levels of ^{137}Cs fallout are lower than 37 kBq/m^2 will not exceed 1 mSv even in 70 years. Table 3.4 summarises data only for population in territories where the ^{137}Cs fallout level exceeds 37 kBq/m^2, viz. roughly 94% of the population (more than 1.36 mln residents) in 1986 and about 54% of the population (780 000 residents) during 1986–2005 received external exposure doses, which do not exceed 5 mSv. At the same time, doses exceeding 10 mSv in 1986 were received by about 18 400 residents who live in 35 RS. Doses exceeding 10 mSv over 20 years (1986–2005) were received by about 194 000 residents of 344 RS. Among the latter RS, there are such where the external exposure dose over 20 years has exceeded 50 mSv. External exposure of the population after 2005 will contribute little to the dose that has been received over the past 20 years.

Table 3.3.1

Breakdown of residents in RS and urban villages in Ukraine with ^{137}Cs soil fallout density exceeding 37 kBq/m^2 vs. intervals of external exposure doses accumulated in 1986 and during 1986–2005, and doses predicted for 70 years (1986–2055)

Dose intervals (mSv)	Years											
	1986				1986–2005				1986–2055			
	No of residents		Number of RS		No of residents		Number of RS		No of residents		Number of RS	
	'000*	%	RS	%	'000*	%	RS	%	'000*	%	RS	%
<1	97	6.7	20	1.1	–	–	–	–	–	–	–	–
1–2	770	53.2	940	50.3	–	–	–	–	–	–	–	–
2–5	491	33.9	741	39.7	780	53.9	869	46.5	413	28.6	409	21.9
5–10	71	4.9	131	7.0	471	32.6	654	35.0	665	46.0	837	44.8
10–20	18	1.2	34	1.8	145	10.1	270	14.5	292	20.2	480	25.7
20–50	0.36	0.03	1	0.1	49	3.4	72	3.9	71	4.9	128	6.9
50–100	–	–	–	–	0.6	0.04	2	0.11	5.1	0.35	13	0.70
Total	1446	100	1867	100	1446	100	1867	100	1446	100	1867	100

* Rounded values.

Collective external exposure dose to the rural population in Ukraine

Based on estimates of average external exposure doses for each RS, as well as with account of information on the population, the collective external exposure dose accumulated by the rural population of Ukraine during the early and mid phases of the accident (1986–2005) was calculated [7] (Table 3.3.2). The collective external exposure dose for 1986–2005 (for RS where the ^{137}Cs soil fallout density exceeds 37 kBq/m^2) is 200 man-Sv. The major contribution (~65%) to the collective dose is attributed to persons whose average external exposure dose over 20 years has been within the interval of 2–10 mSv. The collective dose to 49 000 inhabitants of villages and urban settlements whose average dose over 1986–2005 has exceeded 20 mSv (the share of these inhabitants in the breakdown of the entire population is about 3.4%) accounts for a 14% contribution to the collective dose to the entire population. It is these residents (from 73 RS in northern Ukraine) that have to be considered as the critical group when conducting different medical and epidemiological surveys.

Collective external exposure dose to urban population

The collective external exposure dose accumulated over 20 years following the accident by residents of towns and cities located in territories where ^{137}Cs ground fallout density had exceeded 37 kBq/m^2 was 19 000 man-Sv.

Table 3.3.2

Breakdown of the collective dose accumulated over 1986–2005 by residents of RS and urban villages (at $\sigma_{0,j}^{CS}$ ≥ 37 kBq/m^2) vs. intervals of average external exposure doses accumulated during this period

Average dose interval (mSv)	Collective dose (man-Sv)	Population ('000)	% of total	
			Collective dose	Population
2–5	2785	780	30.3	54
5–10	3226	471	35.1	33
10–20	1838	145	20.0	10
20–50	1312	49	14.3	3.4
50–100	37	0.6	0.40	0.04
Total	9198	1446*	100	100

* Rounded values.

3.3.2. Average and collective internal exposure doses to population in the Kyivska, Zhytomyrska and Rivnenska Oblasts due to consuming radiocaesium-contaminated food products

The internal exposure doses to the population of the three most affected Oblasts in Ukraine (Kyivska, Zhytomyrska and Rivnenska) result from high levels of radiocaesium fallout and high factors of radiocaesium transfer from soil to plants.

On the whole, in 3793 RS in the Zhytomyrska, Kyivska and Rivnenska Oblasts, there live 765 000, 890 000 and 649 000 people, respectively. The majority of residents received doses within 5 mSv in 20 years: about 86% of the Zhytomyrska Oblast population; more than 99% of the Kyivska Oblast population, and less than 70% of the Rivnenska Oblast population [7, 8, 11, and 12]. Doses exceeding 10 mSv in 20 years were received by about 8% of the population living in 236 RS in the three mentioned Oblasts (from 0.3% in the Kyivska Oblast to 17% in the Rivnenska Oblast). The Rivnenska Oblast is distinguished by a fairly large share of residents whose internal exposure dose over 20 years was 5–10 (about 16%), and even 10–20 mSv (14%). In the Kyivska Oblast, the percentage of population with a dose of 10–20 mSv is only 0.22%, and that for the Zhytomyrska Oblast is 4.0%.

The collective exposure dose to population of the Kyivska, Zhytomyrska and Rivnenska Oblasts, which was accumulated during 1986–2005 due to consuming food products contaminated with accident-source radiocaesium was 5915 man-Sv [7 and 12]. At this, the collective internal exposure dose to the Rivnenska Oblast population is 55% of the collective dose estimated for all three Oblasts (despite the fact that the rural population in this Oblast accounts for only 28% of the total population living in these three Oblasts); the rural population of the Kyivska Oblast accounted for about 39%, and the population of the Zhytomyrska Oblast accounted for 33% of the total collective internal exposure dose to the population of the three most affected Oblasts in Ukraine. 6.9% of the population (158 800 residents in 229 RS) in three Oblasts with doses 10–50 mSv and 7.3% of the population with doses 5–10 mSv account for 48% and 20%, respectively, of the total collective internal exposure dose; 67% of the population (over 1.5 mln residents) with doses within 1 mSv over 20 years contributed to less than 13% of the collective dose.

3.3.3. Effective exposure doses to population in regions of general-dosimetry certification

Since in rural settelements, which are officially [13–15] considered to be radio-contaminated, general-dosimetry certification was conducted in 1991–2005, separate estimates of internal, external and total exposure doses were carried out for different post-accident periods for regions where the mentioned RS are located, viz. 73 regions in 12 Oblasts of Ukraine. In estimating the average exposure doses for regions, which are given below, not only RS where general-dosimetry certification was conducted were taken into account [16], but all the RS in the region being considered as well.

Average effective external and internal exposure doses for 1986

Conventionally, internal radioiodine exposure was considered separately, and was not accounted for in the total effective dose for 1986. This stemmed from Ukraine's concept of radiation protection of population in the post-accident period. However, dose estimates both with account of iodine radioisotopes and without this source were made in regions where general-dosimetry certification was conducted since 1991 (Table 3.3.3).

Table 3.3.3

Average effective external and internal exposure doses to population in regions of general-dosimetry certification in 1986

Oblast, Raion		^{137}Cs in soil, kBq/m²*	No. of RS	No. of residents	Average exposure doses, mSv			
					External	Internal		
						^{131}I	^{137}Cs	$^{131}I + {}^{137}Cs$
Vinnytska	Haisynsky	17	63	44 900	0.47	0.70	0.32	1.0
	Nemyrivsky	22	90	46 300	0.50	0.75	0.35	1.1
	Tomashpil'sky	28	33	32 000	0.69	1.0	0.48	1.5
	Tul'chynsky	43	51	45 000	1.5	2.2	1.0	3.2
Volynska	Kamen'-Kashyrsky	27	63	59 560	0.79	1.2	0.54	1.7
	Liubeshivsky	19	45	41 500	0.51	0.76	0.35	1.1
	Manevytsky	25	69	45 900	0.71	1.1	0.49	1.5
Zhytomyrska	Yemil'chynsky	41	119	40 070	1.3	0.99	0.46	1.5
	Korostensky	112	112	54 900	3.6	0.93	0.43	1.4
	Lugynsky	179	47	21 360	4.8	1.2	0.57	1.8
	Malynsky	52	104	28 050	1.4	1.0	0.48	1.5
	Narodytsky	395	79	20 680	12	3.5	1.6	5.1
	Novograd-Volynsky	15	108	52 610	0.34	0.39	0.18	0.57
	Ovrutsky	147	152	67 380	3.8	1.6	0.75	2.4
	Olevsky	94	55	39 300	3.0	0.82	0.38	1.2
Kyivska	Bilotserkivsky	58	60	51 500	1.1	0.86	0.40	1.3
	Boguslavsky	88	38	29 300	2.7	1.6	0.73	2.3
	Borodiansky	64	42	24 700	2.2	0.67	0.31	0.98
	Vyshgorodsky	69	56	47 400	1.6	0.58	0.27	0.84
	Ivankivsky	66	72	20 904	1.9	0.60	0.28	0.89
	Kagarlytsky	60	50	29 280	1.8	1.3	0.59	1.9
	Kyevo-Sviatoshin.	21	48	89 170	0.56	0.18	0.08	0.26
	Makarivsky	27	66	35 550	0.77	0.62	0.29	0.90
	Myronivsky	37	45	33 280	1.0	0.86	0.40	1.3
	Obukhivsky	27	43	26 700	0.72	0.65	0.30	0.95
	Polis'ky	279	40	9490	10	3.1	1.4	4.5
	Rokytniansky	106	20	25 550	3.5	2.0	0.91	2.9
	Taraschansky	91	34	30 520	2.7	1.8	0.82	2.6
	Fastivsky	20	46	33 960	0.59	0.58	0.27	0.9
Rivnenska	Beresznivsky	37	53	45 810	1.1	0.86	0.40	1.3
	Volodymyretsky	61	66	53 500	1.8	1.2	0.56	1.8
	Dubrovytsky	101	56	46 500	3.3	1.8	0.84	2.6
	Zarichnensky	67	49	29 180	1.9	1.2	0.55	1.7
	Rokytnivsky	79	38	42 290	2.3	1.4	0.63	2.0
	Sarnensky	53	62	56 970	1.6	1.1	0.52	1.7

Oblast, Raion		^{137}Cs in soil, kBq/m²*	No. of RS	No. of residents	Average exposure doses, mSv			
					External	Internal		
						^{131}I	^{137}Cs	$^{131}I + ^{137}Cs$
Cherkaska	Zvenygorodsky	71	39	40 300	2.2	3.3	1.5	4.8
	Kanivsky	44	54	33 700	1.5	2.3	1.1	3.4
	Katerynopil'sky	71	22	18 300	1.8	2.6	1.2	3.8
	Korsun'-Shevchenk.	41	55	34 500	0.94	1.4	0.65	2.1
	Tal'nivsky	54	41	29 910	1.4	2.1	0.97	3.1
Chernihivska	Kozeletsky	19	108	53 190	0.57	0.37	0.17	0.54
	Koriukivsky	17	79	21 400	0.37	0.44	0.20	0.64
	Ripkynsky	39	115	30 100	1.1	0.75	0.35	1.1
	Semenivsky	49	86	20 610	1.1	0.86	0.40	1.3
	Chernihivsky	31	125	68 800	0.62	0.85	0.39	1.2

* Weighted average value for raion.

The highest average external exposure doses were received by population in the rural areas of the Narodnytsky (12 mSv) and Polisky (10 mSv) raions of the Zhytomyrska and Kyivska Oblasts. This is attributed to a fairly high level of ^{137}Cs soil fallout in these regions.

Since vegetation contamination in 1986 was of the surface kind and it was determined by radioactive fallout levels, the reconstructed effective internal exposure doses to the population living in the Narodnytsky and Polisky raions were also the highest, viz. with account of iodine radioisotope contribution to the effective dose, these doses (over 256 days in 1986) were 5.1 and 4.5 mSv, respectively.

Average effective external and internal exposure doses in 1987–2005 and certain dose relationships

The territorial breakdown of regions of general-dosimetry certification in the Kyivska, Zhytomyrska and Rivnenska Oblasts by intervals of average external and internal exposure doses in 1987–2005 is different, viz. regions with the highest external exposure doses exceeding 10 mSv are located in the north of the Kyivska and Zhytomyrska (Narodytsky Raion) Oblasts, whereas regions where the internal exposure dose exceeds 10 mSv are located in the north of the Rivnenska Oblast.

In the majority of regions of the Zhytomyrska, Kyivska, Rivnenska and Chernihivska Oblasts (Table 3.3.4), the relative contributions of external and internal exposure doses (including ^{131}I exposure) to the total dose in 1986 are about identical (roughly 50%). However, since 1987, when vegetation contamination occurred via the root pathway (depending essentially on the types of soil), the rel-

Table 3.3.4

Relative (percentage) contributions of external (Ext) and internal (Int) exposure pathways to the total exposure dose during different periods of 1986–2005

Oblast, Raion		Years									
		1986		1987–1990		1991–2000		2001–2005		1986–2005	
		Ext.	Int.	Ext.	Int.	Ext.	Int.	Ext.	Int.	Ext.	Int.
Vinnytska	Haisynsky	31	69	93	7.0	91	9.0	93	7.0	54	46
	Nemyrivsky	31	69	94	6.0	92	8.0	94	6.3	54	46
	Tomashpil'sky	31	69	93	7.0	91	9.0	93	7.4	54	46
	Tul'chynsky	31	69	96	4.0	95	5.0	96	4.1	55	45
Volynska	Kamen'-Kashyrsky	31	69	12	88	10	90	12	88	14	86
	Liubeshivsky	31	69	8.0	92	6.0	94	8.0	92	10	90
	Manevytsky	31	69	12	88	10	90	12	88	15	85

Oblast, Raion		Years									
		1986		1987–1990		1991–2000		2001–2005		1986–2005	
		Ext.	Int.	Ext.	Int.	Ext.	Int.	Ext.	Int.	Ext.	Int.
Zhytomyrska	Yemil'chynsky	47	53	36	64	30	70	35	65	37	63
	Korostensky	72	28	85	15	81	19	85	15	79	21
	Luhynsky	73	27	52	48	46	54	52	48	56	44
	Malynsky	49	51	83	17	80	20	83	17	65	35
	Narodytsky	70	30	75	25	70	30	75	25	72	28
	Novograd.-Volynsky	38	62	56	44	49	51	55	45	46	54
	Ovrutsky	62	38	43	57	37	63	43	57	46	54
	Olevsky	71	29	54	46	47	53	53	47	57	43
Kyivska	Bilotserkivsky	47	53	92	8.0	90	10	92	8.3	68	32
	Boguslavsky	54	46	94	6.0	93	7.0	94	5.9	73	27
	Borodiansky	69	31	70	30	64	36	69	31	68	32
	Vyshgorodsky	66	34	81	19	76	24	80	20	73	27
	Ivankivsky	69	31	73	27	68	32	73	27	70	30
	Kagarlytsky	49	51	93	7.0	92	8.0	93	6.6	70	30
	Kyevo-Sviatoshin.	69	31	78	22	73	27	77	23	73	27
	Makarivsky	46	54	75	25	70	30	75	25	60	40
	Myronivsky	45	55	78	22	73	27	77	23	60	40
	Obukhivsky	43	57	88	12	85	15	88	12	63	37
	Polis'ky	69	31	79	21	74	26	79	21	74	26
	Rokytniansky	55	45	90	10	88	12	90	10	72	28
	Taraschansky	51	49	96	4.0	95	5.0	96	4.0	72	28
	Fastivsky	41	59	82	18	78	22	82	18	60	40
Rivnenska	Beresznivsky	47	53	30	70	25	75	30	70	33	67
	Volodymyretsky	51	49	31	69	26	74	31	69	34	66
	Dubrovytsky	55	45	34	66	29	71	34	66	37	63
	Zarichnensky	52	48	20	80	16	84	19	81	23	77
	Rokytnivsky	53	47	19	81	15	85	19	81	23	77
	Sarnensky	50	50	28	72	23	77	28	72	31	69
Cherkaska	Zvenygorodsky	31	69	97	3.0	96	4.0	97	2.8	55	45
	Kanivsky	31	69	96	4.0	95	5.0	96	3.8	55	45
	Katerynopil'sky	31	69	95	5.0	94	6.0	95	5.0	54	46
	Korsun'-Shevchenk.	31	69	90	10	88	12	90	10	53	47
	Tal'nivsky	31	69	93	7.0	92	8.0	93	6.8	54	46
Chernihivska	Kozeletsky	51	49	61	39	55	45	61	39	56	44
	Koriukivsky	36	64	45	55	39	61	45	55	40	60
	Ripkynsky	50	50	64	36	58	42	64	36	57	43
	Semenivsky	46	54	62	38	56	44	61	39	54	46
	Chernihivsky	33	67	62	38	56	44	61	39	46	54

ative contributions of both these pathways of exposure in different regions were found to be essentially different. In the majority of regions in the Vinnytska, Kyivska and Cherkaska Oblasts, and in several regions in the Zhytomyrska Oblast, the contribution of the external exposure dose to the total dose in 1987–1990, 1991–2000 and 2001–2005 exceeded 70%, and even 95%. At the same time, in all three

regions of general-dosimetry certification in the Volynska Oblast, and in all six regions of the Rivnenska Oblast, this contribution did not exceed 30%, and even 10%.

This is associated with high ^{137}Cs «soil-vegetation» transfer factors. At the same time, the regions of the southern and central parts of the Zhytomyrska and Kyivska Oblasts are characterised by chernozem soil, which made for the small contribution of the internal component to the total exposure dose. However, since the highest levels of radioactive fallout were in these territories, this resulted in high levels of external exposure doses received by the population in these territories.

Average total effective exposure doses in different periods of 1986–2005

Table 3.3.5 summarises the estimates of average total effective exposure doses received by residents (weighed by their number in each RS) living in regions of general-dosimetry certification for different periods during the post-accident years: 1986, 1987–1990, 1991–1993, 1994–2000, 2001–2005 and 1986–2005.

Table 3.3.5

Average total effective exposure doses received by the population living in regions of general-dosimetry certification during different periods following the Chornobyl accident

Oblast, Raion		Average total internal and external exposure doses, mSv					
		1986	1987–1990	1991–1993	1994–2000	2001–2005	1986–2005
Vinnytska	Haisynsky	1.5	0.41	0.15	0.22	0.10	2.4
	Nemyrivsky	1.6	0.43	0.16	0.23	0.10	2.5
	Tomashpil'sky	2.2	0.60	0.22	0.32	0.15	3.5
	Tul'chynsky	4.6	1.2	0.45	0.66	0.30	7.3
Volynska	Kamen'-Kashyrsky	2.5	5.3	2.5	3.4	1.3	15.0
	Liubeshivsky	1.6	5.0	2.4	3.3	1.2	13.6
	Manevytsky	2.2	4.6	2.2	3.0	1.1	13.2
Zhytomyrska	Yemil'chynsky	2.7	2.9	1.3	1.8	0.71	9.4
	Korostensky	4.9	3.4	1.3	1.9	0.82	12.3
	Lugynsky	6.6	7.4	3.1	4.4	1.8	23.3
	Malynsky	2.9	1.4	0.53	0.76	0.34	5.9
	Narodytsky	17	13	5.1	7.3	3.2	45.8
	Novograd-Volynsky	0.91	0.50	0.21	0.29	0.12	2.0
	Ovrutsky	6.2	7.1	3.1	4.3	1.7	22.4
	Olevsky	4.2	4.4	1.9	2.6	1.1	14.2
Kyivska	Bilotserkivsky	2.4	1.0	0.37	0.53	0.24	4.5
	Boguslavsky	4.9	2.3	0.84	1.2	0.55	9.8
	Borodiansky	3.2	2.5	1.0	1.4	0.62	8.7
	Vyshgorodsky	2.5	1.6	0.62	0.90	0.39	6.0
	Ivankivsky	2.8	2.1	0.85	1.2	0.52	7.6
	Kagarlytsky	3.6	1.5	0.57	0.83	0.38	7.0
	Kyevo-Sviatoshin.	0.81	0.58	0.23	0.33	0.14	2.1
	Makarivsky	1.7	0.82	0.32	0.46	0.20	3.5
	Myronivsky	2.3	1.1	0.42	0.60	0.26	4.7
	Obukhivsky	1.7	0.66	0.25	0.36	0.16	3.1
	Polis'ky	15	10	4.0	5.8	2.5	37.3
	Rokytniansky	6.3	3.1	1.2	1.7	0.76	13.1
	Taraschansky	5.3	2.2	0.82	1.2	0.54	10.1
	Fastivsky	1.4	0.58	0.22	0.32	0.14	2.7
Rivnenska	Beresznivsky	2.4	2.9	1.3	1.8	0.72	9.1
	Volodymyretsky	3.6	4.8	2.1	3.0	1.2	14.6
	Dubrovytsky	5.9	7.7	3.4	4.8	1.9	23.6

Oblast, Raion		Average total internal and external exposure doses, mSv					
		1986	1987–1990	1991–1993	1994–2000	2001–2005	1986–2005
Rivnenska	Zarichnensky	3.6	7.6	3.5	4.9	1.9	21.5
	Rokytnivsky	4.2	9.6	4.4	6.2	2.4	26.9
	Sarnensky	3.3	4.7	2.1	3.0	1.2	14.3
Cherkaska	Zvenygorodsky	6.9	1.8	0.66	1.0	0.44	10.8
	Kanivsky	4.9	1.3	0.48	0.69	0.31	7.7
	Katerynopil'sky	5.6	1.5	0.55	0.80	0.36	8.8
	Korsun'-Shevchenk.	3.0	0.84	0.32	0.46	0.20	4.8
	Tal'nivsky	4.5	1.2	0.45	0.65	0.29	7.1
Chernihivska	Kozeletsky	1.1	0.76	0.31	0.44	0.19	2.8
	Koriukivsky	1.0	0.65	0.28	0.40	0.16	2.5
	Ripkynsky	2.2	1.4	0.55	0.79	0.33	5.2
	Semenivsky	2.3	1.4	0.58	0.83	0.35	5.5
	Chernihivsky	1.9	0.81	0.33	0.47	0.20	3.7

The highest average total (external and internal) exposure doses (Table 3.3.5), which exceed 20 mSv in 20 years, were found in the population living in the Lugynsky and Ovrutsky Raions of the Zhytomyrska Oblast. These regions are characterised by fairly high average levels of ^{137}Cs fallout (150–180 kBq/m^2), which contributed to significant external exposure doses. Besides, the mixed kinds of soil in these regions make for the relatively high values of ^{137}Cs «soil-vegetation» transfer factors and, respectively, high internal exposure doses. Therefore the relative contributions of both these pathways to the average dose accumulated during 1986–2005 are about equal.

The average total exposure doses accumulated during 1986–2005, which exceed 20 mSv, were also found in the villages of the Dubrovytsky, Zarichnensky and Rokytnivsky Raions of the Rivnenska Oblast. The raion-average ^{137}Cs fallout density in the RS of these regions is 70–100 kBq/m^2, making for relatively low (less than 5 mSv for this period) external exposure doses.

The major contribution (80 and more per cent) to the exposure dose received by the inhabitants of these regions was made up by internal exposure due to consuming radio-contaminated food products made locally.

Collective exposure doses in different periods of 1986–2005

Table 3.3.6 summarises estimates of collective total exposure doses received by inhabitants of regions with general-dosimetry certification during different periods of 1986–2005, as well as the per-

Table 3.3.6

Collective total (external and internal) exposure doses received by the population in regions of general-dosimetry certification in different Chornobyl post-accident periods and per cents of the collective dose associated with external exposure pathways

Oblast, Raion		1986		1987–2005		1986–2005	
		Collective dose					
		man-Sv	%*	man-Sv	%*	man-Sv	%*
Vinnytska	Haisynsky	66.96	31	39.3	92	106.2	54
	Nemyrivsky	73.79	31	42.9	93	116.7	54
	Tomashpil'sky	70.15	31	41.3	92	111.5	54
	Tul'chynsky	208.87	31	118.4	96	327.3	55
Volynska	Kamen'-Kashyrsky	149.42	31	743.1	11	892.5	14
	Liubeshivsky	67.08	31	497.8	7.3	564.9	10
	Manevytsky	103.17	31	502.3	11	605.4	15

Oblast, Raion		1986		1987–2005		1986–2005	
		Collective dose					
		man-Sv	%*	man-Sv	%*	man-Sv	%*
Zhytomyrska	Yemil'chynsky	109.70	47	267.3	33	377.0	37
	Korostensky	269.83	72	403.6	83	673.4	79
	Lugynsky	141.18	73	357.5	50	498.7	56
	Malynsky	82.27	49	84.4	82	166.6	65
	Narodytsky	355.47	70	591.5	73	946.9	72
	Novograd-Volynsky	48.07	38	59.0	53	107.1	46
	Ovrutsky	416.61	62	1094.2	40	1510.8	46
	Olevsky	163.75	71	394.5	51	558.2	57
Kyivska	Bilotserkivsky	122.23	47	109.0	91	231.3	68
	Boguslavsky	144.81	54	142.7	93	287.5	73
	Borodiansky	78.18	69	137.9	67	216.1	68
	Vyshgorodsky	116.18	66	166.4	79	282.6	73
	Ivankivsky	59.13	69	98.8	71	157.9	70
	Kagarlytsky	106.71	49	97.3	93	204.0	70
	Kyevo-Sviatoshin.	72.63	69	113.2	76	185.9	73
	Makarivsky	59.34	46	64.1	73	123.4	60
	Myronivsky	76.43	45	78.4	76	154.8	60
	Obukhivsky	44.52	43	38.1	87	82.6	63
	Polis'ky	139.09	69	214.7	77	353.8	74
	Rokytniansky	162.26	55	171.8	89	334.0	72
	Taraschansky	160.83	51	146.5	96	307.4	72
	Fastivsky	48.85	41	43.0	80	91.9	60
Rivnenska	Beresznivsky	108.20	47	309.4	28	417.6	33
	Volodymyretsky	193.05	51	590.7	29	783.7	34
	Dubrovytsky	273.71	55	826.0	31	1099.7	37
	Zarichnensky	104.87	52	521.7	18	626.6	23
	Rokytnivsky	178.99	53	956.5	17	1135.5	23
	Sarnensky	187.58	50	625.3	26	812.8	31
Cherkaska	Zvenygorodsky	279.70	31	156.4	97	436.1	55
	Kanivsky	165.32	31	93.4	96	258.7	55
	Katerynopil'sky	102.27	31	58.6	94	160.9	54
	Korsun'-Shevchenk.	103.29	31	62.7	89	166.0	53
	Tal'nivsky	133.17	31	77.9	93	211.1	54
Chernihivska	Kozeletsky	59.52	51	90.0	58	149.5	56
	Koriukivsky	21.63	36	32.0	42	53.6	40
	Ripkynsky	65.69	50	91.1	62	156.8	57
	Semenivsky	48.20	46	65.3	59	113.5	54
	Chernihivsky	128.31	33	124.7	59	253.0	46

* Percentage of collective external exposure dose.

centage of the external exposure dose in the total collective dose. This percentage varies with region from 7% (Liubeshivsky Raion in Volyn') to 97% (Zvenygorodsky Raion in Cherkaska Oblast). The maximum contribution of external exposure (over 90%) has been estimated for regions in the Vinnytska Oblast and several regions in the Cherkaska Oblast. The minimum contribution has been estimated for regions in Volyn' (7–11%) and the Rivnenska Oblast (17–30%). The maximum collective doses were received by the rural population of the Ovrutsky Raion in Zhytomyrska Oblast, and of the Dubrovytsky and Rokytnivsky raions in the Rivnenska Oblast.

3.3.4. Average total and collective effective exposure doses received by the entire population of Ukraine, which were accumulated in 1986–2005

The maximum average effective total exposure doses in 1986 (Table 3.3.7) were estimated to be 2.1 mSv for the residents of the Zhytomyrska and Kyivska Oblasts. During 1987–2005, the maximum average total exposure doses received by the population in the Oblasts were as follows: Rivnenska (4.6 mSv), Zhytomyrska (3.9 mSv), Kyivska (2.8 mSv) and Volynska (2.9 mSv). Overall, during this period, the maximum cumulative total exposure doses were received by the population of the following Oblasts: Rivnenska (6.2 mSv), Zhytomyrska (5.9 mSv), Volynska (3.8 mSv), Kyivska (4.9 mSv) and Cherkaska (3.5 mSv).

Table 3.3.7

Average total (internal and external) exposure doses accumulated in different post-accident periods in Oblasts of Ukraine

Oblast	Population ('000)	Average doses, mSv			Collective dose, man-Sv		
		Years			Years		
		1986	1987–2005	1986–2005	1986	1987–2005	1986–2005
Vinnytska	1953	1.1	1.1	2.2	2233	2111	4345
Volynska	1047	0.88	2.9	3.8	920	3067	3987
Luganska	2832	1.3	1.8	3.1	3650	5085	8735
Dnipropetrovska	3810	0.71	1.3	2.0	2699	4885	7583
Donetska	5328	1.1	1.7	2.9	5892	9316	15 208
Zhytomyrska	1548	2.1	3.9	5.9	3213	5977	9189
Zakarpatska	1203	0.54	0.75	1.3	644	903	1548
Zaporizhska	2045	0.57	1.0	1.6	1161	2011	3172
Ivano-Frankivska	1375	1.2	1.2	2.4	1594	1667	3260
Kyivska	1874	2.1	2.8	4.9	3911	5253	9164
Kirovogradska	1233	0.86	1.0	1.9	1059	1283	2343
Autonomous Republic of Crimea	2005	0.61	1.0	1.6	1232	2017	3249
L'vivska	2671	0.53	0.87	1.4	1424	2336	3760
Mykolaivska	1301	0.61	0.88	1.5	799	1143	1942
Odes'ka	2656	0.81	1.0	1.8	2161	2692	4853
Poltavska	1732	0.76	1.1	1.9	1324	1916	3240
Rivnenska	1162	1.6	4.6	6.2	1870	5295	7165
Sumska	1425	0.93	1.3	2.2	1326	1819	3145
Ternopil'ska	1150	0.76	1.0	1.7	872	1103	1976
Kharkivska	3163	0.79	1.0	1.8	2487	3205	5692
Khersonska	1222	0.44	0.71	1.2	543	868	1411
Khmel'nytska	1528	0.77	1.0	1.7	1182	1474	2656
Cherkaska	1522	1.8	1.7	3.5	2781	2593	5374
Chernivetska	914	1.5	1.3	2.9	1410	1229	2639
Chernihivska	1427	0.95	1.4	2.3	1352	1959	3311
City of Kyiv	2469	1.1	1.6	2.7	2793	3941	6734
City of Sevastopol	381	0.90	1.1	2.0	342	422	764
Total	50 976	–	–	–	50 873	75 572	126 444

The residents of the Donetska Oblast received the highest collective doses in 1986–2005 (in excess of 15 000 man-Sv) because of the highest population in this Oblast rather than due to the radiation factor.

3.3.5. Absorbed thyroid doses to Ukraine's population due to radioiodine released from the accident source

Due to the ChNPP accident release, radioiodine fallout covered practically the entire territory of Ukraine. This became a source of internal thyroid exposure (by consuming radio-contaminated food products and via inhalation) for practically the entire population in Ukraine.

The levels of ^{131}I fallout in the territory of Ukraine were very irregular, and the Oblast-average values varied within 0.01 MBq/m^2 (Ivano-Frankivska Oblast) to 2.02 MBq/m^2 (Kyivska Oblast) [17 and 18]. The most contaminated territories (0.16–2.02 MBq/m^2) were the following northern Oblasts: Kyivska, Zhytomyrska, Rivnenska, Chernihivska, Cherkaska and Volynska (map chart in Fig. 3.3.2).

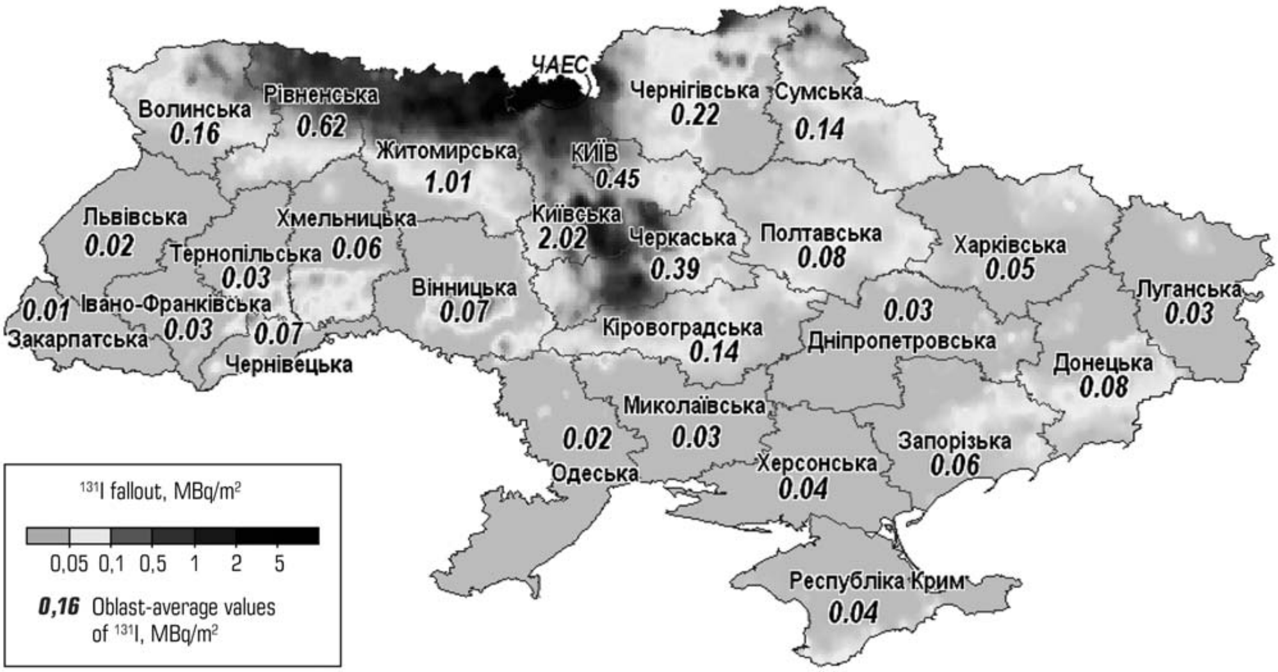


Fig. 3.3.2. Territorial distribution of cumulative ^{131}I fallout on the territory of Ukraine resulting from the ChNPP accident [17 and 18]

In May-June 1986, investigators made more than 150 000 direct measurements of radioiodine activity in the thyroid gland of people (mainly in children and adolescents) [19–21] who lived on the most affected territories in the Kyivska, Zhytomyrska and Chernihivska Oblasts.

By analysing and generalising the results of these measurements, and using radioiodine environmental migration models, investigators reconstructed the absorbed thyroid doses for residents in all inhabited localities of Ukraine [22–24]. Within each inhabited locality, 38 gender-age doses were estimated as follows: for each age group in the age interval of 0–18 years for boys and girls.

Group-averaged thyroid doses for residents in the northern regions of the Kyivska, Zhytomyrska and Chernihivska Oblasts

The most affected territories in Ukraine are 13 northern regions in the Kyivska, Zhytomyrska and Chernihivska Oblasts. The most affected (both from the point of view of exposure doses and possible radiological after-effects [25 and 26]) were children and adolescents at the time of the accident (Table 3.3.8).

Analysis of dose estimates has shown that, in the Zhytomyrska Oblast, the highest thyroid doses (5000–7000 mGy) were taken in by children and adolescents in four villages of the Narodytsky Raion: Nozdrysche, Nove Sharno, Khrystynivka, and Mali Min'ky. In the Kyivska Oblast, the highest thyroid doses (2000–4000 mGy) were received by children and adolescents in five settlements in the Polis'ky Raion: Varovychi, Kovshylivka, Klyvyny, Volodymyrivske, and Denysovychi, as well as in the village Horodchan in the Chornobyl'sky Raion (presently, the Ivankivsky Raion). For children and adoles-

Table 3.3.8

Average radioiodine thyroid doses (mGy) absorbed by children and adolescents living in Ukraine's northern regions in the Kyivska, Zhytomyrska and Chernihivska Oblasts

Oblast	Raion	Number of RS	Population of age 0–18 (1986)	Raion-average absorbed thyroid dose, mGy		
				Raion-average	Min*	Max*
Zhytomyrska	Korostensky	113	33600	221	37	1470
	Luhynsky	49	7500	318	79	1138
	Narodytsky	76	7000	1559	119	6879
	Ovrutsky	154	22700	533	82	2166
	Olevsky	60	19000	213	44	1259
Kyivska	Ivankivsky	67	7100	199	55	632
	Borodiansky	45	15600	161	52	797
	Vyshgorodsky	58	18400	263	69	757
	Kyevo-Sviatoshynsky	51	45200	51	22	128
	Makarivsky	63	10400	205	85	716
	Polis'ky	61	8100	778	16	7269
Chernihivska	Kozeletsky	107	16100	130	26	605
	Ripkynsky	112	9900	236	34	1471
	Chernigivsky	125	18200	427	43	6528

* Within region RS.

cents living in village Vesniane in the Polisky raion, the average thyroid dose was about 7300 mGy. In the Chernihivska Oblast, the highest thyroid doses (1500–7000 mGy) were absorbed by children and adolescents living in settlements in the Chernihivsky region: for the residents of villages Moskali, Mn'ov, and Skupari, these doses were in the interval of 1500–2000 mGy; for the village Tsentral'ne, the dose was 3200 mGy; and for the village Lokot'kiv, the dose was even as high as 6500 mGy. The average thyroid dose received by children and adolescents living in the cities of Kyiv, Zhytomyr, and Chernihiv was 53, 40 and 128 mGy, respectively.

Average thyroid doses to children and adolescents living in different Oblasts in Ukraine

In all Oblasts in Ukraine, the city of Kyiv and the Autonomous Republic of Crimea, the Oblast-average thyroid doses to children and adolescents were estimated separately for each 38 gender-age groups (weighted by the population of the gender-age group in a separate RS) (Table 3.3.9). It turned

Table 3.3.9

Average gender-age thyroid doses (mGy) for Oblasts in Ukraine. M – boys, F – girls

Oblast	Age in 1986 (years)											
	1-18		1		5		10		14		18	
	F	M	F	M	F	M	F	M	F	M	F	M
Kyivska	76	85	170	162	103	110	53	65	42	59	28	38
Chernihivska	54	62	120	121	74	82	37	45	32	39	20	28
Zhytomyrska	80	94	169	170	109	122	57	74	46	66	29	47
City of Kyiv	32	32	77	68	47	48	21	21	17	20	12	12
Cherkaska	49	61	112	117	70	79	34	48	26	44	18	28
Rivnenska	64	77	143	149	89	98	43	59	38	55	23	35
Khersonska	12	16	27	32	17	21	8	12	6	11	4	7
Kirovogradska	31	38	73	77	45	52	21	29	17	26	11	16

Oblast	Age in 1986 (years)											
	1-18		1		5		10		14		18	
	F	M	F	M	F	M	F	M	F	M	F	M
Vinnytska	13	16	29	32	18	21	9	12	7	11	5	7
Sumska	25	31	59	62	37	42	18	24	14	22	9	13
Poltavska	19	23	45	48	27	32	13	17	11	16	7	11
Dnipropetrovska	5	6	12	13	7	9	3	4	3	4	2	3
Khmel'nytska	14	18	31	35	19	24	10	14	8	13	5	8
Donetska	8	10	20	21	13	14	6	7	4	6	3	4
Chernivetska	14	16	32	33	20	21	9	12	8	11	5	7
Volynska	32	39	70	76	44	50	22	31	19	29	12	18
Ivano-Frankivska	7	8	15	16	9	10	5	6	4	6	2	4
Mykolaivska	8	9	17	19	11	13	5	7	4	6	3	4
Odes'ka	6	6	13	14	8	9	4	5	3	4	2	3
L'vivska	5	6	12	13	7	9	4	5	3	4	2	3
Kharkivska	9	10	22	22	13	15	6	7	5	7	3	4
Luganska	4	5	10	9	6	6	3	3	2	3	1	2
Zaporizhska	10	12	23	26	14	17	7	9	5	7	4	5
Ternopil'ska	6	8	15	16	9	10	4	6	3	5	2	4
Zakarpatska	3	4	6	7	4	5	2	3	2	3	1	2
AR of Crimea	13	16	29	33	18	22	9	12	7	10	5	7
City of Sevastopol	20	19	49	43	30	31	13	14	11	13	8	8

out that the average taken in thyroid doses in different Oblasts of Ukraine fall within the interval of 3 mGy (Zakarpatska Oblast) to 94 mGy (Zhytomyrska Oblast). The highest Oblast-average doses for different age groups were estimated for the Zhytomyrska (29–169 mGy), Kyivska (28–170 mGy), Chernihivska (20–121 mGy), Rivnenska (23–149 mGy), and Cherkaska (18–117 mGy) Oblasts.

Based on children and adolescent thyroid doses aggregated into equal areas, the entire territory of Ukraine can be divided conventionally into three dose zones (Fig. 3.3.3):

(1) Zone of high thyroid doses (in excess of 35 mGy), which includes five northern Oblasts: Kyivska, Zhytomyrska, Chernihivska, Rivnenska, and Cherkaska.

(2) Zone of relatively moderate thyroid doses (14–34 mGy), which includes six Oblasts: Sumska, Poltavska, Kirovogradska, Vinnytska, Khmel'nytska and Volynska Oblasts, as well as the Khersonska Oblast and the Autonomous Republic of Crimea.

(3) Zone of relatively low thyroid doses (less than 14 mGy), which includes the remaining 12 Oblasts of Ukraine.

3.4. Exposure of population in contaminated territories to sources of non-accident origin

Presently, according to international criteria, the ChNPP accident phase relates to the final recovery stage of the accident – chronic irradiation [25]. At this stage, emergency exposure doses are insignificant, and reducing them at reasonable cost is impossible in the majority of cases. Hence, the current radiation protection system provides for reducing population follow-up exposure doses associated with other controlled prolonged-action non-emergency sources by employing countermeasures optimisation procedures.

Controlled «non-emergency» sources are technogenically-enhanced natural sources (TENS): indoor radon-222, and natural radionuclides in building materials and potable water.

Fig. 3.3.3. Average thyroid doses to children and adolescents for Oblasts of Ukraine (age at the time of the accident)

Fig. 3.4.1 shows the weighted-mean total current population exposure doses in contaminated territories.

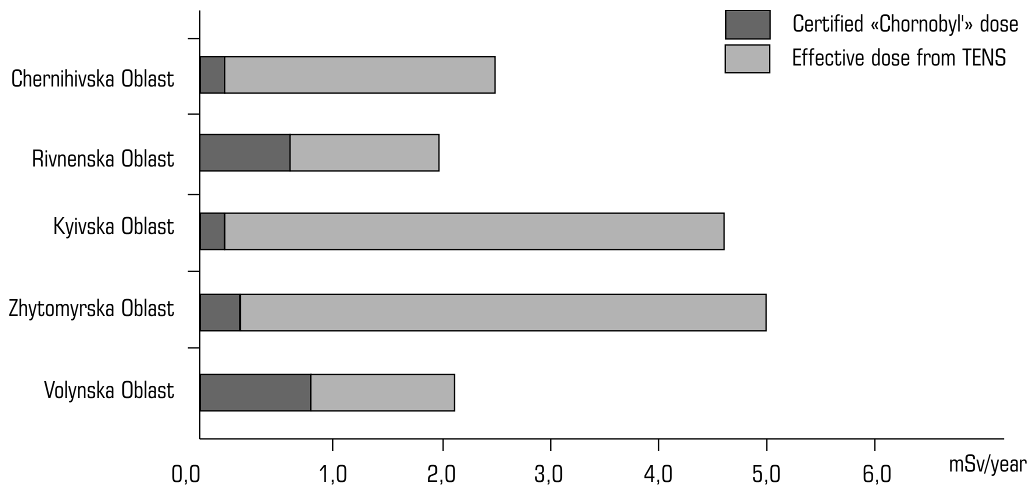


Fig. 3.4.1. Current effective exposure doses from sources of «non-emergency» origin on territories of separate Oblasts for population related to the category of ChNPP accident victims

For the majority of territories contaminated due to the ChNPP accident, follow-up «emergency» exposure doses in the breakdown of the controlled component of current total doses make up 5–10% (except for separate regions of the Rivnenska Oblast).

The breakdown and percentage of each source in the current total exposure dose to population living in contaminated territories in the Rivnenska and Kyivska Oblasts are shown in Fig. 3.4.2.

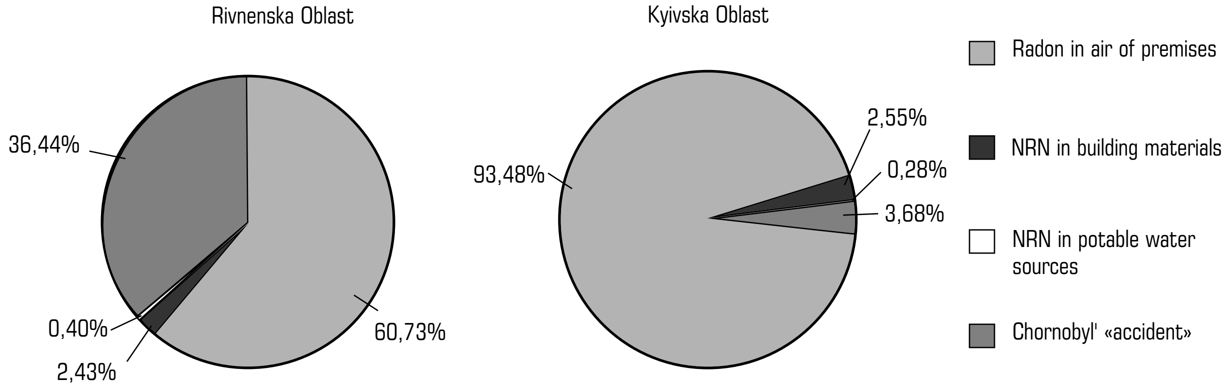


Fig. 3.4.2. Breakdown and percentage of separate irradiation sources in the total and current effective exposure doses to population

4. SOCIAL POLICY OF THE CHORNOBYL ACCIDENT CONSEQUENCES OVERCOMING

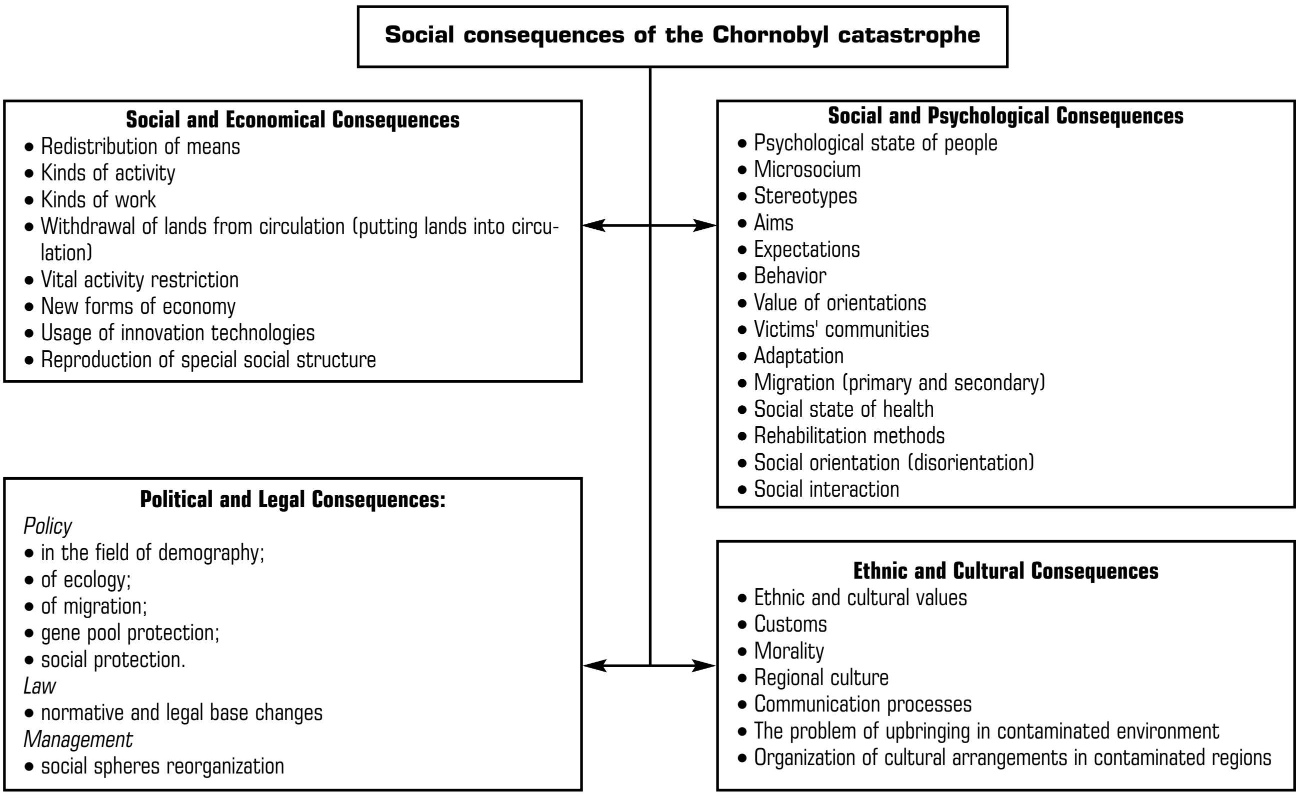
4.1. Social consequences of the Chornobyl accident from 20-year period stand

Today social consequences of the Chornobyl accident require attention and consideration in the context of the results of twenty-year (economical, political, cultural, etc.) transformations in the Ukrainian society, and of «purifying» processes of the ecological environment of contaminated territories, which lead to revision of the social risks for the different categories of victims and search of new models for chances of vital activities and reproduction of the affected community life. Peculiarities and scopes of social consequences - direct and remote, direct and mediate, are due to be revised as the conditions of the community and the environment have been dynamically changing.

The general dynamic assessment of social consequences is possible only by complex unification of the different sources of information: state and administrative statistics, results of research and practical examinations, polls, expertise estimations, etc. Such conception is carried out by the Institute of Sociology of the National Academy of Sciences of Ukraine that has been conducting regular research «Social and psychological monitoring of the Chornobyl accident consequences» since 1992 till now, their results are represented in thirteen publications of research works [1–13] and are taken into account at making appropriate management decisions.

The Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of the Chornobyl catastrophe is a consumer of this works.

A range of social Chornobyl accident consequences is extremely wide (see Scheme 4.1.1) each component requires attention and the appropriate reaction of the state and community. The social monitoring showed that it is mistaken to reduce the policy of the Chornobyl accident consequences overcoming to social assistance, as it leads to the social exclusion enormous masses of victims from the field of vital activities and in some cases even in the social degradation. Hence, a problem and development of individual groups and cogorts of affected people continues to get complicated, transforming effectiveness of the post accident social policy to a challenging problem for Ukraine, especially for the population of affected regions [14].



Scheme 4.1.1. Structure of social consequences of the Chornobyl accident by results of social and psychological monitoring of Institute of Sociology of NASU (1992–2005))

Social policy implies a system of measures aimed at fulfilling social programs, profits support, population living standard, employment assurance, support of social sphere fields, prevention of social conflicts [15]. National policy in the sphere of complex protection of the Chornobyl accident victims is based on the following basic principles:

• priority of life and health of the Chornobyl accident victims, the complete responsibility of state for providing safe and harmless conditions of life and labour;

• complex solution of the tasks of health protection, social policy and usage of the contaminated territories by national programs;

• social protection and complete recovery of losses to victims;

• usage of economical methods for life improvement by providing policy of preferential taxation of the citizens, who are victims of the Chornobyl accident, and their associations;

• implementation of measures on professional re-orientation and raising the Chornobyl accident victims' skill levels;

• cooperation and consultations between state structures and victims (their representatives, all social groups) at taking decisions on social protection at local and state levels;

• international cooperation on health protection, social and antirad protection, labour protection, usage of world experience in solving the issues [16].

Before 1990 the complete legal and legislative field on affairs of social protection and determination of the status of the Chornobyl accident victims did not exist. Resolutions of CPSU Central Committee and the USSR Supreme Council, orders of branch ministries and departments were in force. Now the principles of legislative protection of the Chornobyl accident victims are in the Law of Ukraine No. 796-XII «On the status and social protection of the citizens who are the Chornobyl accident victims» February 28, 1991; the law identifies the basic regulations regarding the constitutional right of the citizens who are the Chornobyl accident victims for their life and health protection; a united procedure of determining the status of the victims was defined. On the basis of the Law, appropriate acts were developed and enacted.

In 1991-2004, the Verkhovna Rada of Ukraine introduced a number of changes in the Law specifying legislative norms, expanding victims' social guarantees, introducing a new procedure of determining victims' categories considerably expanding a range of privileges and compensations to the affected children, whose disability is attached to the Chornobyl catastrophe. A function of coordinating actions to overcome social consequences was entrusted to the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of the Chernobyl catastrophe of Ukraine.

Immediately after the Chornobyl NPP accident in 1986 the compensation policy for all the categories of the Chornobyl accident victims, was introduced in Ukraine. Compensation was conducted in the form of payments and free of charge and out-of-turn various services, which led to considerable rising of expenses scope in the national budgets. After recognition of independence in the country, the political institutions which were on the stage of formation, on behalf of the their electorate energetically began to solve the existing problems caused by the Chornobyl catastrophe, as a result, the Parliament repeatedly gave its consent to pay out all expenses without the due estimation of the resources. Thus the obligations taken were not completely fulfilled, and «the Chornobyl payments» placed a heavy burden on the National budget [17].

After a number of years «the Chornobyl problem» became more social than technical: today almost 90% of funds provided by the National budget on financing of the Chornobyl programmes have a social orientation. That's why from January 2004, commissions and the majority of social protection of people, affected from the Chornobyl catastrophe programmes resigned to the Ministry of Labour and Social policy, responsible for implementation of social policy in the country.

By the decree of the President of Ukraine (05.03.2004) № 283 determined the coordination and development of programmes of state policy realization in the field of social protection of people, including the Chornobyl catastrophe affected people as the main tasks for the Ministry of Labour and Social policy. It gives wide opportunities to solve the problems of social protection of the Chornobyl catastrophe affected people, to create governing vertical on the national scale.

4.2. The system of social protection and service of the Chornobyl accident victims

According to the Law of Ukraine «On the status and social protection of the citizens who are the Chornobyl accident victims», the direct participants of the Chornobyl accident consequences elimination, the most vulnerable groups of population (children and invalids), residents of the settlements, which are on the territories with the increased level of radioactive contamination, are taken under the special state protection.

On January 1, 2005 in Ukraine 2 594 071 persons had the status of the Chornobyl accident victims (Table 4.2.1). With reducing of a total number of victims by 19% in 1997–2006, that is completely natural that two typical peculiarities were determined. Perhaps, the contingent of category 1 «Chornobyl invalids» increased by 1.8 times. The number of Category G, those who worked beyond the territory of the Exclusion Zone, increased only by 3%, a number of category 2A – participants of the accident consequences elimination in 1986–1987 decreased (by 24%). It means that the first wave of «liquidators», men of the young age got the strongest impact to their health.

Table 4.2.1

Dynamics of the total number of the Chornobyl accident victims by categories (on January 1, 1997–2006)

Categories of the Chornobyl accident victims		Number of the Chornobyl accident victims				
		1997	2000	2005	2006	2006 to 1997, %
Category 1: Invalids whose state of nonoperability related with the Chornobyl accident		59 582	86 775	105 251	106 824	179
Category 2		339 666	307 982	276 072	268 815	79
includ-ing	2a (liquidators of accident consequences in 1986–1987)	252 939	227 135	197 817	191 167	76
	2b victims	86 727	80 847	78 255	77 648	90
Category 3		558 637	549 649	537 504	533 144	95
includ-ing	3a (liquidators of accident consequences in 1987–1990)	69 620	62 729	55 391	52 346	75
	3b victims	489 017	486 920	482 113	480 798	98
Category 4		1 169 804	1 150 273	1 081 469	1 065 022	91
Category D: people who worked beyond the territory of the exclusion zone		2530	2862	2780	2606	103
Children victims (including those with thyroid gland irradiation in 1986)		1 083 107	1 264 329	643 030	617 660	57
Total		3 213 326	3 361 870	2 646 106	2 594 071	81

Source: Data of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe, 2006.

The status of the Chornobyl accident victims is reviewed by the Commission on vexed questions of determination of the status of people who participated in elimination of consequences of accident at the Chornobyl NPP.

The information on victims is gathered in Database of the Chornobyl accident victims, which was formed with the Ministry of Ukraine of Emergencies, and the main task of which is the provision of the central and local executive bodies with trustworthy information. Now in Ukraine there are 19 109 families which have privileges due to the loss of breadwinner whose death is related to the Chornobyl accident [19]. Such families are in all regions of the country (Table 4.2.2).

Unfortunately the number of families that had broken or had not been formed due to resettlement, watch specifics of work at the NPP, state of health of liquidators, support personnel, migrants etc. is not studied. The tendency of rising of people who don't want to form the family has been clearly defined as well as changes in the hierarchy of reasons why young people do not see themselves under the status of being married, and «Chornobyl» factor plays here its decisive negative role. Along with this all the categories of victims consider family to be the main institute of surviving.

In the context of the Chornobyl accident consequences overcoming and with the aim of regulation of social protection of not sufficiently provided families and families with children the Laws of Ukraine «On the national assistance to families with children» and «On the national social assistance to not sufficiently provided families» are accepted. In the first quarter of 2005 411.6 thousand not sufficiently provided families and 932.8 thousand families with children received the national social assistance, among which a significant part is the Chornobyl catastrophe victims'.

The Law of Ukraine «On universal obligatory national retirement insurance», which came into force since January 1, 2004, stated a new procedure of pension assignment [16], which keeps the norms for earlier retirement of the Chornobyl accident victims that is of 2 to 13 years earlier than the age envisaged by legislation. About 190 thousand persons used this privilege, and in 2005, its total value was over 684 million of hryvnas [19].

Table 4.2.2

The number of the families which have privileges due to the loss of breadprovider whose death is related to Chornobyl accident (as of January 1, 2006)

Oblast	Number of families	Oblast	Number of families
Autonomous Republic of Crimea	155	Odeska	167
Vinnytska	332	Poltavska	440
Volynska	1057	Rivnenska	1734
Dnipropetrovska	743	Sumska	247
Donetska	915	Ternopilska	203
Zhytomyrska	2058	Kharkivska	596
Zakarpatska	114	Khersonska	72
Zaporizhska	139	Khmelnytska	186
Ivano-Frankivska	118	Cherkaska	929
Kyivska	4776	Chernivetska	90
Kirovogradska	227	Chernihivska	740
Lvivska	306	The city of Kyiv	2544
Luhanska	136	The city of Sevastopol	9
Mykolayivska	76	Total in Ukraine	19 109

Source: Data of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe, 2006.

Problems that have to be addressed: revising the minimal pensions for disabled recovery operation workers; increasing the amounts of additional pensions for injuries to the health of victims; follow up on the issue of all allowances and pension raises, including those provided in the Law of Ukraine «On the Status and Social Protection of Citizens who Suffered as a Result of the Chornobyl catastrophe».

One of the components of social protection of victims was resettlement of population from contaminated territories and improving the living conditions of people who were disabled as a result of the Chornobyl catastrophe (Tables 4.2.3–4.2.5). Since the government took a decision on evacuating and relocating victims from contaminated territories, more than 52 000 families (164 700 persons, including 90 784 persons in 1986–1990) were evacuated and resettled [19].

Table 4.2.3

Evacuation from the zone of absolute resettlement (of families)

	Total	Including by the regions			
		Zhytomyr	Kyiv	Rivne	Chernihiv
It was planned to evacuate	18 147	8480	8721	721	228
Evacuated in 1990–2005	14 893	5961	8382	344	206
Including:					
2001	45	40	5	–	–
2002	68	68	–	–	–
2003	91	91	–	–	–
2004	60	60	–	–	–
2005	79	79	–	–	–
Residents of the zone of absolute (obligatory) resettlement	1258	734*	81*	517**	12**

* It is necessary to resettle families by their desire; ** refused to be resettled.

Source: Data of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe, 2006.

Table 4.2.4

Evacuation from the zones of guaranteed voluntary resettlement and intensive radiological control

Resettled	Families	Resettled	Families
in 1990–2005 (total)	14171	2000	370
Including by years:		2001	286
1996	1367	2002	86
1997	945	2003	229
1998	504	2004	69
1999	615	2005	–

Source: Data of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe, 2006.

On January 1, 2006 44 191 families including 10 630 families of disabled due to the Chornobyl accident and 15149 families of migrants from radioactive contaminated territories, which have been on the housing list since 1990–1991 and 18 412 families related to Category 2, were on a waiting list for providing the Chornobyl accident victims with housing.

It is worth mentioning that, during 1993–2005, housing was provided to 7351 families of disabled Chornobyl residents who, pursuant to the existing law, should be provided with housing from the state budget during one year since the instance of being placed on the housing list. To address their housing issue completely, about 5.8 billion hryvnas are required. Paying indemnity for immovables losses by the victims is scheduled to be completed by December 31, 2007.

Recovering of an active lifestyle of victims; their orientation, health level, feelings, and migration attitude depends largely on addressing a wide gamut of issues related to their financial and living conditions [22]. With account of this, the major lines of the Chornobyl construction program are as follows: 1) improving the living conditions of affected population on contaminated territories and in compact resettlement localities by building medical establishments and schools, gas networks and supplying gas to dwellings; 2) creation of jobs in compact resettlement localities; and 3) taking urgent measures in zones of unconditional (compulsory) resettlement. One of the challenges of implementation of this program is a large number of uncompleted construction projects, viz. 1419 as of 01.01.2006. Housing and living conditions of victims should be guaranteed by the program of social development of the affected communities and territories.

According to the data of social monitoring of the Chornobyl accident consequences victims note worsening of their health level during the post accident period and the role of the ecological factor of health worsening grows. If in 1999 the negative influence of ecological situation in the affected regions on the health had by 49% of interrogated people, in 2001 this part increased up to 64% [23] with the regional differences [24]. The level of ecological risk perception affects self-appraisals on the health level: the higher is radiation risk perception level, the lower is estimation of their health [25].

Such category as 30 km-zone self-settlers change self-estimation of their health particularly sharply [27]. If in 1999 40% of self-settlers estimated themselves as having chronicle diseases or disable-

Table 4.2.5

Provision with housing of families Chornobyl disabled

Provision with housing	Families	Provision with housing	Families
in 1990–2005 (total)	7351	2000	713
Including by years:		2001	602
1996	845	2002	247
1997	858	2003	340
1998	525	2004	168
1999	839	2005	152

Source: Data of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe, 2006.

ment, in 2003 the part of such citizens was 82%. Now the well-known vital optimism and mythological consciousness will not prevent them from estimating their health conditions sensibly as low [27].

The health of the population, including the victims of the Chornobyl catastrophe, must be considered both as a medical and physical, and a social and economic issue whose condition and development trends define the future well-being and safety of the entire society.

The results of social monitoring of population show the rising role of forming ecological culture, which is the main human activity that is directed to organization and transforming of the environment according to the own needs and purposes [25].The adequate estimation of global factors and adequate behavior in the radioactive contaminated region is rising with a citizen's education.

Surveys have fixed divergences in daily functioning and reflection of values in consciousness. The social imbalance between the fixed set of values and the actual possibilities of their fulfilment makes individuals lose inclination for cultural stimuli and civilised means of achieving them; provokes upheavals in the value-and-norms level of the ethnic culture aimed at destructing the motivation-and-will sphere of personality formation [29].

In case of appropriate reorganization, educational courses, programs of the educational field the system of information would stimulate the cognitive activity of the people. The direct reduction or indirect compensation of the available risks can be reached by means of specially developed and adapted for every target group programs [30, 31]. The lost chain of cultural-and-educational establishments has not been replaced with alternative structures.

A lot of the Chornobyl accident victims are underemployed or they work occasionally (Table 4.2.6). In 1998, the residents of the Zone 2 (obligatory re-settlement) had the highest level of employment (69%), and in 1999, the part of employment sharply reduced by22%, and it was 47% [31]; in 2003 it remained almost at the same level. The similar tendency occurred among the residents of the Zone 3 (obligatory resettlement). The least part of employment was among the residents of the exclusion zone (3%) in 1998 it was 0%.

Table 4.2.6

Distribution of different groups of population by the kinds of employment (%)

Groups of population	Kinds of employment							
	Full time work		Part time work		Work occasionally		Unemployment	
	1998	2003	1998	2003	1998	2003	1998	2003
Exclusion zone residents (Zone 1a)	–	3	–	0	–	2	–	8
Zone 2 residents	69	48	14	2	0	5	2	8
Zone 3 residents	65	41	12	4	1	3	2	10
«Clean» zone residents	43	53	8	11	6	6	4	12

The part of underemployment (or hidden unemployment) had the tendency of reduction. Since 1998 to 2003 the state of employment among the residents of Zones 2 and 3 got worse in comparison with the residents of the «clean» regions. On the contrary, the state of employment of the residents of the «clean» regions got considerably better (except the unemployment level). Hence, the recovering economic situation in the country has resulted in the labour market revival; however, the level of employment of the affected population has dropped significantly.

The main cause of loss of the work by the Chornobyl accident victims is retirement (Table 4.2.7).

It is indicative that in Zone 3 unemployment after leaving schools almost twice increased [31]. The limited nature of production activity on the considerable areas of the contaminated territories made social payments the main source of welfare as for pensioners, as a whole, which creates socially passive psychology of the groups with the dominant orientation to paternalistic models of life. In order not to loose victim's groups, it is necessary to recover productive capacities and the models of self-employment.

4.3. Preserving the cultural legacy of the Chornobyl zone

The Ukrainian Polissia, as part of the historical region of the Slavs' ancestral fatherland, belongs to the most unique historical and ethnographic regions of the Slavic world. In all spheres of material and spiritual culture of native Polissia inhabitants, there are a multitude of relic phenomena preserved to date, which are critical for recreating the ethnic history of Ukrainian and other Slavic peoples.

The Chornobyl catastrophe has changed this unique and little studied territory into a depopulat-

Table 4.2.7

Distribution of the causes of unemployment by the regions of residence 1999–2003 (% of respondents)

The causes of unemployment	The region of residence			
	Zone 2		Zone 3	
	1999	2003	1999	2003
Dismissal in connection with reorganization or liquidation of enterprise (factory)	19	5	5	6
Dismissal for other causes	19	12	9	9
Unemployed after leaving school, trade school, graduating from higher school	5	2	7	13
Unemployed after the discharge from the army	0	2	0	0
Retirement	32	74	35	60
Own business liquidation	5	0	9	4
Others	19	6	35	7

ed wilderness where the ethnocultural heritage of generations was severed. The exclusion zone and the zone of unconditional (compulsory) resettlement engulfed into oblivion 4125 sq. km of land, on which 136 000 people living in 178 settlements preserved the culture of pre-Ukrainians over many centuries.

Forced resettlement and scattering of native Polissia inhabitants has inevitably led to destruction of the spiritual microcosm of a compact ethnic group and its assimilation in a new ecological and cultural environment. The resettled people left behind a doomed consistent ethnocultural and lingual continuum, which is disappeared from the Earth forever. Destructive processes are being observed even in the zone of guaranteed voluntary resettlement.

Rescuing the cultural legacy has started with the process of in-depth system-integrated search for and registering of ethnocultural values to create a multiprofile regional scientific and information fund including mobile exhibits to be removed, and fixed historical monuments (memorials, historical entombments and graveyards, and archaeological artefacts), which are remaining on relocation territories and are subject to regular memorial conservation monitoring.

By enactment of the Verkhovna Rada of Ukraine, these activities are the responsibility of the Historical and Culturological Expedition of the Ministry of Chornobyl Affairs of Ukraine. Since 1992, it has been working in compliance with a long-term integrated program involving interim creative teams from profile academic institutions, higher education establishments, museums and public organisations of Ukraine.

During 1993–1995, field exploration has been conducted; traditional folklore and the language and history of the land has been recorded using photo, audio and video means; a thorough inventory was taken of fixed historical monuments, archaeological artefacts and monumental art. Anthropological materials, the archive documentary legacy and museum-significant artefacts are also being collected.

Since 2001, these activities are organised by a special State Research and Production Enterprise «Centre for Protecting the Cultural Legacy from Emergencies» set up within the Ministry of Emergencies of Ukraine.

For today, in-depth explorations covered 311 affected settlements in Central Polissia and 94 compact resettlement localities. These activities have resulted in collecting an extensive research source fund comprising over 110 000 documents (including 50 000 photo negatives, 1600 hours of audio and 320 hours of video recordings; about 14 000 archive hardcopy documents) and over 10 000 ethnographic exhibits, which are kept in interim fund repositories in Kyiv, Ivankov, and Chornobyl. An inventory has been taken of over 1 000 fixed monuments in 500 settlements, among which there are many newly discovered archaeological and historical monuments. For instance, a sensation was the discovery of an early Neolith site of the 6^{th} millennium B.C. on the Prypiat' River and the medieval town of Chornobyl dated back to the late 11^{th} – early 12^{th} century (archeological digs are underway now). The results of prospecting work have been published in 30 scientific and scientific-popular editions (with a total volume of 475 printer's sheets), and several historical-ethnographic exhibitions have been held.

A unique archive and museum fund has been collected. But a pressing problem is its conservation, legal protection and introduction into scientific and general cultural circulation. At the same time, a topical issue is urgent prolongation of recovery of prospecting work of Polissia's cultural heritage, which is steadily perishing.

Among the countries that were affected by the Chornobyl accident, only Ukraine has created a unique museum-archive. Only Ukraine created an international image of a country that is concerned with conserving the unique cultural heritage in affected territories, being aware of its significance for world culture.

Presently, the Center for protection of the cultural heritage from emergencies is working on creating a Museum-archive of the ethnic-and-cultural heritage of the affected regions in Ukrainian Polissia. Based on its experience and information-and-material base, it would be practical to develop a system of preventive strategies for protecting the national cultural heritage in the event of such catastrophes.

4.4. Activity of the Centers of social and psychological rehabilitation and information of the Chornobyl accident victims

Remote negative consequences of the Chornobyl accident have, first of all, social and psychological nature and they are related, first of all, with the collapse of the traditional forms of organization of people vital activity, impossibility of valuable economic activity on the contaminated territories, and with constant dreads of the Chornobyl accident victims regarding adults and children's health.

Only Centers of social and psychological rehabilitation and information of population, which were formed by the Ministry of Emergencies and on the matters of population protection from the Chornobyl accident consequences with support of UN programs during 1994–2000 (Borodyanka, Boyarka, Ivankiv, Korosten, Slavutych), were purposefully occupied with the Chornobyl accident victims' psychological problems overcoming.

The basic tasks of these institutions were: 1) rendering social and psychological support to population of the contaminated regions, 2) activation of people for constructive solving of the problems, 3) development of social responsibility and abilities of every person to take responsibility for own life without complete relying on the government, 4) development of social links and societies. Crisis conditions overcoming rate is directly proportional to the time needed for such recovery.

There are two optimal strategies: 1) restoring the previous way of living – it is effective under conditions of short-term crises (fires, floods, explosions, etc.); and 2) developing new group norms and behaviour patterns that would fit new living conditions when it is impossible to revert to the previous way of life.

Rehabilitation centers demonstrated high practical effectiveness (Table 4.4.1). Over 90% managers and residents of the regions, where the centers function, indicate the essential effective influence on the communities' life.

Table 4.4.1

Estimation of influence and psychological rehabilitation of population Centers on community's life (m %)

Influence degree	Managers	Adults	Adolescents
Strong	61	27	73
Middle	33	58	21
Weak	6	9	4
Absent	0	6	2

Centres have become an integral and requisite part of the social life of communities, and they have a significant impact on normalising social processes. Actually, these establishments render social and psychological support not only to the victims of the Chornobyl catastrophe, but to all residents requiring such support. Besides working in inhabited localities where they are stationed, the Centres are extending their activities to a large number of villages in regions through field actions or by involving the residents of such villages to activities conducted in the Centre itself seminars, round-table discussions, and so forth. The Centres' activities cover the following: setting up public associations oriented to self-governance when addressing issues vital for community members, with involvement of respective professionals; elaborating local and regional development programs; Centre-based training of small-business professionals; supporting youth programs, and so forth. Essentially, the Centres can be transformed to regional development centres, which will deliver methodical and professional support to similar organisations in other inhabited localities, e.g. village youth centres, etc.

Unfortunately, the unique gains of Centers don't get large-scale distribution in Ukraine.

4.5. Development of social partnership in recovering life at the contaminated territories: UNDP programs

Chornobyl revival and development program (ChRDP) began its activity in 2002 on the basis of recommendations of the Report «*Humanitarian consequences of the Chornobyl NPP accident: Strategy of Revival*», initiated by UN agencies. ChRDP is the third phase of UN Chornobyl program, which acted in 1999–2002, in particular, of the work on support of social and psychological rehabilitation of the Chornobyl accident victims. The goal of ChRDP activities is support of Ukraine Government efforts to overcome long-term social, economical and ecological consequences of the Chornobyl accident, to provide more favourable conditions of life and assurance of constant human development in the affected regions. Owing to the partnership with international organizations, regional and district state administrations, rural bodies research institutions, nongovernmental organizations and private business ChRDP renders support to communities in realizing their initiatives on economical and social development and environment revival, promotes distribution of the Chornobyl accident information in Ukraine and abroad.

Among national partners are the following: the Ministry of Emergencies of Ukraine, profile committees of the Verkhovna Rada of Ukraine, regional and district state administrations, rural bodies, public communities, research institutions and nongovernmental organizations, which act on the contaminated territories.

The ChRDP resorts to world-proven practice in regional development through community involvement, thereby changing the «victim syndrome». To date, the CRDP was funded to about USD 3.5 mln. ChRDP activities extend on 17 the most affected districts in four regions of Ukraine: Borodyansky, Ivankivsky, Kyevo-Svyatoshynskyi, Makarivskyi, Poliskyi (Kyiv region); Brusylivskyi, Yemilchynskyi, Korostenskyi, Luhynskyi, Ovrutskyi, Olevskyi, Narodytskyi (Zhytomyr region); Chernihivskyi, Ripkinskyi (Chernihiv region); Dubrvytskyi, Zarichnenskyi and Rokytnivskyi (Rivne region).

The key activities of the ChRDP are as follows:

• *Promoting state policy improvement* – supporting legislative changes and innovation strategies focused to overcome the Chornobyl catastrophe consequences (sustained development of affected regions, safe living conditions, and informing the population in detail).

• *Self-organisation and development of communities* – enhancing the potential of communities in implementing their own priority programs of social and economic development and environmental recovery.

• *Institutional support* – extending the capacity and consolidating the potential of organisations and institutions, which should promote social and economic development and environmental recovery of contaminated regions.

CRDP tasks are realized via activities of main technical components of the program. «Small grants» given within the project, become the means of persuasion of both the communities, and state administrations in potential advantages of such partner relations.

As of December 2005, 171 communities are created and they act in 133 villages, (about 20 thousand members) who solve concrete problems of revival and development of villages: construction of schools, bath-houses, medical, realization of youth and pub and obstetrical units (MOU), creation outpatients' units of youth and public centers, markets, service centers, parks cleaning, gasification and water supply projects.

It is worth noting that contribution of UNDP/ChRDP to mentioned projects of societies was 34%, and the rest of funds the society itself involved from both local budget funds, and private sponsors, and, above all, the society itself contributes to 20% of the total cost of the project by funds or conducting some kinds of building work by own strength. It is particularly important from the necessity of assurance of the work results stability exists.

With the program promoting the Agencies of local economical development were created and financially supported in three districts of Zhytomyr region (Brusyliv, Korosten and Ovruch) and in two districts of Kyiv region (Borodyanka and Ivankiv) for support of development of small and middle business undertakings, realization of favourable climate for investments, development of cooperation between authorities and business regarding stable economical development of the region. The total sum of the grants was about US $ 140 thousand.

The ChRDP is maintaining a continuous dialog with the Government of Ukraine. It is developing a program for implementing the «Strategy of Recovery» recommendations, in particular, within the framework of interregional cooperation between Ukraine, Russia and Belarus, and for social and economic recovery of affected territories. The Chornobyl Forum for economic development of affected ter-

ritories has started its activities. It is pooling the efforts of national and foreign business entities, separate potential investors, the authorities, the scientific community, and the public.

In 2004–2005 41 group received and successfully realized the grants (in total sum US $ 72 000 for development of business plan, economy and business study, new business registration, etc.

The breakdown of fund raising for 125 community projects in 2003–2005 to a total of about USD 2 mln is as follows: local authorities – 39%; UNDP/ChRDP – 34%; communities – 18%; and sponsors – 9%. Information materials on safe living conditions in contaminated territories have been prepared and are being disseminated among the population through local institutions and the mass media; and seminars have been held for medical personnel and teachers.

In 2006, ChRDP is continuing cooperation with the Government of Ukraine especially regarding the 20 year Chornobyl accident anniversary. UNDP is a co-organizer of the international conference «20 years since the Chornobyl accident». The number of arrangements with representatives of countries-donors are scheduled.

4.6. The main problems of further social development of affected communities and territories

4.6.1. Social problems of the Chornobyl NPP workers and residents of the town of Slavutych

Following the Memorandum on mutual understanding between the Government of Ukraine and the Governments of the countries of «Great Seven» and Commission of European Commonwealth concerning the Chornobyl NPP closing, on December 15, 2000 Ukraine closed the Chornobyl NPP.

Pre-term closing of the Chornobyl NPP, much complicated solving medical, social, ecological, radiation, technical and other problems, of the town of Slavutych. The situation is becoming acute due to absence of a nationwide program on decommissioning of the ChNPP. Besides, there is no nationwide program for converting the object «Shelter» to an environmentally safe system. The problem of saving and developing the town of Slavutych has to be considered just against such considerations [33–37]. The key issue in Slavutych is the problem of social protection of people. The town was built after the accident for residence of the liveware of the Chernobyl NPP, and it is monoprofile. Its territory relates to the zone of intensive radioactive control.

On January 1, 2005 17.3 thousand persons or 71% of 24 365 persons of the town of Slavutych population have the status of the Chornobyl accident victims including the accident elimination participants of Category I – 661 persons; Category II – 5233 persons; Category III – 2209 persons. 5847 children have been identified as victims of the accident.

Because the ChNPP operation has been terminated, the city has lost a source of local budget funding and roughly 10 000 jobs, as well as the option of additional social funding. The key tasks of the town are: 1) preservation, development and maintenance of the town social infrastructure in corpore; 2) creation of compensative jobs; 3) effective management of human resources; 4) provision of social payment and guarantees to the staff who are dismissing and the town residents.

The state structures of different levels have taken the decisions concerning assurance of the town of Slavutych active vitality and social guarantees to the state special enterprise «Chornobyl NPP» workers and the town of Slavutych residents in connection with the station closing. The President of Ukraine, the Prime Minister of Ukraine, Inter-departmental commission took decisions on complex solution of the Chornobyl NPP problems.

Unfortunately, so far, the considerable part of the mentioned documents concerning assurance of the town of Slavutych vital activity has not been realized. For example, due to insufficient level of financing of the only medical institution in the town has formed critical situation in the town: morbidity with temporal disability of the Chornobyl NPP workers increased 17.8%; for 9 months of 2005 the number of the registered HIV-infected persons 26% increased; now 60 drug addicted people are registered, and 383 are with the disease of alcoholism at the medical institution; in the town of Slavutych mostly people of capable of working age die; in 2004 53% of them were people of 18–59; the amount of doctors is 37.7 persons per 10 thousand of population, and, in total, in Ukraine they are 41.3; in fact in 2005, the town medicine was financed in the amount of 13.1 million hryvnas at need of 19 million hryvnas.

So far, the measures of completing construction of social infrastructure facilities and dwelling houses, which are envisaged by the Program of social protection, are not realized in full measure. The overall turn for getting dwelling and improvement of dwelling conditions in the town of Slavutych consists of 946 persons including 32 families that have been registered since 1992.

The most insistent is the problem of creation of compensation jobs in the town. In 2005, the special economical zone «Slavutych», which aim was involving investments for creation new jobs in the town

and assurance of placing in jobs of the Chornobyl NPP, who were dismissed in connection with its preterm closing, was abolished. The subjects of the special economical zone «Slavutych» are 16 enterprises with 19 investment projects of total value of US $ 78 908 thousand; realization of the projects envisages realization of 839 new jobs. Slavutych has the best figures in Ukraine on investments per capita (US $ 1270). Since the beginning of the projects realization in the special economical zone the investments were involved to the amount of US $ 30 732 thousand 626 jobs were created.

Instead it is necessary to create 3750 new jobs in Slavutych for 2001–2008. For this financing from the state budget in the amount of 15.7 million hryvnas is necessary, this fund is not allotted.

Under difficult social and economical conditions the main task of the municipal administration became the search of alternative sources of financing; the municipal administration concentrated all their efforts on uniting their residents.

The town effectively cooperates with the international donor organizations – TACIS, AMP (USA), UNESCO, the Assembly of investors of the Chornobyl fund «Shelter» and many others. The town of Slavutych society continues the work related with the Chornobyl NPP accident consequences overcoming, social protection of the population of adjacent to the Chornobyl NPP territories. Soon it schedules to conduct the second public hearing on realization of the conceptual New safe confinement project.

At the government level, it is necessary to review all the legislative and regulatory acts on Chornobyl to draft a new consolidated regulatory document. Two state programs have to be adopted: 1) on converting the object «Shelter» to a safe condition; and 2) decommissioning of the ChNPP units.

Jointly with the international community, it is necessary to elaborate the Shelter Implementation Project to convert the object «Shelter» to an environmentally safe system. With account of the Orhuz convention, it is necessary to hold a new tender on elaborating a new Confinement Feasibility Report.

Pursuant to paragraph 9 Section 6 of the Memorandum on Rapport between the G7 Governments, the EU Commission and the Government of Ukraine regarding decommissioning the ChNPP, the parties will meet al least once a year to monitor implementation of the integrated program in support of decommissioning the ChNPP.

To implement the recommendations of several Parliamentary hearings of the Verkhovna Rada on the Chornobyl' catastrophe, a central body should be set up to manage these issues. The town of Slavutych can be the site of its location.

4.6.2. Changes in settlers' structure in contaminated regions

In total, in Ukraine the number of villages of small population steadily rises. A network of rural settlements is thinning out [38]. The «degenerative» villages are «falling into decay» (the part of persons of pension age is over 50%, and if the population is up to 200 persons, it is over 40%) and «dying» (with population, which is less than 50 persons, or where there are no children up to 16, or the part of persons of pension age is over 65%).

Degradation of rural settlement network actively occurs in the Northern East of Ukraine from 40 to 60%. In the majority of Central and Eastern regions of Ukraine up to 27 – 31% villages is degrading. There are least degrading villages in Western regions in Kherson region and in the Autonomous Republic of Crimea. Chornobyl consequences have affected mostly the rural population.

In the *exclusion zone* (2.12 thousand square kilometers in Kyiv and Zhytomyr regions) evacuation of population was realized from 76 settlements in 1986. There is an unpopulated town (Prypiat) and 63 villages over (20 of them are physically destroyed) now, 11 villages degraded and are dying, one town (Chornobyl) degraded to mostly temporary watch-standing settlement, network of Chornobyl district settlements was practically annihilated, and the town itself disappeared from the map of Ukraine.

At the beginning of 1991 about 50 thousand persons lived in the *zone of obligatory evacuation* (2.00 thousand square kilometers, 92 settlements of West and East traces of contamination) due to evacuation from the zone 17 villages in Kyiv region and 19 villages in Zhytomyr region became completely unpopulated. Other 56 settlements degraded, but their degree of decay was not uniform. The villages of Volyn and Rivne regions, which were practically non-evacuated due to unwillingness to be evacuated, and one urban village Narodychi least of all degraded. The villages of Chernihiv, Kyiv and Zhytomyr, which are incompletely evacuated, most of all degraded, most of them are dying due to youth migration. The degrading urban villages Poliske and Vilcha gradually transform into temporary settlements [39–40].

In *the zone of guaranteed voluntary evacuation* (22.62 thousand square kilometers in the West, East and south traces of contamination) there are 835 settlements here.

Due to irrevocable migration from the zone, first of all of youth, who were particularly active in late 1980s and in early 1990s, depopulation and degradation of villages accelerated, especially in Kyiv, Chernigiv and Zhytomyr regions (tens of villages quickly pass on to the category of dying villages, some

of them are depopulated). The situation has not changed in Volyn and Rivne regions. Since the second half of 90s the volumes of migration and depopulation began reducing, and somewhere (the north districts of Zhytomyr region) fertility rises. Degradation rates of the settlements in this zone are considerably slower, and in some districts the certain revival is observed.

Zone of intensified radio ecological control is 26.71 km^2. It consists of 1290 settlements (almost 1690 thousand persons live). The main factors of «Chornobyl» influence on development of settlement network in the zone were the following: firstly, psychologically conditioned reduction of women's fertility, and increase in spontaneous irrevocable migration of youth; secondly, creation of a new town of Slavutych for the Chornobyl NPP workers; development of infrastructure and increase of population of tens of villages, some urban villages and towns due to arrangement of evacuated people and resettlers in Borodyansky and other districts of Kyiv region belonged it to Zone 4. «Chornobyl» influence on the most of villages was negative, but in the places of moving in «Chornobyl» resettlers it was positive.

Thus, during the first post accident decade both local very negative (in the places of victims evacuation), and positive direct «Chornobyl» influences on the settlement network through migration activity were observed.

Since 1990s the mediated influence of «Chornobyl» component on intensification of demographic crisis, especially in the villages, comes out for the forefront and begins to dominate.

Chornobyl accident directly caused complete desert of one town and a hundred villages; creation of a new town; irrevocable degradation of 67 villages, a town and 3 urban villages at least; rapid degradation of up to one thousand of villages, located in the north part of Zhytomyr and Kyiv regions and in the west part of Chernigiv region. If to take into account that for 1986–2001 in Ukraine about 1000 villages disappeared, «Chornobyl» contribution into the total degradation of rural settlement network can be estimated as 10–15% to a first approximation. However, in Zhytomyrska and Kyivska Oblasts, these issues presently outweigh all other factors.

4.6.3. Role of local communities in the Chornobyl NPP accident consequences overcoming

Due to the Chornobyl NPP accident the territory of over two thousand settlements in the area of twelve regions of Ukraine were found contaminated [41]. The most of these settlements are villages and urban villages, the residents of which are oriented at developing traditional branches production, agricultural production [42]. All the categories of victims almost completely use their homestead lands only with one purpose: they grow products only for their own consumption [43].

In spite of importance of housekeeping incomes, the incomes from the main job or pensions, various social payments are determinant for the most of families. Improving the living conditions of victims cannot be resolved by the outdated private household economy, and the rural residents are not expecting a growing income due to expanding the areas of lots allocated to the private household economy or farming [44].

They are pinning their hopes on the production activities of people who can still work, in spite of intense paternalistic attitudes [45].

And, given that developing production capacities yields long-term benefits, the victims' demand in production capacities is growing at a much higher rate than the demand in different kinds of payments and privileges [46]. The problems are as follows:

Institutional – legal (legislative), methodical, and management support in overcoming the accident consequences should ensure structural change in the entire social life in affected territories; introduce, in the first place, competition; and overcome monopoly in all its forms.

Co-existence – of private enterprises and farms as market structures with local self-administration bodies with regard to property relations, management, modern forms of production organisation, and processing and selling cultivated products.

Existence of settlements as social structures. Sharing of production and social support functions between enterprises, municipal bodies and public associations. It is the public who have to address the problem of creating new jobs; otherwise one can expect moral degradation and criminal-oriented behaviour of the majority of population.

There is a challenge of building new mechanisms of community functioning based on existence of the private property institute where the interests of manufacturers are often not only in disagreement with the interests of the territorial community but are diametrically opposed to them in many cases. This calls for finding compromises between them. Developing such mechanisms is the task of exclusively local self-administration bodies. World practice has developed the principles of interaction of state authority structures and those of the civil society. The local self-administration bodies should be changed to civil society structures capable of being effectively involved in public activities. Local taxes

should be levied directly to the local council account rather than the fiscal agencies. The fiscal agencies should receive not the payment itself but rather a copy of the payment order on paying the local tax.

The rights of local self-administration bodies, i. e. communities, including rural ones, are specified fairly comprehensively in respective laws, though there are no essential changes because of lack of awareness in the area of legislation and absence of law enforcement mechanisms. There is an urgent need in developing mechanisms for enforcing legislative norms. A pressing issue is training/retraining and advanced training of village administration and village council executives. The top-priority task is to change the village administration chairman from a stooge to a formal and informal leader of the community, and to a territorial manager.

The budget should be transparent and available to the public (in the village and/or regional library). The mechanism of meeting challenges should be personal initiative under continuous supervision of state entities and the public. The motives should be mainly moral and financial, and linked to administrative ones – and only in this order. However, there are *measures that can be taken practically without state financial expenditures*, viz. introducing democratic procedures to the routine activities of local authorities.

Measures requiring relatively minor capital outlay are investment in human assets: ongoing retraining of all personnel, and unlimited access to education for all youth cohorts [47]. The level of education of urban and rural residents differs dramatically.

Measures requiring major capital outlay – development of a modern infrastructure favourable for business development, mainly non-agricultural production.

Promotion of communities development, the use of its organization and human potential can become the locomotive of developing contaminated territories and guarantee of the Chornobyl NPP accident negative consequences overcoming.

4.6.4. Scenarios of reviving the life attitude of victims: development and safety

Modern approaches to social policy with regard to victims call for changing the attitude of victims to an active lifestyle and increasing their awareness of radiological safety standards. This should become one of the major focal points in their life, among others.

Research conducted by the Centre of Social Appraisal of the Institute of Sociology of the NASU has identified options of positive social influences in the social development format: scenarios of promoting development and safety with the aim of introducing most pressing change in key human activity areas, viz. management, professional and common radiological safety awareness along such lines: improving the management system; improving the systems of financing and allocation of required resources; staffing and improving the level of staff training; and boosting the local social potential.

The social projects of improving activities in each area are meant to be the following ones: models of positive social influence with a view to mitigate the radiological risk and address pressing victims' issues through organisational and self-organisation efforts including the following: organisational aspects (proposals on «up-down» planning; and self-organisation aspects (scenarios of local social projects).

The sources of social influences in each area are state management subjects and self-administration promoters; the administration of medical, educational, and production establishments and organisations; trade unions, communities; local communities; active workers; charitable organisations and benefactors, including international ones; communities and organisations sharing common problems/interests (medical, educational, production, and so forth); and enterprises (businessmen/women).

A. ***Medicine and recovery:*** 1) acknowledge the right to self-protection to elimination of the radiological risk for the entire affected population; 2) acknowledge the necessity of medical personnel's involvement in disseminating knowledge in self recovery, including a list of self-recovery means and techniques, along with their teaching in medical professional training programs; 3) put the following medical advice topics on the list of services provided by medical establishments: independent mitigation of the radiological risk; self-recovery; and self-prevention of diseases.

B. ***Education and information:***

B1. *Improving of professional skills of specialists in the following areas:* 1) medicine and recovery – the priorities are quality diagnostics and effective treatment, and introducing methods of self-recovery and prevention; 2) education and communication – add the radiological factor to the curriculum of retraining teachers; 3) production and household area – to train in techniques of personal dosimetry and safe housekeeping methods; 4) management – to introduce the fundamentals of radio ecological safety to existing legislation norms and spread the best experience; 5) to train personnel – volunteers for assistance in each specific area; and 6) to train in means of personal daily protection from the adverse effects of radiological factors.

B2. *Improving the general education of affected population:*

1) to acknowledge as compulsory the formation of daily radiation safety attitudes in the affected population on the basis of educational establishments; 2) to introduce instruction materials on radioactive elements and safe living in a radio-contaminated territory in the basic school curriculum; and 3) to introduce programs of social and psychological support for victims to revive their life attitude.

C. ***Production and housekeeping:*** 1) to analyse the quality of the investment environment and the possibility of its improvement with a view to retraining workers, starting up new production facilities and an infrastructure; 2) to intensify the activities of local business schools; 3) to improve substantially dosimetry monitoring and make available daily dosimetry data; 4) to introduce the practice of personal dosimetry monitoring at enterprises, in local communities, and by the general public.

D. ***Improving the management system:*** 1) practical approval of a person's right to radio ecological safety and personal active protection; 2) review of legislative provisions to revive the population's attitude and enhance personal radio ecological safety; 3) improving legislative and regulatory acts in governing business development; 4) developing effectiveness criteria and due coordination of actions of various management entities; 5) improving the financing system with involvement of public monitoring of target allocation of funds; and 6) ensuring information transparency of management actions.

The high social significance of implemention of social projects in daily life of communities will dramatically increase their chances of breaking the «viscous circle» of limited options, increase radiological safety awareness, and promote recovery and development of the victims' community.

4.6.5. Dynamics of victims' social and psychological conditions

The accident, evacuation, and participation in the elimination work – all these are events of the past, but for the victims of the Chornobyl accident they remain the constant factor of high subjective meaning [48]. The social and psychological after-effects of the Chornobyl catastrophe whose main indicators are as follows: state of health, psychological condition and social attitude, destabilisation of people's behaviour and awareness, and deterioration of the physical condition, have become the key indicators of welfare, and major changes in the lifestyle and attitude of those who became victims of the ChNPP accident and its after-effects.

The integral and multivalued peculiarity of individual and social perception is deep-rooted «victim's syndrome», which grows from 19% in 1992 to 35% in 1999 according to the data of social monitoring of the Institute of sociology of the National Academy of Sciences [49]. These people do not forget the catastrophe, they do not believe the essential consequences elimination, they consider themselves and their children to be victims for all their life, they have the increased level of anxiety, low living standard, low level of adaptive activity, high level of disappointment in people, with their own forces and with better future [48].

So far, to treat a number of the following social syndromes either by medical means, or at the expense of material compensations, or by rehabilitation of the environment was a failure:

- *«victim's syndrome»* – victims for all the life
- *«constant social exclusion syndrome»* – absence of interests, paternalism, demands for «national eternal rent» and sympathy from others
- *«evacuation and resettlement syndrome»* – the disturbed picture of the world, weak adaptation to the new conditions
- *«syndrome of lost health»* – annual self-appraisals of the level of adults and children's health become worse and worse.
- *«uncertainty and confusion syndrome»* – at almost complete distrust to the government and support on own forces and on the family victims transfer all their problems solution to the state
- *«ignorance syndrome»* – ignorance of situation, laws and rules of vital activity in the contaminated environment, victims live out of the everyday concepts of subjective risk.

Social-psychological state of affected people is distinctive with a number of paradoxes: 1) discontent with authorities and complete personal passivity often combine with orientation to national assistance for life for them and their children – assistance and more assistance; 2) high anxiety by state of ones health is not supported by observing the elementary sanitary and hygienic norms and rules of behaviour in contaminated regions; 3) inclination to amplification of own state, which Chornobyl factor destructiveness is constantly searched in, is not shown on the practical own participation in ecologically oriented measures or influence on taking decisions by authorities; 4) interest and amplification of subjective estimations of the risks instead of concentration on the search of chances of innovation models of survival; 5) insularity on the family interests and archaic and prim-

itive forms of farming, loss of feeling of society potential, its leaders' role, instead of these big hopes for God and «strong authorities».

The 20 post-accident years have not only failed to erase the processes of formation of an inadequate life attitude, reversal of life priorities, and enhancement of horrors, but, on the contrary, they have fixed them more distinctly. In evaluating life situations, one can see that irrational attitudes and emotional subconscious responses prevail. Each cohort of victims has acquired specific profiles of social and psychological losses due to the accident, though several features are typical for all of them.

Satisfaction with life conditions and level of optimism. Mass perception of victims is characterized by predominance of pessimistic orientations of the life situation, which was created after the Chornobyl accident. Only a quarter of victims are optimistically disposed [49].

The dominants of mass perception. The personal moral and cultural characteristics (honesty, well breeding, tactfulness) have the highest rating in mass perception.

Praxeological personal characteristics (responsibility, initiative, diligence, knowledge), which under conditions of crisis and instability in the society must serve to active self-organization and initiative of people, are pushed off the second place.

During 1991–2004, there was an increase in the dominant attitude related to meeting the essential needs of people; ensuring safe living conditions, and enforcing law and order in society. As in the early post-accident years, the affected population is concentrated on elementary survival issues, the most pressing ones being financial support, food products, and medical aid. Orientation of mass consciousness to consolidation of democratic values has slipped into the background in victims, and has lost much of its significance.

The problems related to children future, prices rising, health state, the Chornobyl NPP accident, provision of the family with food products and other goods remain the most actual ones among all the categories of victims.

Values. The leading values are focused on the health, children, family, material prosperity, and favourable moral and psychological climate in the society [50, 51]. Victim's orientation to self-organization, self-protection, initiative (including rising skill level, opening own business, land acquisition for farming) remains poorly shown.

Priorities linked to entrepreneurship remain nonessential. The victims, in addressing the issues of their own survival, rely mainly on themselves, their family and kin. In these matters, they rely little on public organisations, and do not trust the authorities [52].

Ecological component in the victims' vital activity. Residents of the contaminated territories point out environment conditions worsening in their settlements, which negatively influences their health conditions. Solving the environment problems is mostly relied on the central and local authorities. Readiness to the own participation in ecologically oriented measures is extremely low. Only 25% of the residents of Zones 2–3 agree to take part in such measures of nature protection as «planting of trees and gardens in the settlements» and «cleaning and putting in good order of settlements».

High anxiety with their own health and their children's health conditions without observing rules of behaviour in contaminated regions would seem to actuate precautions as to usage of forest mushrooms and berries. Instead the constant gathering, storage and coming out forest products from the contaminated territories for sale is observed.

The victims' perception of the ChNPP accident and the influence of its consequences on commonplace consciousness is characterised by the following: 1) a significant role of subjective self-perception of environmental conditions, health, and orientation of victims; 2) a huge difference between objective appraisals and subjective self-appraisals; and 3) in extreme conditions the people are governed mainly by subjective appraisals, i.e. subjective risks prevail over objective ones.

Models of survival. The victims demonstrate passive survival model mechanisms, resulting from absence of a system of rehabilitation measures to wrest the victims from a state of fatality and escapism.

Situation is such that 40–62% of the residents cannot determine their needs in the simple, clear and necessary services and objects for everybody. Desocialization is such that about 40% are not able, for example, to determine such insistent problem as gasification of settlements and buses [53] (Table 4.6.1).

The same high level of uncertainty from 40% to 64% is fixed concerning the additional needs of the individual kinds of activity and service. What can be more common in the settlement than the complete system of service? Instead, 48% victims did not indicate it, and only 2% indicated that they had it in their settlement (Table 4.6.2). The most urgent need in new jobs was indicated by 59% of the residents.

Search of new models of survival in desocializated victims’ societies is an extremely actual and too complex task.

Table 4.6.1

Estimations of the state and needs in some components of the social infrastructure of settlements by the residents of contaminated territories (2003, %)

Some components of the social infrastructure	We do not need	We do not have, but we need	We have but not enough	We have enough	It's difficult to say
Medical establishment	5	15	28	5	46
Children's infant schools	5	18	19	11	47
School	6	8	14	19	52
Children's non-school institutions	7	20	14	6	54
Post offices	9	5	22	21	55
Radio network	5	5	15	15	57
TV broadcasts reception	4	5	24	13	55
Gasification	4	34	15	10	38
Buses	4	24	25	7	41
Library	3	16	18	12	61
Culture palace (club)	4	6	16	13	61
Sport complex	5	23	9	4	60
Access to INTERNET	6	19	10	4	62
Church	6	16	5	29	44

Table 4.6.2

Estimations of needs in individual kinds of activities and services by the residents of contaminated territories (2003, %)

	We have had it, it has been done	We need	We don't need	It's hard to say
To rehabilitate environment, make it safe for life	2	18	2	50
To create new jobs, provide every-body with job	1	59	3	38
To create conditions for effective methods of economy	2	46	2	50
To create a complete system of services in our settlement (educa-tion, medicine, post office, trans-port, etc.)	1	48	2	48

Conclusions

1. The majority of victims are still in a state of social and psychological deadaptation. On the whole, the affected population is failing to demonstrate a real readiness to actual motive-driven behaviour in the short term.

It would be expedient to introduce the concept of social risks to the system of criteria for emergencies. The subjective risk, which is formed in humans by social and cultural traditions and daily living conditions, is ruining objective risks. Thus, people who started living in contaminated territories on their own reduced their subjective risks as compared to objective ones, whereas the resettled persons, on the contrary, enhanced them.

2. The acuteness of the resettlement issue in the minds of the population has practically dropped to the level of the nationwide trend that common people want to change their place of residence. Therefore, it would be practical to leave the victims living in the affected zones as they are based on a social contract between them and the state, viz. both parties undertake to bear the liabilities set forth in the contract.

At the same time, socioeconomic and social-cultural life should be revived in the affected zones in

due time. The communities, and moreover, children and adolescents cannot be kept in a waning life atmosphere.

3. Employment of affected population, in their opinion, demands more management by the state. The issue of unemployment, with the exception of self-employment, calls for immediate action. The victims believe that the most promising industries will be processing agricultural products, production of consumer goods, and home craft with implementation of innovative technologies.

In all affected territories, it is necessary to support extension and refresher courses for the majority of able-bodied population, and develop business and non-agricultural production, the more so because the victims themselves see this as a means of improving their welfare.

4. All the residents of Zones 2 and 3, and the majority of those resettled receive one or several kinds of welfare. In the majority of cases, these are: 1) privilege vouchers for recovery; 2) privilege taxation for victims; and 3) additional payments to those living in contaminated territories.

Welfare has to be maintained in the future, however, the state social policy has to extend the range of services provided, and not reduce them to welfare alone. It would be expedient to base the social policy on the principle of social rehabilitation of active disabled persons and communities, rather than on medical and financial aid alone. Target techniques and rehabilitation means should be adapted to at least three «social cohorts» of victims:

- «Self-supporting» – those who after rehabilitation are capable of providing themselves and their families with all essential means;
- «Semi self-supporting» – those who require some welfare for their self-support; and
- «Dependents» – those who can live only on welfare.

5. The level of systematic informing of victims is extremely low. Of high significance is the peculiar peoples' channel: «communicating with relatives, friends and acquaintances». Of very low significance are specialised, and, in this case, the most competent sources: «advice of medical workers, ecologists, and legal advisers», which have to be supported regularly.

6. Liquidators (recovery operation workers) are a special cohort who, at the risk of life and limb, stopped the disaster. Nowadays, the majority of them believe that society has forgotten them, and they advise no one to volunteer for recovery operations in the event something similar happens. The phenomenon of social oblivion, especially in a situation when the world community is trying to forget Chornobyl', is critical for Ukraine. Post-war Europe put in a lot of effort to remind of Nazism; Jews have done everything and are taking steps now to remind everyone of the holocaust. We have to take all necessary action to keep the unrecovered consequences of Chornobyl from slipping away into oblivion.

7. Almost all of Chornobyls issues would have been resolved more effectively and adequately if, immediately after the accident, monitoring of the victims' registry would have been launched. Ukraine, in the 80s' of the past century, had at its disposal world-class science and engineering, and an extensive background in computerised information systems. Everything was in place for monitoring the victims' registry. However, the authorities were not aware of the significance of this activity. Hence, we become flustered when public organisations disclose horrible data on the incidence rate level, social deadaptation, and mortality rate among liquidators. However, all these phenomena should be substantiated by valid statistical data.

8. It is necessary to spread the valuable experience of Centres for social and psychological rehabilitation and informing of affected population.

9. The existing Chornobyl Recovery and Development Program is worthy of extensive state and public support.

5. MEDICAL ASPECTS

5.1. Population health

Analysis and review of the key results of scientific research in the first 10 years after the accident have shown that the ***medical consequences of the Chornobyl accident differ dramatically from those initially predicted****.* The key contributors to health problems in all cohorts of sufferers were non-stochastic effects covering a wide range of non-neoplastic forms of somatic and psychosomatic diseases. In the majority of cases, such diseases reduced the working capacity of affected people and increased mortality.

In 2001, using the results of 15-year monitoring of different groups of affected people, Ukrainian scientists, jointly with experts from the WHO, UNSCEAR, IAEA and other organisations, developed a forecast of the future health situation and recommendations on elimination of the medical consequences of the accident within the next few years [1].

5.1.1. Potential adverse impact on health from nuclear radiation accidents

The Chornobyl catastrophe has demonstrated that nuclear radiation accidents are multifactor events with respect to their adverse impact on human health. One of the key factors is radiation exposure. A measure of the possible adverse impact of radiation on man's health is absorbed dose.

Radiation exposure can cause certain medical consequences, including cancer (of the thyroid gland, leukemias and solid carcers), genetic anomalies etc. Due to the absence of adequate receptors, exposure to radiation often causes stress, and anxiety about the health of suffered individuals and their families. Such anxiety is an unbiassed effect of the population's response to accident-induced contamination of territory, and results in grave psychosocial consequences.

The Chornobyl radiation accident was also the cause of economic loss in many countries, but especially in Ukraine, Belarus and Russia. Most importantly, this has undermined the family economy of communities which live on contaminated territories. Such negative economical effects promoted the endemia of contaminated areas.

The most contaminated territories of the Ukrainian Polissia are located on sod-podzolic and sandy soils which always were endemic by significant microelements (iodine, selenium, cobalt, iron etc.) essential for normal metabolism. In the pre-accidental period, the lack of microelements was partially compensated by importation of food, including marine products with a high content of the above mentioned microelements. The undermining of the family economics practically excluded from the food allowance of rural population imported goods leading to the need of consuming exclusively home-made and locally produced food and as a result to exsacerbation of endemy of territories, appearance of diseases depending on unbalanced nutrition.

5.1.2. Functioning of affected people registries

The key aspect of health monitoring programs was the creation of the State Registry of Ukraine (SRU) for people who suffered due to the Chornobyl NPP (ChNPP) accident. The number of people included in the SRU has increased from 264,857 in 1987 to 2,846,455 in 1996. At the beginning of 2006 (01.01.2005), the SRU included 2,405,890 persons of following groups of registration:

– clean-up workers (liquidators) of the ChNPP – 229 884;

– evacuees from the 30-km zone of the ChNPP – 49 887;

– dwellers of radiation-contaminated territories – 1 554 269;

– children born by parents of above identified groups – 428 045 [2].

A comparison of SRU data with other forms of State statistics reports has demonstrated the incompletenesse both in the general registration of sufferers in the SRU and in coverage them by medical follow-up (Fig. 5.1). Therefore, the registration strategy has failed to provide an effective feedback with the local units of the SRU and operational usage of registration data at the regional level.

The difficulties in maintaining and developing the SRU are related to many factors including (1) obsolete hardware (2) lack of staffing at all levels of its functioning, (3) inappropriate dosimetry, (4) inappropriate scientific-methodical and information-analytical support. The main reasons for these deficiencies is unstable and insufficient financing.

Other specialised registries in the Ukraine are as follows:

– Clinical Epidemiological Registry of the RCRM, AMS of Ukraine (representative samples from SRU for each registration group and control groups with a total of 42 000 persons);

– National Cancer Registry of the Institute of Oncology, AMS of Ukraine, which is being in function since 1996;

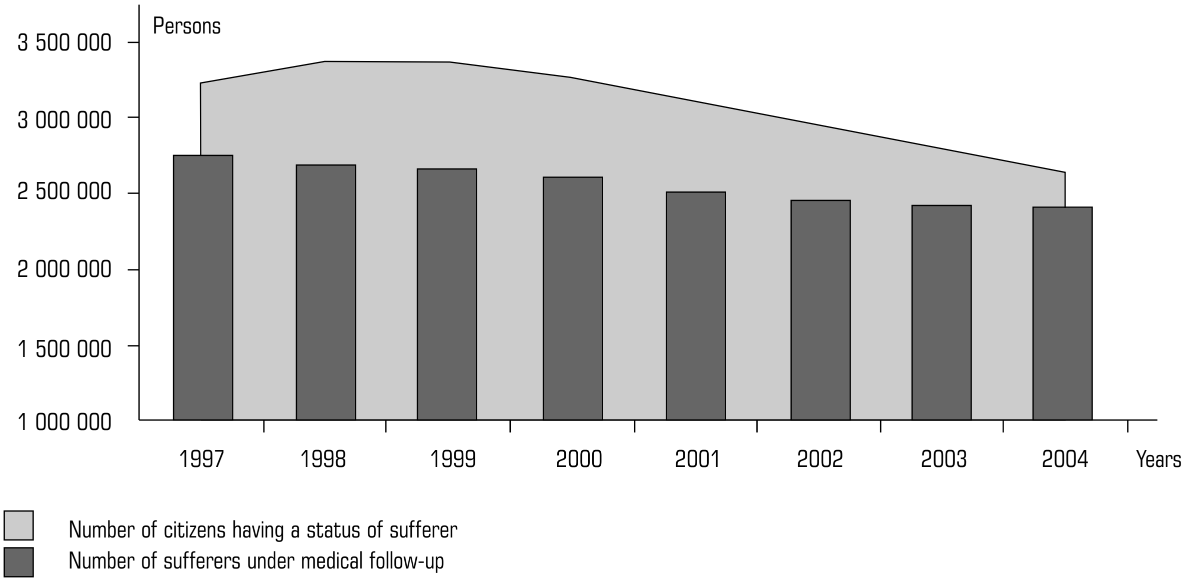


Fig. 5.1.1. Dynamics of number of people registered as sufferers under medical follow-up in the healthcare establishments of the Ministry of Health of Ukraine in 1997 to 2004; data of Research Centre for Radiation Medicine, Academy of Medical Sciences of Ukraine (RCRM, AMS of Ukraine)

– Clinical Morphological Registry of Thyroid Cancer (Institute for Endocrinology and Metabolism named by V.P.Komissarenko, AMS of Ukraine);
– Ukrainian Haematological Registry (RCRM, AMS of Ukraine);
– Automatic Control System of Databases for Monitoring of the Medical and Demographic Consequences of the Chornobyl Accident (ACS DB DEMOSMONITOR, RCRM, of Ukraine).

During the 20 years after the Chornobyl accident among the Ukraine's affected people radiation-induced stochastic and deterministic effects were registered as well as other health consequences resulting from exposure to radiation during the accident itself and clean-up works.

5.1.3. Stochastic effects

Children's thyroid cancer

The increase of thyroid cancer (TC) incidence in children started in 1989. According to the data of the Institute for Endocrinology and Metabolism of the AMS of Ukraine withing 1989–2004 only in Ukraine 3,400 people who had been children and adolescents at the time of the accident had undergone surgery for thyroid cancer. *Eleven of them have died.* In 2001 the 369 new cases of thyroid cancer were registrated, in 2002, 2003 and 2004 they were 311, 337, and 374 respectively, meaning that the morbidity has plateaued with no obvious decline in the nearest future (Fig. 5.1.2) [3].

In spite of the almost 99% short-term effectiveness of the treatment of thyroid cancer patients, their long-term quality of life will be reduced due to the necessity for life-long substitution therapy with thyroid hormones; limited physical and physiological capacities, and disturbances of the reproductive function. All of them will require state medical support in the future.

Thyroid cancer in adults exposed to radiation

After 2001, the medical community registered an expert-predicted excess of thyroid cancer in clean-up workers of 1986–1987. Amongst male, the nationwide level was exceeded in 1990 to 1997 by 4-fold, and in 1998 to 2004 it was exceeded by 9-fold; amongst female clean-up workers the level was exceeded by 9.7-fold and 13-fold respectively.

An increase in the rate in other monitored groups which was not predicted in 2001 was registered as well:
– amongst evacuees by 4-fold in 1990–1997, and by 6-fold in 1998–2004) compared to the nationwide level;
– *among adult dwellers of radioactive-contaminated territories* the increase was 4.1-fold in 1990–2004 compared to 1980–1989, and 1.6-fold compared to the nationwide level [4].

The dependence on the level of radioiodine fall-out and thyroid cancer cases was demonstrated for the first time both for children and adolescents and adults. An increase in the number of thyroid cancer cases is being forecasted for the next years.

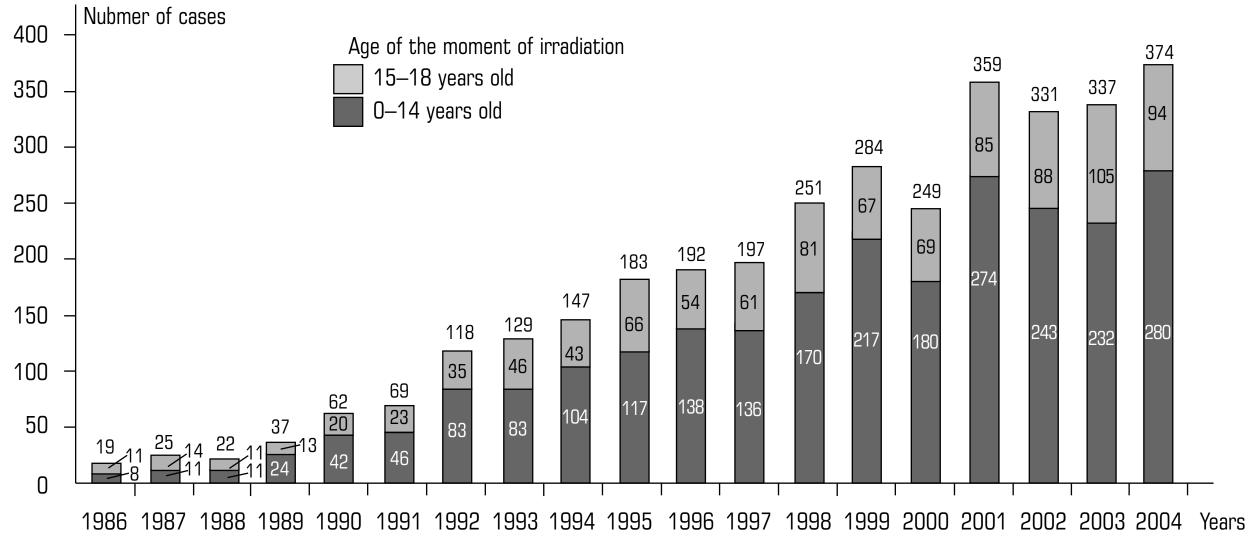


Fig. 5.2. Number of thyroid cancer cases in children and adolescents in Ukraine (0 to 18 years old at the time of the Chornobyl accident) (data of the Institute for Endocrinology and Metabolism named by Acad. V. P. Komisarenko of the AMS of Ukraine)

Table 5.1.1

Standardized incidence rates of thyroid cancer (ICD9 193) in different groups of affected people in Ukraine for 1990–2004 (data of RCRM AMS of Ukraine)

Group	Expected number of cases	Actual number of cases identified	Standardized incidence rates SIR (%)	95% confidence interval
Clean-up workers	28.1	156	554.3	467.3–641.3
Evacuees from the 30-km zone	31.1	175	563.5	480.0–647.0
Inhabitants of radioactive-contaminated territories	151.5	247	163.1	142.7–183.4

Leukemia

In 15 years after the accident, the leukemia incidence among clean-up workers who had been exposed to significant doses of radiation tended to increase: among 134 convalescents of acute radiation sickness (ARS) 5 oncohematological patients died shortly after onset of the diseases.

In a cohort of 110 645 clean-up workers in Ukraine for the time period of 1986–2000 an international groups of experts working within the framework of the Project of Ukraine – USA collaboration on elimination of the consequences of the Chornobyl accident, confirmed 101 cases of leukemia including 49 cases of chronic lymphoblastic leukemia; 15 cases of chronic myeloid leukemia; 18 cases of acute leukemia; and 4 cases of of large granular lymphocytes leukemia [5].

Risk studies have shown a probable increase in the leukemia incidence rate (Table 5.1.2).

Table 5.1.2

Risks of leukemia in the 15 years after radiation exposure (data of the joint Ukrainian-American project in studying leukemia cases, November 2005)

Type of leukemia	Relative excess risk, ERR*	95% confidence interval	Probability level, *p*
All types of leukemia in clean-up workers	2.41	0.11–7.54	0.03
All types of leukemia (except chronic lymphatic leukemia) in clean-up workers	3.22	–0.61–12.89	0.041
Chronic lymphatic leukemia in clean-up workers	1.55	–0.67–7.93	0.306
All types of leukemia (without chronic lymphatic leukemia) in atom bomb survivors	4.55	2.83–7.07	0.01

* Indices standardised by the year of birth and place of residence.

Studies in the framework of French-German Chornobyl initiative did not find any excess of leukemia among the dwellers of territories contaminated by radionuclides.

Data on leukemia cases among children who had been exposed in utero are contradictory and require further verification.

Other malignant tumours morbidity

The results of an 18-year analysis have shown that clear evidence for a growth in the incidence of cancer has been established only for clean-up workers,, whereas in other exposed groups the incidence rate of cancer is much lower than in Ukraine as a whole (Table 5.1.3). These data match earlier forecasts. Nevertheless, it is not possible to be sure that there will not be future variations in incidence and mortality rates due to malignant neoplasms occurring up to 40 years after exposure.

Table 5.1.3

Standardized incidence rates for all forms of cancer (ICD9 140-208) for different groups of affected people in Ukraine for 1990–2004 (data of RCRM AMS of Ukraine)

Group	Expected number of cases	Identified number of cases	Standardized incidence rates, SIR (%)	95% confidence interval
Clean-up workers	4529	4922	108.70	105.6–111.7
Evacuees from the 30-km zone	2615	2182	83.40	79.9–86.9
Inhabitants of radioactive-contaminated territories	13 211.6	11 221	84.90	83.4–86.5

A 1.9-fold increase in the rate of breast cancer of females clean-up workers of 1986–1987 comparing to its level among the respective age groups of the female population of Ukraine revealed during 1990–2004 aroses anxiety (Table 5.1.4).

Table 5.1.4

Standardized incidence rates of breast cancer (ICD9 174) in different groups of exposed female in Ukraine for 1990–2004 (data of RCRM AMS of Ukraine)

Group	Expected number of cases	Identified number of cases	Standardized incidence rates, SIR (%)	95% confidence interval
Clean-up workers, females	100.2	279	278.5	245.8–311.2
Evacuees from the 30-km zone	254.1	198	77.9	67.1–88.8
Female dwellers of radiation contaminated territories	1153.1	756	65.6	60.9–70.2

The breast cancer incidence rate for evacuated females increased by 1.6-fold, but this value does not exceed national level.

Molecular-genetic studies conducted in the Urology Institute of the AMS of Ukraine jointly with the Medical University in Osaka (Japan) have shown that in 53% of investigated cases, mutation inactivation of the oncosuppressor gene p53 occurred; and in 96% of cases precancerous changes in the urothelia of the urinary bladder had developed among patients inhabitants of contaminated territories due to chronic long-term exposure over 14 years to low-dose ionising radiation. This has caused genetic instability which may lead to development of predominantly invasive forms of cancer of urinary bladder [6].

Genetic damage

Selective cytogenetic monitoring of critical groups of exposed Ukrainians has been conducted for twenty years after the accident.

In all the groups monitored during different post-accident periods, the rate of chromosome aberrations in peripheral blood lymphocytes (both integral and specific for ionising radiation exposure *in vivo*) significantly exceeded pre-accident indices characteristic for spontaneous chromosome mutagenesis [7]. An increased frequency rate of chromosome aberrations was found in children who had been exposed to combined ^{131}I and ^{137}Cs radiation, especially on iodine-deficient territories. The influence of thyroid pathology on induction of chromosome non-stability in human somatic cells was demonstrated [8]. A deferred cytogenetic effect has been found in successive cell generations in the progeny of irradiated parents proving for real transmission of chromosome non-stability [9].

At the remote period after the accident an inadequate response of the chromosome apparatus to testing mutagenic burden *in vitro* as an adaptive response of the children of contaminated territories and genome non-stability in clean-up workers with significant individual variation were revealed [9].

A statistically significant 1.6-fold increase in the rate of mutations in minisatellite DNA loci of children due to preconception exposure of parents was found. Irradiation of mothers did not result in increasing mutation of minisatellite DNA loci of germ-line cells [10].

5.1.4. Deterministic effects

Acute radiation syndrome

Acute radiation syndrome (ARS) is a universally recognised deterministic consequence of the Chornobyl NPP accident. After the in-depth retrospective analysis (in 1989) of the case histories of 237 persons who had been diagnosed in 1986 as ARS, the real number of affected people with such diagnosis dropped to 134 persons. Among them, 28 patients died in the first three months after the accident; 14 died during the first 15 years, and 16 more died in the following years (data on the January 1st, 2006) despite continuous follow-up, regular treatment and rehabilitation measures (Fig. 5.1.3).

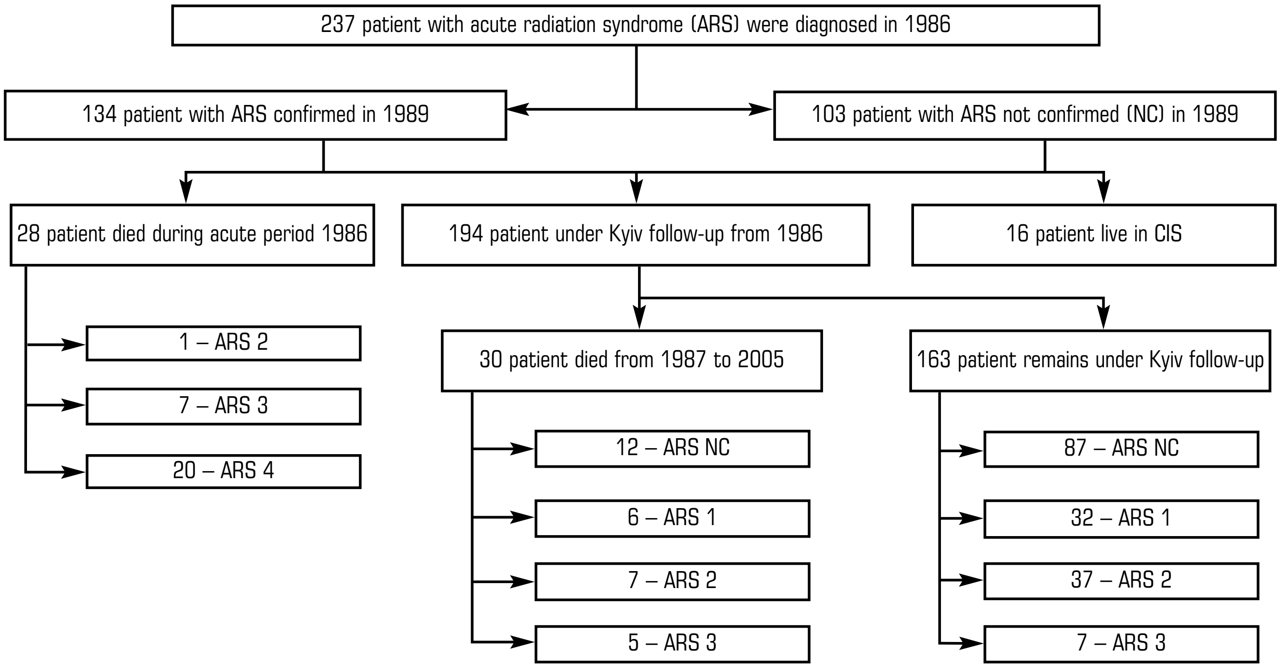


Fig. 5.1.3. Number of patients under follow-up examination in Kyiv (RCRM) that changes due to their death

Those people who have endured ARS and remain alive are suffering from chronic diseases of internal organs and systems (from 5–7 to 10–12 diagnoses concurrently), originating from the combined influence of different harmful agents associated with the Chornobyl accident, primarily radiation exposure. The somatic pathology of these affected people is characterised by an initially high and stable level of nervous system diseases, significant inflammation and erosive-ulcer processes in the gastrointestinal tract, and a progressive increase in the incidence of hepato-biliary, cardiovascular and respiratory system diseases.

For the majority of these people, typical radiation associated problems include the development of radiation cataracts (the incidence rate of which depends on the absorbed radiation dose), and the consequences of radiation burns of the skin with different grades of severity (in 1/3 of the sufferers). Burn problems range from radiation dermatitis in small areas and depth lesions up to the amputation of a limb in one of the patients.

Practically all people with ARS, irrespective of its severity, were assigned to group II of disability due to stable losses of working capacity involving both low levels of health indices and impossibility to work as a professional nuclear industry worker or fire fighter. The majority of these people annually, or more often (depending on their health condition), undergo in-patient follow-up and treatment in the clinic of the RCRM AMS of Ukraine.

The results of prolonged follow-up and of overall assessment of the health state of this cohort of people indicate an unfavourable prognosis concerning the effectiveness of supportive therapy and follow-up care measures aimed of prevention of disease complications and extending their lifespan [11].

Cataract

Totally 165 cases of ***radiation cataract*** have been registered. This kind of eye pathology considered to be a specific deterministic effect of radiation exposure. It has been found that radiation cataract can develop due not only to high radiation doses, but also to radiation doses much lower than 1 Gy (Table 5.1.5). Available data (from follow-up of 14,731 clean-up workers) suggest that radiation cataract should be considered as a stochastic effect of radiation exposure [12].

Table 5.1.5

Dose-effect for radiation cataract in clean-up workers (data of RCRM AMS of Ukraine)

Dependence of risk on:	Level of additive-relative risk	P
radiation cataract	3.451 (1.347; 5.555) на 1 Гр	< 0.05
duration of participating in recovery operations	1.095 (1.017; 1.173) на 1 log (1/tdn)*	< 0.05

* tdn – number of days when people took part in elimination of consequences.

A dose-dependent increase in prevalence of involution cataract, choroid retinal central macular degeneration, and pathology of the vitreous body among clean-up workers has been confirmed.

The dwellers of the zone of guaranteed voluntary resettlement demonstrate a higher incidence rate of involution cataract, central vision dystrophies and pathology of retina vessels compared to residents of less contaminated territories.

Immunological effects

Studies during 20 postaccidental period confirmed that the immune system belongs to critical systems by its radiosensitivity. Immunological follow-up of over 120 000 people of different registration groups in the RCRM of AMS of Ukraine allowed to identify basic types of radiation injury and immune system recovery, emphasized its significance in forming remote radiation effects. Studying the dose dependencies and the exposure time has shown that 11–13 years after exposure 23.2% of clean-up workers retained manifestations of combined immunodeficiency, namely T-link depression involving a high degree of correlation of the number of $CD3^+$ HLA^- DR^- cells with the absorbed dose [13].

Some HLA-antigenes (HLA-A10; HLA-A28; and HLA-B38) and their combinations associated with high radiosensitivity of the human body were identified. The presence of HLA-B5, Cw2, and Cw5 antigens in the patient's phenotype is predictive for high resistance and low risk of diseases depending on radiation exposure [14, 26].

A significant spread of cytomegalovirus and hepatitis types C and B viral infections [15] amongst the people exposed to different doses of radiation was found.

Thresholds for appearance and maintaining of radiation-induced immune injuries were established in the remote period 15 to 18 years after exposure at the level of 200–350 mSv. Interaction of the immune and nervous systems can intensify immunological disorders. Adaptive and activation type responses in people exposed to sub threshold doses are most likely related to psychological stresses and other side-effects [16].

Dose-dependent effects in the immune system are observed even offer 15 or more years at both individual and group levels. In the remote period the number of cells with TCR mutation directly correlated with impairment of immunity in convalescents (Fig. 5.1.4).

A high proliferation activity and accumulation of $CD34^+$ cells after exposure to high doses reflects adaptation processes and in combination with reduced apoptosis becomes a basis for forming late radiation-induced effects, in particular, leukemia [17].

Non-tumour diseases

General morbidity and disability. The results of epidemiological studies have shown that, during 1988–2003, the number of healthy individuals among the 1986–1987 clean-up workers has dropped from 67.6% to 7.2%, whereas the number of patients with chronic diseases has grown from 12.8% (in 1988) to 81.4% (in 2003). Within the structure of non-tumour diseases the leading positions belonged to the diseases of cardiovascular, digestive and nervous systems (Table 5.1.6).

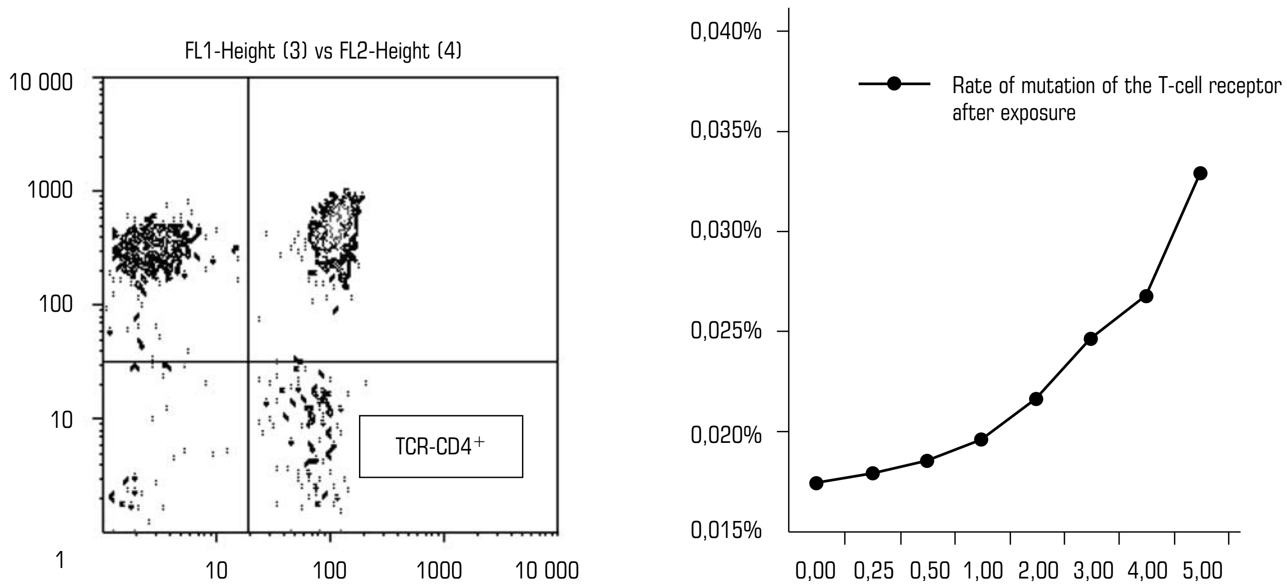


Fig. 5.1.4. Cytofluorogram of lymphocytes with T-cell receptor mutations and histogram of T-cell receptor mutations rate compared to absorbed doses (data of RCRM, AMS of Ukraine)

Table 5.1.6

Prevalence (‰) and structure (%) of non-tumor diseases among clean-up workers of 1986–1987 (males) according to follow-up of subsequent years (data of RCRM, AMS of Ukraine)

Classes of diseases	1988		1999		2003	
	‰	%	‰	%	‰	%
All diseases	420.0	100	3012.1	100	3530.7	100
Cardiovascular system diseases	95.6	22.8	676.2	17.3	932.6	26.4
Digestive system diseases	96.8	23.1	733.0	24.3	887.9	25.1
Nervous system and sensory organs diseases	85.3	20.3	555.5	18.4	563.8	16.0
Respiratory system diseases	47.0	11.2	340.3	11.3	334.2	9.5
Musculo-skeletal system diseases	35.3	8.3	270.7	8.99	295.7	8.4
Endocrine system diseases	41.3	9.8	168.0	5.6	218.8	6.2
Urogenital system diseases	9.8	2.3	77.4	2.6	98.4	2.8
Mental disorders	5.8	1.4	29.8	1.0	24.9	0.7
Skin and subcutaneous tissue diseases	2.0	0.5	16.1	0.5	13.0	0.4
Hematological diseases	1.1	0.3	6.9	0.23	8.2	0.2

Doses of external whole-body exposure within 0.1–1.0 Gy are a risk factors for a wide range of non-tumor diseases onset in clean-up workers of 1986–1987. The incidence rate is higher among the clean-up workers who have been exposed to radiation doses exceeding 250 mSv [18].

Among the clean-up workers of 1986-1987 a high level and burst in growth of disability from 2.7‰ to 208.3‰ during 1988–2003 were demonstrated. According to the SRU data, at the level of external whole-body exposure doses over 0.25 Gy, a high level of disability occurs in liquidators of older age groups (40–59 years old at the time of examination).

Negative trends in the ***health state of adults evacuated from Prypiat and the ChNPP 30-km zone*** were established. From 1988 to 2002 the number of healthy people amongst examined people decreased from 67.7% to 22%, whereas the number of chronic patients increased from 31.5% to 77%, the prevalence of non-tumour diseases increased from 631.5 to 3,037.2‰; and the incidence increased from 377.4 to 1,104.5‰. Since 1991–1992, the morbidity rate of adult evacuees is being exceeded similar indices for Ukraine's adult population.

In dynamics of follow-up a higher overall incidence and prevalence rate of diseases were being

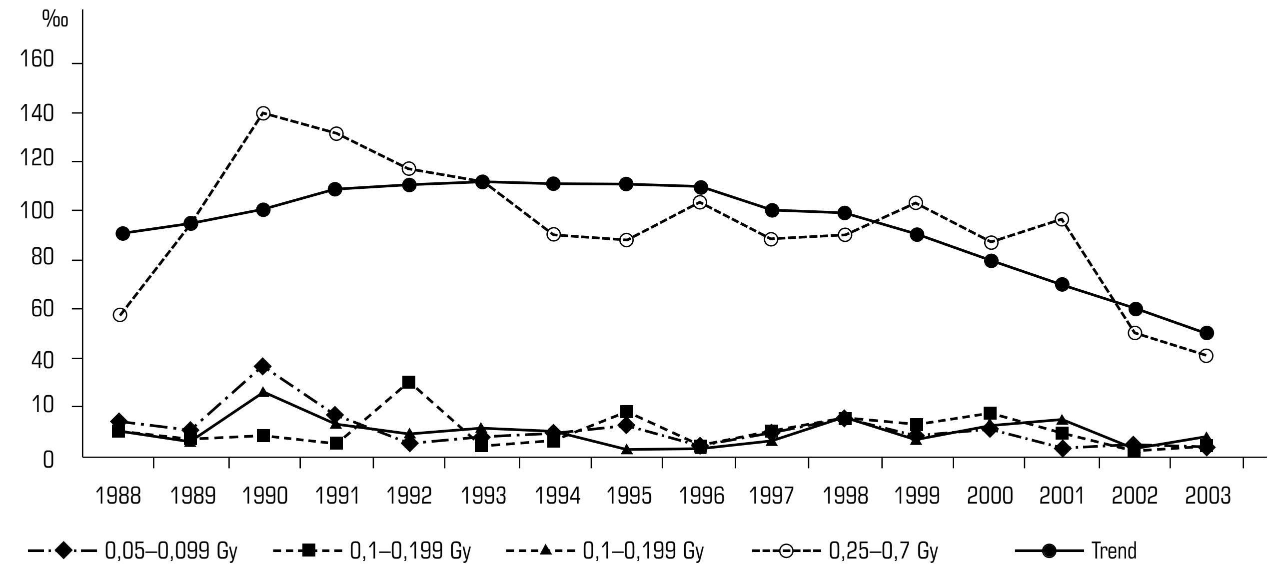


Fig. 5.1.5. The dynamics of non-tumour morbidity of 1986-1987 clean-up workers during the years of follow-up depending on the whole-body external irradiation doses (data of RCRM, AMS of Ukraine)

revealed in cohorts of evacuees who lived on the radiation-contaminated territories compared to evacuees dwellers of conditionally non-contaminated areas [19].

According to study data, negative health conditions are not only a result of radiation factor influence. A variety of non-radiation effects such as social-economic, domestic, behavioural, play a significant role in health impairment in the post-accident period. The evacuated adult population disability indices since 1988 to 2002 increased from 4.6‰ to 103.4‰.

Among the population living on radiation-contaminated territories during 1988–1999, the prevalence of diseases and incidence increased more than by 2-fold (from 620.9 to 1275.6‰, and from 309.5 to 746.0‰ respectively); since 1993–1994, the incidence rates of affected people had exceeded the population ones.

The incidence rate of radiation contaminated territories dwellers depends on the people's place of residence. It was found in a special cohort study of residents of radiation contaminated territories, that

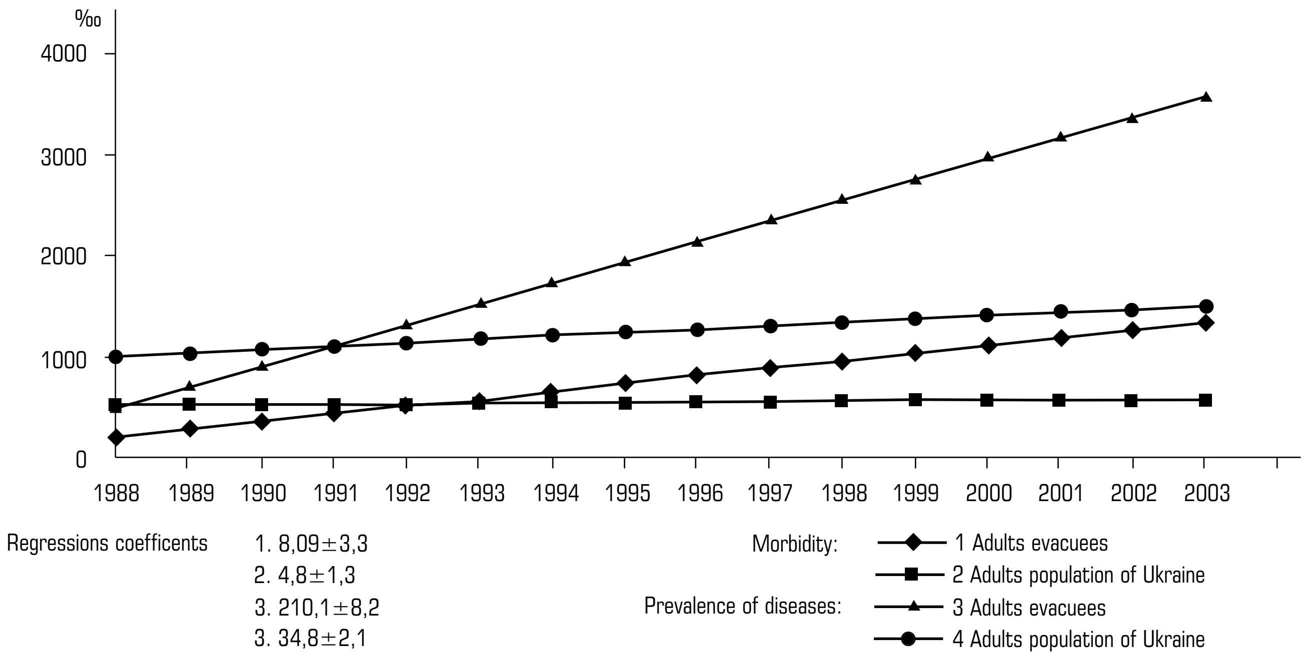


Fig. 5.1.6. Incidence and prevalence of non-tumour diseases in evacuees from the town of Prypiat compared with that of Ukraine's population in 1988–2003 (data of RCRM, AMS of Ukraine)

people with thyroid absorbed doses exceeding 200 cGy demonstrated higher relative risk of development cardiovascular diseases, especially in the form of cerebrovascular pathology, as well as a higher risk of development of endocrine pathology and diseases of the musculoskeletal system , comparing to those with thyroid absorbed doses below 30 cGy.

Cardiovascular diseases

Cardiovascular diseases in affected people are associated with radiation exposure. Minimal absorbed doses have been established for clean-up workers which induced an increase of cardiovascular morbidity (Table 5.1.7).

Table 5.1.7

Minimal doses of exposure, which cause an increase of cardiovascular patologies in liquidators of accidents consequences (data of RCRM AMS of Ukraine)

Nosology	Codes of ICD-10	Codes of ICD-9	External exposure, Gy; $p < 0,05$
Angiopathy and angiosclerosis of the retina	H35.0	362.1	≥0.5
Essential hypertension	I10–I15	401–405	≥ 1.0
Coronary heart disease	I20–I25	410–414	≥ 0.25
Endomyocardial fibrosis	I42.0	425.0	≥ 0.1
Cerebrovascular diseases	I60–I69	430–438	≥ 0.25

A dependency of cerebrovascular pathology on exposure doses has been found for clean-up workers. The risk of development of these diseases is higher in exposed people with absorbed doses 0.5–1 Gy compared to people with absorbed doses below 0.1 Gy [20].

Neuropsychiatric effects

Neuropsychic disorders in affected people are being kept as a challenging problem nowadays [20].

Neuropsychic disorders in the remote period of ARS demonstrate a progressive pattern with a successive change of phases from the vegetovascular and vegetovisceral disorders to the cerebro-organic and somatogenic disease (Fig. 5.1.8).

Post-irradiation organic mental disorders were observed in 62% of patients with absorbed doses above 1 Sv. Neuropsychological studies revealed dose-dependent indices of damage in the left temporal area, deep cerebral structures and frontal formations primarily in the left hemisphere. A quantitative neurovisualising feature of the late ARS period is the atrophy of hemispheres' cerebral cortex and dose-dependent involvement of conduction pathways in the dominant hemisphere.

Studies of a representative cohort of clean-up workers by a standard psychiatric interview

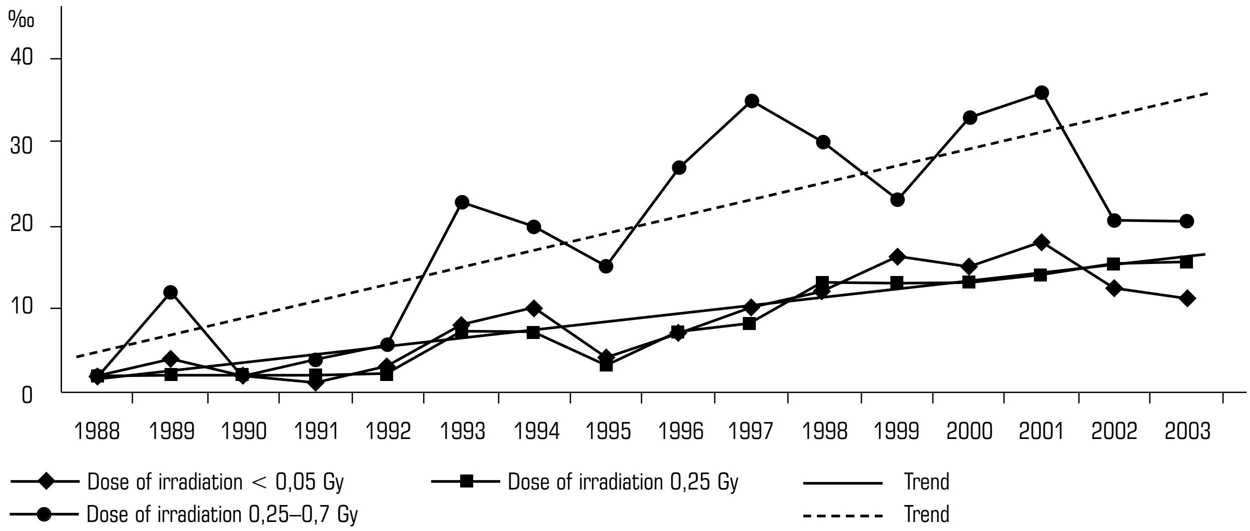


Fig. 5.1.7. Cerebrovascular diseases incidence rate for clean-up workers of 1986–1987 depending on external whole-body exposure doses (data of RCRM, AMS of Ukraine)

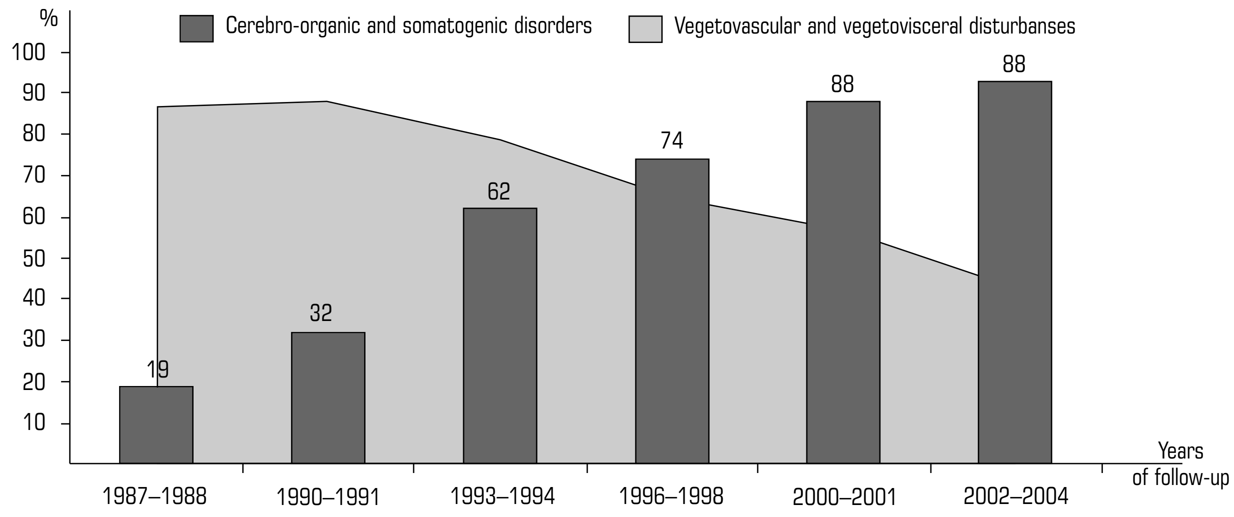


Fig. 5.1.8. Dynamics of vegetative and organic mental disorders after acute radiation syndrome

within the framework of the French-German Chornobyl Initiative have demonstrated an increased prevalence of mental disorders up to 36% among clean-up workers as compared to the Ukrainian population (20.5%), as well as growth of depression up to 24.5% as against the Ukrainian population (9.1%).

Since 1990 the follow-up studies have registered growth of schizophrenia prevalence among the personnel of the Chornobyl exclusion zone, with up to 5.4 cases per 10 000 as against 1.1 case per 10 000 in Ukraine. These data are of preliminary characteristics and need to be a subject of future clinical investigation and epidemiological confirmation on more larger cohort.

Characteristic mental disorders of the remote period after accident in investigated clean-up workers are variants of organic personality disorders. Exposure-dependent neuropsychiatric, neurophysiological, neuropsychological and neurovisualising disorders were identified at the whole-body exposure in doses above 0.3 Sv.

The mental health of females evacuated from the town of Prypiat was deteriorated due to posttraumatic stress disorders, depression, somatoform disorders, anxiety and social disfunction.

The bronchopulmonary systems

According to data of the Ministry of Health of Ukraine, in 2004, the incidence rate of chronic bronchitis, non-specific bronchitis, and emphysema among the adult and adolescent affected due to the ChNPP accident increased comparing to 1990 from 316.4 to 528.47 per 10,000 persons, the incidence rate of bronchial asthma grew from 25.7 to 55.44 per 10,000 persons respectively.

Under the joint influence of external irradiation and inhalation of fission-product composition of radionuclides, the bronchopulmonary system becomes one of the key target tissues, later it transforms clinically into a chronic obstructive lungs disease (COLD). This is evident from a comparative clinical morphological examination of COLD in 2,736 exposed patients and in 309 unexposed patients with COLD obtained from 1987 to 2005.

According to data of the Clinical Epidemiological Registry of the RCRM, AMS of Ukraine (16,133 examined clean-up workers), the COLD incidence rate is growing. In the group of 7,665 clean-up workers of 1986–1987 with absorbed doses of 250 mSv and above a significant relative risks of chronic obstructive bronchitis incidence were revealed; relationship between chronic bronchitis and exposure was dose-dependent (Fig. 5.1.9)

COLD pathomorphosis associated with the action of radiation-dust and other injuring factors in 1986 clean-up workers is characterised by a change in the minimal clinical symptoms of the early period followed by rapid development of fibrotic changes in the lungs and mucous membrane of the bronchus, and their progressive deformation, which is followed by intensification of ventilation disorders [21].

Diseases of the digestive system

In the early post-accident years, the pathology of digestive system was conditioned by disorders in vegetative regulation of the motility and secretory functions of the stomach. Furthermore they resulted in onset of erosive gastroduodenitis and peptic ulcers of the stomach and duodenum.

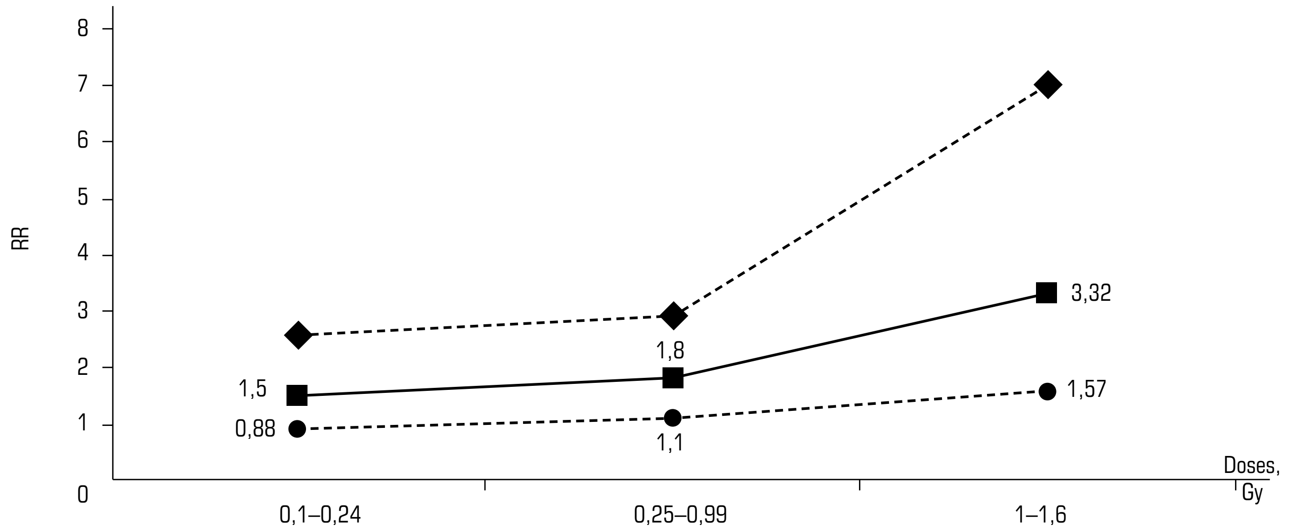


Fig. 5.1.9. Relative risks (RR) and the 95% confidence interval of chronic obstructive bronchitis (491.2, ICD-9) prevalence among males clean-up workers of 1986–1987 with different whole-body absorbed doses (data of clinical epidemiological study of RCRM, AMS of Ukraine from 09.1992 to 04.2004).

During the first decade after the accident, the incidence rate of peptic ulcers in clean-up workers and residents of contaminated territories significantly exceeded these indices of Ukraine's population. The increase in the peptic ulcers incidence rate and severity of its clinical course in the persons mentioned were induced by Chornobyl catastrophe-related factors.

Recent studies in the clinical and morphological aspects of peptic ulcers in persons evacuated from the territories with high level of radioactive contamination have identified a progressive course of inflammation in the stomach, development of which had coincided in time with the ChNPP accident, and presently is manifested as peptic ulcers incidence [22].

Development of chronic hepatitis and liver cirrhosis are the remote effects of Chornobyl catastrophe, which, in the early stages after the ChNPP accident, had been identified as diffuse changes in the liver with features of adaptive-compensatory hepatopathy [23].

Hemopoietic system's state

The results of monitoring of the hemopoietic system of the Chornobyl NPP accident affected people during 20 years showed that part of the examined persons had deviations in peripheral blood counts. In the first 1–2 years 25% of the clean-up workers showed evidence of peripheral blood leukopenia, negligible number of persons had in peripheral blood an increased content of red blood cells and haemoglobin level (9.5%), increased white blood cells counts (12%), thrombocytoppenia (9%), increase of counts of eosinophils (10.5%), lymphocytes (14.5%) and monocytes (10.5%).

Such unstable deviations were registered at the remote time after the accident: leukocytosis and leukopenia in 24% and 19.7% of examined people, thrombocytopenia in 7.6%, thrombocytosis in 2.4%. In 15% of cases, there was a combination of different syndromes, such as leukopenia and thrombocytopenia, leukopenia, anaemia and thrombocytopenia.

For the entire follow-up period there were characteristic qualitative disturbances in the nucleus and cytoplasm of granulocytes, lymphocytes and red blood cells. Among megakaryocytes an increase in the number of «old» cells was registrated with the presence of gigantic form of platelets, cells with polymorphic granularity; and some of the examined people had thrombocyte aggregates and clusters of micro and macro forms.

The ChNPP accident affected people who have different quantitative and qualitative disturbances in the elements of all hemopoietic processes comprise a risk group of oncohematological diseases. In the risk group of 4,200 individuals selected for examination by haematologists of the RCRM of AMS of Ukraine among 46 000 injured children 11 cases of leukemia have realized to date.

Non-tumour thyroid pathology

Chronic thyroiditis (Fig. 5.1.10) and other non-tumour thyroid pathology are a pressing problem for all cohorts of affected people. This problem is especially challenging for residents of iodine-endemic territories in the Ukrainian Polissia.

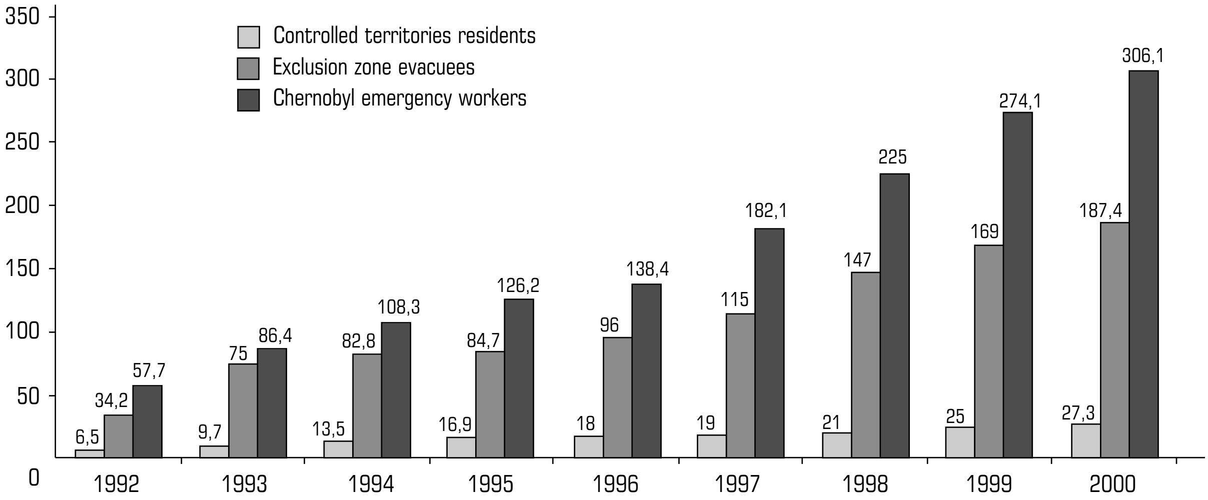


Fig. 5.1.10. Prevalence of chronic thyroiditis in Ukraine in groups of affected people (adults and adolescents, per 10 000; data of Ministry of Health of Ukraine)

State of health of children population

Persistent negative changes in the health state of the children population belong to medical consequences of the Chornobyl catastrophe.

Statistical data on the health condition of children of 0–14 years of age who had suffered due to the ChNPP accident has shown that in all post-accident years their morbidity tends to grow progressively from 455.4‰ in 1987 to 1,367.2‰ in 2003. The prevalence of non-tumor diseases is also tending to grow (Fig. 5.1.11).

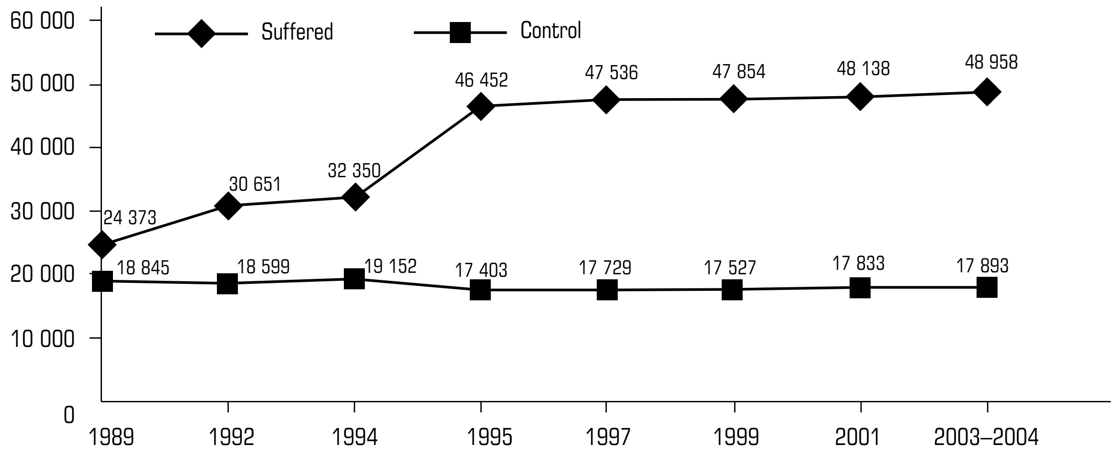


Fig. 5.1.11. Dynamics of non-tumour diseases prevalence (per 10,000) among children and adolescent affected due to the Chornobyl catastrophe (data of RCRM, AMS of Ukraine)

Presently in the structure of disease incidence of children of 0–14 years predominant are diseases of the respiratory, nervous, and digestive systems, of the skin and subcutaneous tissue diseases, infections and parasitic diseases, and diseases of blood and hemopoetic organs.

A portion of healthy among exposed children has been decreasing (from 27.5% in 1986–1987 to 7.2% in 2003) whilst that of exposed children with chronic diseases has been increasing (from 8.4% in 1986–1987 to 77.8% in 2003); and the number of disabled children among them exceeds the mean population level in Ukraine by a factor of 4. The most unfavorable changes have been observed in adolescents with high doses of thyroid gland irradiation and in adolescents irradiated in utero. The number of healthy individuals among them is less than 3%.

Significant changes concern to the incidence of digestive organ diseases (23.9‰ in 1988 and 72.5‰ in 2003). The incidence rate of combined involvements of digestive tract has increased, and are being diagnosed even in children of preschool age.

The consequences of the Chornobyl catastrophe influenced significntly on the immune system of children. In 82.5% of children (against 39.5% in, the control group, $p < 0.05$), an immune imbalance has

been identified being a background for allergic skin damages, otorhynolaringological and bronchopulmonary diseases as well as of immunodeficient states.

A distinctive feature of somatic pathology is multisystem, multiorgan characteristics of effects, their relapsing time course with relative resistanceto treatment.

An appraisal of radiation risks for adolescents who are residing on contaminated territories has shown that 92.8% of irradiation effects will be related to exposure of the thyroid gland; 4.8% – to external gamma-radiation exposure; 2.3% – to internal irradiation by ^{137}Cs, and 0.1% – to exposure to ^{90}Sr. These risks could be realized up to 2055.

Dynamic follow-up of children who had been exposed to ionising radiation in utero has shown that irradiation of thyroid gland and the central organs of fetus's immune system in dosage range of exposures characteristic for the Chornobyl accident can induce affects, which are manifested after the birth as growth and development disturbances, increasing rate of stable involvement of the chromosome apparatus, disturbed functioning of the immune system, and an elevated risk of incidence of multifactorial pathology.

Studies within the framework of the French-German Chornobyl Initiative have identified a higher rate of nervous system diseases and mental disorders in prenatally exposed children. Exposed children had a lower total IQ due to a lower verbal IQ and a higher rate of disharmonic intellect than unexposed coevals. When this disharmony in prenatally exposed children exceeded 25 points, it correlated with fetus absorbed dose. The mothers of children of both groups had no discrepancies in their verbal intellect.

A radioneuroembryological effect has been identified in the form of disharmonic intellectual development of a child due to a reduced verbal IQ for cases of intrauterine exposure at the 8th and latter weeks of gestation with exposure of the embryo and fetus to > 20 mSv and doses on the thyroid gland in utero > 300 mSv reflecting a dysfunction of the cortical-limbic system mainly in the dominant (left) hemisphere. It has been shown that on condition of a radiation accident with emission to the environment of radioiodine nuclides with relatively low doses of external irradiation brain damage is possible both at the most critical cerebrogenesis stage (8–15th gestation weeks), and during later periods of pregnancy when thyroid absorbed doses in utero are the highest.

Children born by exposed parents also have poor health. This is confirmed by the high general morbidity rate that oscillated over the past five years within 1,134.9–1,367.2‰ (against 960.0–1,200.3‰ in Ukraine as a whole).

According to data of an in-depth survey, the number of healthy children among them is 2.6–9.2%, (in control group – 18.6–24.6%), and the pathological injury index equals to 5.4–6. This cohort of children is characterised by a reduced capability to adapt to the environment, a retardation of biological age comparing to calendar age, and immunity disorders with most prominent changes in children born of clean-up workers in 1986–1987 exposed to radiation doses of 25 cSv or more.

Children born by exposed parents develop a phenomenon of genome non-stability. They more often manifest external disembriogenetic stigmata, minor malformations of inner organs and congenital malformations, enhanced mutation processes both in indicator cells and target cells that can lead to disturbance of their functions and be a cause of appearance of stochastic and possibly, certain non-stochastic radiation effects.

The mental state of the affected children of all cohorts is significantly worse compared to that of controled groups of the same age. Among the most significant mental deviations are: self-sensation as a victim; a state of social alienation and discrimination, especially with regard to receiving education, employment, and creating a family; lacks of initiative; rental aims; a sense of fatality in perceiving personal health condition; and anticipating inevitable consequences of irradiation for oneself and relatives, expectancy of unhealthy progeny.

This morbid emotional condition is a powerful factor of the initiation of psychosomatic disorders involving further psychosomatic morbidity.

Examination of evacuated adolescents allowed to identify statistically significant relations of psychoemotional stress with separate nosologic groups: neurotic disorders, psychopathy and other mental disorders of nonpsychotic character; non-tumor diseases of the thyroid gland (hypofunction, hyperfunction, and thyroiditis); and gastroduodenal pathology (gastritis, gastroduodenitis, stomach and duodenum ulcers) and vegetative disorders. All this stresses the necessity to develop psycho-social support programs involving nosology-specific measures.

Reproductive losses in women, dwellers of territories contaminated with radionuclides

UNSCEAR drew conclusion (2000) that the increases of congenital defects and reproductive losses which had been shown in some investigations, cannot be connected with radiation influence due to the accident. Taking into account the levels of doses accumulated by population, such conclusion seems to be appropriate and coinsides with main corpus of scientific knowledge of world radiobiology.

Lack of an unified opinion about reproductive effects of low doses irradiation conditioned the necessity of determination of possible influence of radiation factor on the level of reproductive losses in women of Kyiv region living on the territories contaminated with radionuclides.

According to calculations of departmental statistical reports of Ministry of Health of Ukraine no increased risks of reproductive losses during 1992–2003 were found: relative risk was equal to 0.90 with confidence interval (CI) 0.87–0.94, miscarriages as their basic component (0.91 with CI 0.87–0.95), and stillbirths (0.79 with CI 0.71–0.87) among population of radiation contaminated districts of Kyiv region comparing to radioactively «clean» and to region as a whole. No increase of miscarriages probability up to 12 weeks of pregnancy at the same period was found (0,95 with CI 0,90–1,01) [31].

In the frame of Special complex program of genetical follow-up of population in 1999–2003 pp., approved by the Decree of President of Ukraine № 118/99 from 04.02.1999) cases of miscarriages under 12 weeks of gestation among desirable pregnancies were studied in 1442 women with accumulated individual doses of whole-body irradiation, calculated in accordance with «Total dosimetry passportization of the settlements of Ukraine» (2000).

Registration cards of spontaneous abortions in women, living abroad of Kyiv region or Ukraine, as well as cases when one of spouses was ChNPP clean-up worker or resettled from the zone of compulsory resettlement were excluded because of impossibility to define accumulated doses. Spontaneous abortions among the women of above 40 years, having three and more children and medical abortion in the past were excluded as well. Odds ratio (OR) with 95% confidence intervals (CI) were calculated to check the hypothesis about influence of factors on the level of pathology taking into account asymptotic distribution in relation to the group which did not experience the influence of radiation.

The women living in the radiation contaminated settlement and accumulated certain doses of whole-body irradiation, were of increased risk of spontaneous abortions comparing to women living on radioactively clean territory. Risks were increased in all studied groups (Table 5.1.8) [32].

Table 5.1.8

Probability of spontaneous abortions depending on dose of whole-body irradiation, accumulated by woman, Kyiv region, 1999–2003

Year	Accumulated doses of whole-body irradiation							
	total		below 5 mSv		5–10 mSv		above 10 mSv	
	OR*	CI**	OR	CI	OR	CI	OR	CI
1999–2003	1.36	1.14–1.63	1.33	1.09–1.63	1.34	1.01–1.77	1.76	1.05–2.97

* OR – odds ratio; ** CI – confidence interval.

To date reproductively active are women, who had been in prepuberty and puberty ages at the time of accident, in other words, they had been more sensitive to external influences. Exposure, especially thyroid gland in those period could induce hormonal and immune changes with disturbance of reproductive function as an aftermath. It is worth mentioning that some districts of Kyiv region are being iodine deficient that increase the sensitivity of human body to negative impacts [33].

To estimate the influence of confusing factors data were submitted to stratification analysis by groups with accumulated doses above 5,0 mSv and non-exposed.

It was revealed, that the influence of dwelling in contaminated territories was enhanced by: woman smoking; acute infections three months before conception, chronic infections, barrenness treatment in the past, consuming of medications at preconception time (Table 5.1.9). All these increase 2.5–3.0 times the probability of abortion [34].

Table 5.1.9

Estimation of risks of spontaneous abortions among woman of Kyiv region with accumulated whole-body absorbed doses above 5.0 mSv, 1999–2001

Additional risk factor	Odds ratio	Confidence interval
Smoking	3.81	1.49–10.27
Chronic infections	4.63	2.42–9.29
Acute infections	3.22	1.48–7.26
Barrenness treatment	4.72	1.55–16.15
Medications consuming	3.59	1.82–7.55

Thus, the risks of spontaneous abortions in women dwelling in contaminated territories are clearly demonstrated. Notwithstanding the mechanism of development of demonstrated effects the inhabitants of contaminated territories before the giving birth to a child need to realize both counter-measures for reduction of accumulated absorbed doses of radiation, and sanitation of chronic diseases, especially endocrine, and lead a healthy life-style before planning pregnancy [35].

Medical and biophysical accompaniment of Shelter implementation project

Medical and biophysical accompaniment of Shelter implementation project is one of the most challenging problems of current clinical radiobiology.

The originality of these activities is connected to the need of performing working tasks in an environment with high-activity open sources of ionising radiation. Usually such kind of tasks are performed in leakproof rooms using remote-controlled manipulators to considerably reduce the levels of external irradiation and exclude possible intake of radionuclides.

The RCRM of AMS of Ukraine has developed a program for medical and biophysical monitoring of the health state and professional fitness of personnel involved in converting the Shelter to an ecologically safe system. This program takes into account the long-term experience of RCRM in minimising the medical consequences of the ChNPP accident; follow-up results and treatment of the Shelter personnel; requirements of legal and regulatory documents of Ukraine, as well as of the best international practices. The aim of the program is to ensure adequate employment and prevention of occupational and general diseases, as well as industrial casualties.

The program provides for an integrated technology of entrance and final checkup, individual, inspection, periodic and routine (before and after the shift) control, as well as special medical control. The unified regulations for for medical, psycho-physiological and professional selection were worked out with final aim of determination by an expert commission the health category of personnel and its compliance with requirements specific to activities in the Shelter.

Biophysical monitoring is performed in parallel and concurrently with medical monitoring.

According to the results of medical and biophysical entrance checkup, during a year starting from October 2004, of 2,119 personnel of Shelter Implementation Project (SIP) subcontractors, only 1,059 (49.9%) were admitted to work, and 1,060 (50.1%) were not admitted. The reasons of the high non-admission level were different chronic diseases. The SIP subcontractor personnel admitted to work have from 2 to 10 chronic diseases (respiratory, cardiovascular, digestive tract, and nervous system ones). The stage and course of these diseases is not a contraindication for working on the SIP, however, they require a complex of rehabilitation measures.

Biophysical monitoring has shown that the doses of internal irradiation of personal working in the Shelter are 0.1–1.1 mSv. At the same time, in 6 months after stabilisation work had been performed, 16 workers among 123 who had passed special medical and biophysical checkup, received an overall dose (external and internal irradiation) above 10 mSv (the threshold limit dose is 20 mSv). The values of effective external irradiation doses for SIP personnel who have passed special biophysical monitoring are 0.8–13.8 mSv.

5.2. Medical and demographic consequences of the Chornobyl catastrophe

On the eve of the 20th anniversary of the Chornobyl catastrophe, the medical and demographic situation on radiation contaminated territories is evolving under conditions of the on-going demographic crisis in Ukraine (Fig. 5.2.1). Since 1991, the population mortality rate has exceeded the birth rate. As

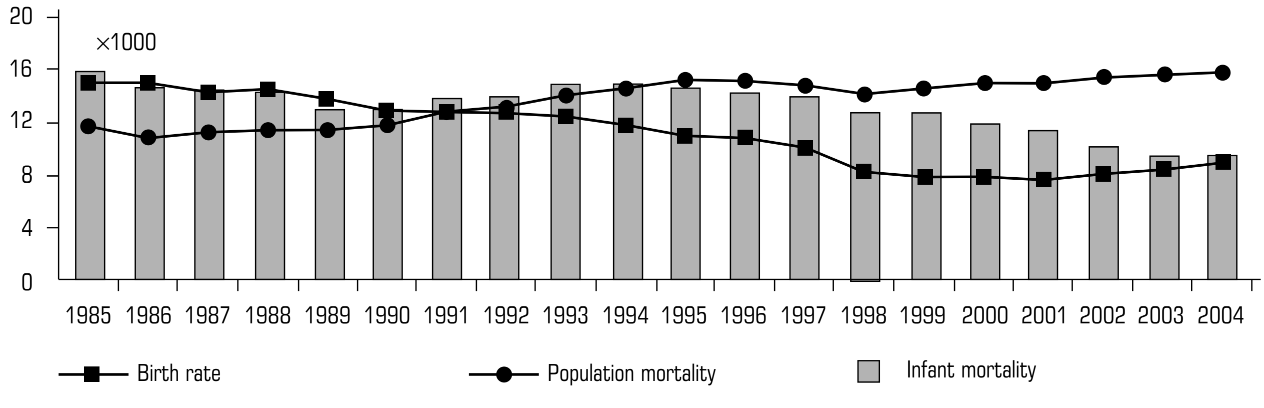


Fig. 5.2.1. Population birth and mortality rates, and infant mortality rate in Ukraine in 1985–2004 (data of State Statistics Commitee of Ukraine)

a result, the average annual population of the country has decreased from 52.1792 mln in 1993 to 47.451 mln in 2004. In radiation contaminated regions, these adverse changes occurred a year earlier and were more pronounced [24]. The demographic situation was deteriorated due to the social and economic crisis that had started in 1991; an inadequate medical service; low living standards; the unfavourable environmental situation aggravated by the Chornobyl catastrophe; and political instability.

The funds allocated to recovering the catastrophe consequences started to be reduced in 1994, this had an adverse affect on implementing measures for radiation control, social and medical care of exposed people [24].

Against the background of the highest mortality level in 2004 (16,0‰) in Ukraine within last decades some positive tendencies are perceptive: since 1998 newborn mortality is being diminished, sinse 2002 started to increase the birthrate. After the most expressed stagnation of 1993–1997 since 1998 the country started gradually go out of social-economical crisis, though by the level of gross domestic product social-economical state now is by 20–30% behind the level of 1991.

To date, compared with earlier appraisals made by RCRM [24], economic activity is not renewed in the exclusion and compulsory resettlement zones, and the hazard of elevated irradiation on the most contaminated territories still persists. Recent relocation and voluntary resettlement of residents to clean areas from contaminated territories contributes to reducing the population, and worsening the family, gender and age composition of the population that is still living on these territories. This negative separation has caused the formation of a cohort of people with worse health indices and reduced reproduction capacity.

According to RCRM generalisations, withing the time after the accident radiation become a factor of migratory behaviour of population [25]. Totally 814 families still living in the zone of compulsory resettlement at 01.01.2005. Residents of other contaminated zones also wish to move to clean areas. Thus, migration induced by ecological problem will go on.

As distinct from the first postaccidental years over last years on the radiation contaminated territories the stillbirth started to decrease and the birth rate started to increase.

The portion of children within 14 years of age among all affected people and in the zone of guaranteed voluntary resettlement exceeds the overall population level. According to the results of the French-German Chornobyl Initiative [26], as against to the national level infant mortality in contaminated areas is persisting and stillbirth of babies 0–6 days old is increasing. In heavily radiation contaminated areas there are two most important causes of mortality: states arising in the perinatal period, and congenital anomalies. The portion of endogenic causes is increasing in neonatal mortality. The relative risk (RR) of infant mortality in radiation contaminated areas since 1991 has clearly exceeded 1.0, and this can be attributed to increasing stillbirth rates in the neonatal period. In the control areas, the RR mortality level at the age of 0–27 days was less than that in contaminated territories, and had no affect on the increase of infant mortality RR. The epidemiological analysis identified a weak correlation between stillbirth, early neonatal, perinatal, neonatal, and postnatal mortality and radiation factors. The radiation factors included levels of soil contamination by ^{137}Cs, and individual and collective radiation doses of the thyroid gland and the whole body in the population living in the most affected regions of the Kyiv and Zhytomyr regions. In other words, current data do not give grounds to exclude the irradiation impact on the fetus in the mother's womb as a factor affecting infant mortality.

Generalisations of vital statistics data by RCRM indicate that, in the post-accident period, population mortality increased nationwide, the average annual increase rates being within 0.28–0.43‰. In radiation contaminated territories (Fig. 5.2.2), mortality is differentiated by zones; the highest rate is

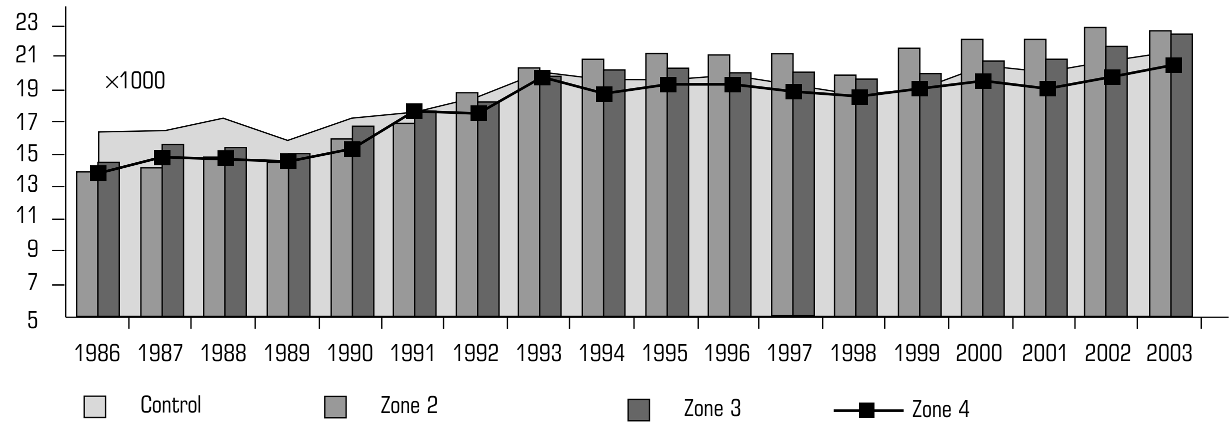


Fig. 5.2.2. Mortality of population of the most contaminated regions distributed by zones of radioactive contamination in 1986–2003 per 1000 of population (data of RCRM, AMS of Ukraine)

in zone 2 (with the exposure limits of 5 mSv/per year and above) and zone 3 (with the exposure limit of 1–5 mSv/per year).

A statistically significant increase of mortality occured in the structure of death reasons of dwellers of radiation contaminated territories due to somatic diseases, primarily diseases of cardiovascular system.

The average annual mortality rate associated with neoplasms is significantly higher in radiation contaminated Kyiv, Zhytomyr and Chernihiv regions than in the control Poltava region (on average by 20%). At the Oblast level, there is a trend of decreasing mortality due to congenital anomalies. The radiation contaminated regions are characterised by significant variations in the average values of this index.

Based on the data of the Ministry of Health of Ukraine summarised by RCRM [27–31], from exposed people who had been under supervision of state medical establishments of Ukraine, 504 117 persons died in 1987–2004, among them 497 348 adults and adolescents (including 34 499 clean-up workers) and 6769 children. At the end of 2004, the structure of deaths was as follows: (a) by registration groups: 9.9% of clean-up workers; 1.5% of evacuees; 87.7% of residents of radiation contaminated territories; 0.9% of children born by exposed parents; and (b) by age groups: adults and adolescents – 99.2%, and children – 0.8%.

Analysis has shown that from the 15^{th} to 20^{th} year after the catastrophe, there was a dramatic increase in the mortality of affected people of primary registration groups 1–3 (Fig. 5.2.3). In 2004, the mortality of all groups of exposed people (16.1‰) exceeded the mortality of the country's population (16.0‰) for the first time. Such an increase occurred primarily due to increasing mortality of clean-up workers and of the dwellers of radiation contaminated territories.

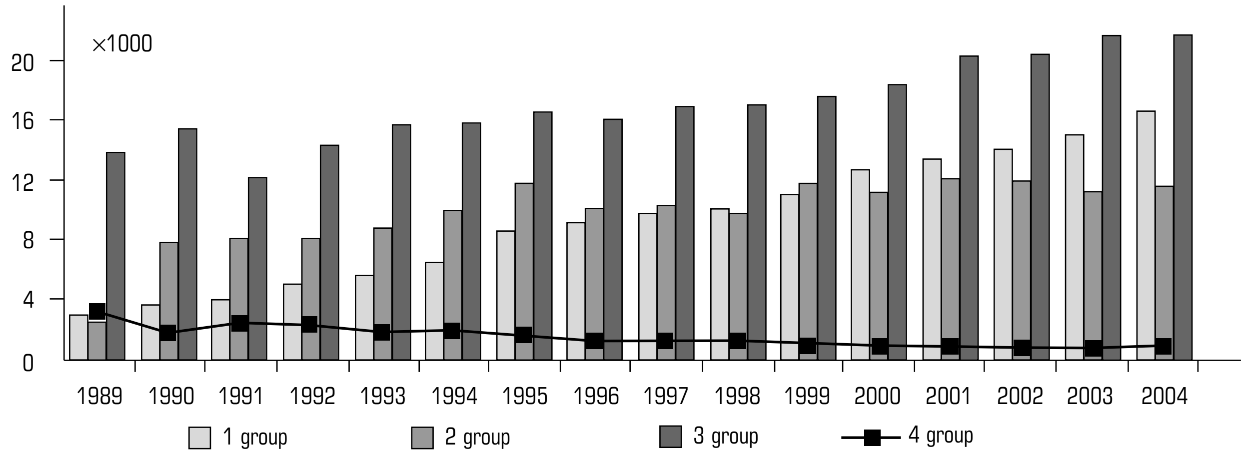


Fig. 5.2.3. Mortality of Chornobyl NPP accident affected people according to the groups of primary count in 1989– 2004 per 1000 persons of corresponding group of registration (data of Ministry of Health of Ukraine)

The mortality of the former was 16.6‰, and that of the latter was 21.7‰ (exceeded the mortality of Ukraine's population by 5.7‰). Last years the mortality of exposed children is progressively decreasing. This can be acknowledged as one of the positive achievements of medical science and practice, and nationwide actions focused on radiation control, and social and medical care of exposed children. At the same time, the mortality of middle-aged and older persons is increasing. This is an alarming symptom because these people are those who at first have been exposed to radiation in their childhood and adolescent period. This generation was continuously exposed until it had grown up to a reproductive age, and will become the parents of the future generation.

The clean-up workers mortality increased from 8.5‰ in 1995 to 16.6‰ in 2004, and exceeded the mortality of Ukraine's total population (6.6 and 6.0‰ respectively). The excess in 1999–2004 is statistically significant (t = 9.6 at mean values of 13.97±0.84 and 5.87±0.7 respectively). Since 1998, their mortality (10.0–16.6‰) exceeded the mortality of able-bodied males of Ukraine's population (8.5–9.5‰). In 1999–2004 the difference between mortality indices is statistically significant (t = 5.62 at mean values of 13.97±0.84 and 9.20±0.11 respectively).

Over the past five years, in the structure of deceased adults and adolescents, the contribution of mortality due to blood circulation disorders increased from 65.5% (116.5‱) to 67.9% (131.3‱), and the contribution of mortality due to neoplasms decreased from 12.6% to 11.7% (at practically equal levels about 22.6‱); mortality due to respiratory organ diseases increased, and the mortality due to dis-

eases of the endocrine system and digestive organs decreased. During 1992–2000 because of neoplasms 3,823 clean-up workers have died;. mortality increased from 9.6‰o in 1992 to 25.2‰o at mortality of adults and adolescents from the population in 2004 equal to 9.9‰o. At the same time, there were no significant changes in the pattern of causes of child mortality.

Due to the absence of objective information on the levels of radiation exposure doses of people by groups of primary registration, presently it is impossible to determine the dependence of mortality on exposure and calculate the risks. At the same time, clean-up workers who had been exposed to acute irradiation when eliminating the accident and its consequences, and residents of radiation contaminated territories exposed to chronic irradiation have shown higher mortality rates. Besides, more than 74 000 affected people among clean-up workers and evacuees live in radiation contaminated territories since the time of the catastrophe and, hence, after being exposed to acute irradiation they are exposed in addition to chronic irradiation, which increases the risk of negative radiation impact.

According to the data of RCRM studies on demographic losses on the contaminated territories [32, 33] it was found that on the most heavily radiation contaminated regions a reduction in the population started in 1990, whereas in a control area and in Ukraine as a whole it started much later after the catastrophe and with less intensity (Table 5.2.1).

Table 5.2.1

Demographic losses in radiation contaminated territories and control districts in 1986–2003 (provided the number of births and deaths was the same as in 1979), '000 persons

Demographic loss	Radiation contaminated districts	Lokhvytskiy district (control)
Direct	–23.6	–10.0
Net	–32.1	–6.0
including: shortage of births	–25.2	–3.2
excess of deaths	+6.9	+2.7
Total	–48.8	–13.2

In radiation contaminated regions, the first significant temporary loss of population was registered in 1987. In the following years, demographic losses increased more markedly and exceeded control levels. It has been acknowledged that the catastrophe was the cause of demographic losses of population in the most heavily contaminated regions and districts due to the cumulative effect of socio-economic conditions and radiation factors.

The most heavily contaminated regions have a lower level of the human development index, which is calculated by taking into account the indices of GNP, demographic development, mean expected life span, and other factors (Table 5.2.2).

Table 5.2.2

Regional human development index in different regions in 2000–2003 (data of State Statistics Committee of Ukraine [34])

Regions	Human development index				Region ranking			
	2000	2001	2002	2003	2000	2001	2002	2003
Volynska	0.485	0.496	0.490	0.488	21	17	15	19
Zhytomyrska	0.496	0.481	0.470	0.474	19	22	21	21
Kyivska	0.539	0.538	0.503	0.518	10	7	12	9
Rivnenska	0.482	0.520	0.499	0.514	22	13	13	13
Chernihivska	0.523	0.509	0.489	0.489	13	16	16	18
Poltavska (control)	0.576	0.599	0.563	0.530	4	4	3	7

Overall the data on demographic indices for a multimillion population including exposed people provide sufficient grounds to admit that the Chornobyl catastrophe and its consequences have had an negative impact on the population's health. In spite of the fact that radioactive contamination of environment and population radiation exposure levels are decreasing, it should be noted that the conse-

quences of the catastrophe have not been eliminated completely in 20 years. Hence, measures aimed at improving the medical and demographic situation and the health state of affected people must be based on removing the accident-induced radiation factor from human environment.

5.3. Strategy of population medical protection

Analysis and generalisation of the key results of scientific research conducted over the past 5 years have confirmed the conclusions drawn in 2001 by Ukrainian researchers jointly with experts from the WHO, UNSCEAR, IAEA and other organisations. These conclusions are based on the results of 15-year monitoring of different groups of exposed people. At the current stage of the late period after the Chornobyl accident, nonstochastic effects in the form of a wide gamut of non-tumour forms of somatic and psychosomatic diseases are the key contributors to its medical consequences. In the majority of cases, they are the key factors causing loss of working capacity and mortality, and constitute a requirement for primary consumption of funds for therapy and prevention.

The stochastic consequences sustain incidence of thyroid cancer in children and adult sufferers of all cohorts. Incidence of other solid tumours is continuing. There is an evident trend in growing incidence of leukemia in clean-up workers, and increasing the instability of the genome of exposed persons and their offsprings.

Effective medical support of exposed people in the future and decades to come calls for development and approving of a clear national program of recovery from the medical consequences of the catastrophe. The project proposals has not yet been approved by the Governement and the Verkhovna Rada of Ukraine.

It would be appropriate for the Government of Ukraine to continue the improving of the systems of medical-sanitary and social care of the population that had suffered as a result of the Chornobyl accident, paying special attention to priority medical follow-up cohorts.

The State Registry of Ukraine of people who suffered as a result of the Chornobyl catastrophe should be changed radically and be transformed from a base of passive one-sided data accumulation to a tool of real-time analysis of verified information required for making strategic and tactical management decisions at the State, regional and district's levels. Such changes will only be possible if: stable and sufficient financing is provided; hardware support of the registry is upgraded; adequate staffing at all levels of its functioning is allocated; and scientific-methodical, dosimetric and information-analytical support are in place.

It is necessary to continue monitoring of medical and demographic consequences, and the peculiarities of biological ageing of the affected population, taking into account the expected trend of increasing incidence of diseases that are the causes of high disability and mortality levels.

Since certain kinds of solid tumors after irradiation have different latency periods of incidence (between 10 to 30 years), it is necessary to continue monitoring this pathology with a special focus on diseases such as female breast cancer, malignant tumors of esophagus, stomach, lungs, colon, ovaries, kidneys, and urinary bladder. Special attention should be paid to those people who have been 0–9 and 10–19 years of age during the Chornobyl accident.

In the next decade, the priority groups for follow-up on thyroid cancer incidence should be adults who have been exposed in childhood as well as the clean-up workers of 1986.

To prevent thyroid cancer incidences in exposed population and clean-up workers it is necessary to take scientifically valid actions focused to timely identification and treatment of precancer pathology.

It is necessary to continue investigating the risks of leukemia and other tumour diseases by using standardised epidemiological programs with obligatory international evaluation of all cases in the three most affected countries.

In the next 10 years, due to increasing incidence of eye pathology and predicted incidence of new cases of the cataract and vascular diseases, a 4 to 5-fold increase in the indication of cataract surgery can be expected (25.6±14.3 per 1,000 clean-up workers without account of probable shortening of the clean-up workers life span). There will be a growing demand for intraocular lenses and medication for conservative therapy of eye diseases, primarily all kinds of vasodilators, antioxidants and vitamin complexes.

It is necessary to intensify children's health surveys, with particular focus on children born by clean-up workers; children from heavily contaminated territories, and to those who have been exposed during prenatal development.

It is necessary to follow up on appraising the contribution of the irradiation dose and other factors to the indices of mortality and non-tumour somatic incidence of clean-up workers and residents of territories contaminated with radionuclides, with special focus on prepathology conditions and early incidence phases.

It is necessary to enhance molecular-genetic and immuno-hematological studies in the incidence of radiation-induced or associated diseases. Assessing the above disorders will make it possible to develop in the next years, along with biological dosimetry indices, the molecular epidemiology of the Chornobyl catastrophe impact on the health of affected people.

At the national and international (Belarus, Russia and Ukraine) levels, it is necessary to expand and intensify fundamental research and applied programs of long-term investigations for remote post-accidental periods.

To minimise the influence of remote stochastic effects, people with acute radiation syndrome should receive a full range of medication, diagnostic and therapeutic services during their entire lifetime.

Priorities for protection and improvement of children health must be:

– providing with addressed highly qualified and specialized medical care;

– purposeful preventive, medical and rehabilitation measures aimed of decreasing the levels of morbidity, disabled states and mortality.

To improve the life quality of dwellers of contaminated territories it is necessary to:

– provide for increase the levels of medical service, social and psychological rehabilitation of population, evacuated from alienation zone and zone of unconditional (compulsory) resettlement;

– provide for realization of optimal systemic counter-measures directed of the decrease of doses internal and external irradiation of population on all territories contaminated with radionuclides;

– develop a network of social-psychological institutions oriented to the overcoming of destabilizing factors of psychological state of all kind of sufferers, first of all, with syndrome of «Chornobyl» victim;

– organize scientific, methodical and practical education system on improvement of the reproductive health; prepare the program on mental correction and social aid provision to children and adolescents aiming of the joint application of countermeasures for reduce the accumulated doses and fulfillment of chronic diseases sanation, in particular, endocrine ones.

In the condition of imperfect mental health care and psychic recovery system neuropsychic disorders in exposed people should remain a priority medical and social problem.

It is necessary to study neuropsychiatric disorders, including organic brain injuries, the chronic fatigue syndrome and disorders in the gamut of schizophrenia, suicides and parasuicides, which have essential clinical and social significance, as well as to develop recommendations on mental health care of sufferers in the event of possible future radiation accidents.

The experience of the first months of converting the Shelter into an environmentally safe system has shown that in the unique radiation-hygienic conditions, in which this activity is being conducted, *the most critical issues are not engineering and technical problems, but rather the key problem of how to ensure the health of people as well as prevent inadequate actions of personnel due to any deviations in their health conditions.*

Entrance and final medical examination of employees who are participating in the Shelter Implementation Project of converting the Shelter into an environmentally safe system, must be conducted exclusively in highly-specialised, adequately equipped medical establishments that have a practical background in medical care and conducting medical examination of persons who were exposed to ionising radiation and, particularly, to incorporation of radionuclides.

Special biophysical and medical checkup is required to verify the paths of penetration of radionuclides into the body, specifying the internal exposure dose, as well as carring out actions on ensuring engineering and radiation safety of personnel of SIP and State Specialised Enterprises subcontractors to prevent radionuclide incorporation.

To secure the health and work capacity of personnel, it is necessary to provide a variety of health improvement and recovery measures, which should be implemented within a framework of individual treatment programs in highly-specialised medical establishments.

5.3.1. Measures of minimising the impact of radiation and endemic factors on the population's health

Contamination of food with radionuclides, an insufficient amount of brought-in food, the poor chemical composition of locally produced food, self-restriction in consumption of some food and a drastic drop in the purchasing capacity of the population have resulted in a significant deformation of food allowances. These factors, against a background of the effect of toxic substances (pesticides, nitrates, nitrites, industrial and vehicle emissions and so forth), ionising radiation, and psycho-emotional stress, resulted an increase of general incidence of disease in the population of affected regions [35, 36].

Among the dietary factors that are especially instrumental in supporting health, the working capacity and active lifespan of humans, a key role belongs to micronutrients, especially vitamins and

mineral substances. Into account should be taken their low content in local food and increasing incidence of diseases due to a deficit of iodine and other microelements (which are the most widespread non-infectious illnesses of mankind) – according to WHO data, there are more than 200 mln goiter patients worldwide [35, 36].

The hazard of incidence of iodine-deficiency diseases has increased due to irradiation of the thyroid gland with radioiodine as a result of the ChNPP accident. The exposed children have experienced a significant burden on the thyroid gland because there is a direct relation between the dose of radioiodine received by the gland, its mass and functional activity, and an inverse relation with a child's age. The tragedy was aggravated by the fact that the majority of radiation contaminated territories of Ukraine, Belarus and Russia are iodine-endemic. In Ukraine alone, more than 15 mln people live on such territories. The joint action of radiation and endemic factors on the thyroid gland increases thyroid pathology, which occurs at younger ages and in more acute forms than in the case of irradiation alone [37].

Consuming iodised food [36, 37] and brown algae (laminaria, cystosorus, and sea oak) as salads, garnish with moin dishes, and culinary products was always considered as a basic, universal, effective and most economic way of preventing iodine-deficit goiter. Such algae have all the microelements that are required in the synthesis of thyroid gland hormones, such as iodine, selenium, copper, zinc, iron, molybdenum, cobalt and others. An optimal method is enriching food with, at least, several microelements [37].

6. ENVIRONMENTAL AND BIOLOGICAL IMPACT

The environmental impact of the Chornobyl catastrophe is determined by two key factors - irradiation of natural objects and their radioactive contamination. Two main sources of irradiation are identified, viz. external and internal.

External exposure is caused by radiation from radionuclides which have passed over a locality in an emission plume, and have fallen out to the soil, vegetation and water surfaces, and skin of humans and animals. Internal exposure is caused by radiation from radionuclides taken by the body.

During the accident, the bulk of radionuclides release from ruined Unit 4 fell out in nearby areas. Presently, these areas are conventionally defined by the 10 and 30 km exclusion zone limits. External exposure levels were biologically hazardous primarily in the 30 km zone where a complex spectrum of biological effects of different intensity was observed. During the acute period of the accident, radiation dose levels in the exclusion zone reached hundreds of roentgen per hour with regard to only gamma-radiation. The beta dose rate was 10 to 100 times higher. This resulted in acute effects in the most radiosensitive species (coniferous trees) or those organisms (invertebrates) most sensitive to exposure. There were no reports of acute exposure effects beyond the 30-km zone.

In the post-accident 20 years, both short-lived and medium-lived radionuclides have decayed completely and external exposure rates have decreased by several orders of magnitude. In the environment, only long-lived radionuclides of caesium, strontium and transuranium elements persist, radiation from which causes chronic irradiation of biological objects with a practically constant exposure rate, i. e. chronic radiation. The effects of chronic radiation have appeared to date in the exclusion zone against a background of the consequences of acute exposure in 1986–1989, with exposure rates declining in time.

The main hazard resulting from radioactive fall-out on contaminated territories (western and northern radioactive traces in the territory of Ukraine) in the first days and weeks post-accident was exposure of the thyroid gland in people (especially children), and in cattle. Iodine radionuclides enter the body primarily in food, mainly, milk and leafy vegetables. The presence of radioactive iodine in the environment was criminally concealed during the most critical early days following the accident, therefore consumption of this food was not prevented. Cows were grazing, and children and adults were consuming fresh milk with high content of ^{131}I. The consequence of this was thyroid cancer incidence in humans. In Ukraine alone, the number of such cases exceeded 2,700 up to the year 2005. In several years after the accident, cattle demonstrated inhibition of the thyroid gland function, i. e. hypothyroidism.

In the City of Kyiv, the rapid monitoring of milk ensured that thyroid gland exposure rates were reduced by 7 to 10-fold by processing contaminated milk to butter and cheese with subsequent keeping in refrigerators. On the 30^{th} – 45^{th} day after the accident, radioactive iodine had effectively disappeared in food.

Since July 1986, the main hazard source in contaminated territories is internal exposure to long-lived ^{137}Cs and ^{90}Sr radionuclides taken in by the organism. This hazard factor will persist for many decades to come.

The main environmental objects responsible for influx of radionuclides to the human body are agricultural products, wild forest products and water. Fallout from the ChNPP accident resulted in contamination of farming land and the large number of inhabited localities. Over the past 20 years and for many years to come, the main ways to prevent internal radiation exposure, in addition to previous measures, is to reduce the levels of radioactive contamination of food based on data and knowledge about the paths and regularities of migration of ^{137}Cs and ^{90}Sr radionuclides in agricultural, forest and water food chains, and in food processing technologies.

The landscape and demographic features of the Ukrainian Polissia comprise a wide spectrum of natural landscapes and patterns of consuming natural products. Therefore, these landscapes call for immediate consideration by researchers and manufacturers of farming and forest products. For example, contamination of the Dnipro River basin and the majority of its tributaries calls for continuously addressing the problem of radionuclide intake by the human body with potable water, fish, and production from irrigated lands.

The following sections will present data on how the accident affected the biota; and on the radiation situation with regard to migration of radionuclides over agricultural, forest and water food chains in territories contaminated by the ChNPP accident. Predictive estimates of the prospects for, and the consequences of, countermeasures to be taken are discussed, in order to provide substantive methods to improve the radiation situation for the next decade.

6.1. Remote radiobiological effects of ionising radiation on biota

On the territory of the 30-km ChNPP exclusion zone, all wildlife, viz. vegetation, mushrooms, lower and higher animals, microorganisms and viruses were exposed to acute radiation in the first post-accident days. They continue to be exposed to chronic radiation to the present day. Depending on the density of radioactive fallout, the physicochemical composition of radionuclides, their biogeochemical conversions and migration in the trophic chains of the ecosystem, the radiation exposure experienced by biota varies widely – from exposures which are lethal to the most radio-sensitive species to exposures similar to background levels of natural radioactivity. Over time, radiation exposures have declined due to decay of radionuclides and their migration into the soil. However, there are still areas within the 10-km exclusion zone where radiation exposure rates of natural vegetation is in excess of several hundreds mR per hour [1].

An extreme manifestation of radiation impact on the biota was pine forest loss. The response of pine trees to radiation in the exclusion zone allows identifying four zones, viz. lethal, sublethal, medium and moderate damage to trees [2].

In the lethal damage zone, there was complete loss of pine trees of any age. The total area in which there was loss of all pine trees exceeded 600 ha. In separate areas of the «red forest», there was loss of other, more radiation-resistant tree stock, in particular, birch and black alder. This loss is indicative of that the absorbed doses for the tree stock in these forest areas had exceeded 200–300 Gy.

In the second year post-accident in the sublethal damage zone, extensive morphological effects in tree formation processes occurred, including gigantic sizes of leaves, fasciation (flattened tissues), off-plan branching, and loss of organs due to a geotropic reaction. The average biota radiation doses in this zone prior to 1991 were under 50 Gy [3].

The medium and moderate damage zone occupies a territory exceeding hundreds of thousands of hectares. In this zone, the trees are characterised by growth inhibition, untimely needle shedding, radiomorphosis, and intensive branch-out.

Radiation induces loss of different species, both plants and animals. Areas with high surface contamination retained only highly radio-resistant species, including lichen and certain species of moss. Loss of pine in the «red forest» involved dramatic changes in the biota composition because loss of this dominant species disturbed the trophic links, succession phenomena were initiated, and new trophic chains were formed, which significantly changed the biocenosis structure.

Biota composition was affected profoundly by termination of economic activities, in particular, agriculture, and by relocation of residents from inhabited localities. In previously arable land, natural vegetation started to regenerate, involving progressive regeneration of the forest formation. Subsequent to these changes in vegetation, which is the nutritive base of herbivores, faunal species composition was also altered. Depopulation of inhabited localities involved a dramatic reduction in abundance of synanthropic species of animals and progressive dropout of synanthropic plants. At the same time, biological diversity started to grow due to an increase in abundance of those species whose normal development was hindered by man's economic activity, in particular, hunting. Hence, the abundance of previously rare species of fauna and flora has increased over recent years.

Presently, in the exclusion zone there are 17 species of plants and 19 of animals registered in the Red Book of Ukraine. The number of mammals increased to a total of 66 species. The number of wild boar increased roughly by 10-fold to more than 7,000, the number of foxes has increased to 1,200, and the number of beavers has increased to 1,500. The number of herbivorous – moose and roe deer – has also increased. A group of Przewalski's horses brought in from Askania Nova seamlessly integrated into the biota of the exclusion zone, and presently their number has grown significantly. At the same time, the number of carnivorous species, in particular, wolves is also increasing.

In territories that were radio-contaminated, the highest activity of radionuclides is concentrated in dead-leaf residue and the surface soil layer. Hence, organisms living in the surface soil layer are exposed to excess radiation. This layer concentrates numerous groups of different species of fauna, mushrooms, and bacteria, which are thus exposed to high ionisation radiation levels. With decreasing radiation dose rates, the soil fauna and microorganisms regenerate, but the species composition of new groups differs from the pre-accident one. Numerous species of insects and ticks experienced dramatic changes.

Hence, at first sight, the biota in the exclusion zone is flourishing due to reduced anthropogenic pressure. Dedicated radiobiological studies, however, have detected aberrations at the cellular and subcellular levels of organisation of biological systems and many animal and plant organisms have clearly shown cytogenic cell damage [4 and 5]. Responses to radiation exposure demonstrate abatement of protection and immunity systems. A growing rate of plant injury with different types of fungus disease, formation of excrescences and galago of different etiology, and manifestations of bacterial cancer have increased.

These phenomena are temporary and, with progressive decrease in environmental radioactivity, the biota status will regenerate gradually. Presently, however, there are no grounds yet to assume that it has regenerated completely because the effect of radiation on cell genetic structures involves such structural and functional changes which will be retained in numerous generations of cells. The downstream effects will include cell division capacity loss, mutations, and sterility. To date, visible outer well-being is masking genetic effects, including a dramatic increase in chromosome aberrations in the cells of meristematic tissue of plants, and in the white blood cells and generating tissue of animals [6].

Extensive experiments have demonstrated that, under conditions of chronic irradiation, irreversible molecular damage of the cells' genetic apparatus progressively accumulates; including peculiar memorising of the dose and cumulative exposure effects. Besides, since plant and animal organisms accumulate radionuclides in the tissues of their organs, primarily radioactive caesium and strontium isotopes, and the latter spread irregularly over the ultrastructural components of a cell, the «internal irradiation» caused by these isotopes is characterised by enhanced action effectiveness due to the transmutation effect. Since many species populations are exposed, adverse effects will invariably be manifested over the next decades.

Among radiobiological phenomena responsible for remote exposure effects, the following are most prominent: radiation-induced genome instability; exposed cells loose their capacity to receive position information adequately; cumulativeness of chronic radiation doses; non-equivalence of external and internal radiation exposure; latent DNA damages; and radiation mutagenesis [6 and 7].

Due to genome instability, exposed organisms experience increasing incidences of genetic damage in the form of chromosome and micronuclei aberrations, and growing spontaneous variability. Genome instability has been found in many plant and animal species that are subject to chronic irradiation [8]. Induced genome instability is an extremely hazardous phenomenon because it can involve loss of the established gene pool, which normally ensures reliable positions of species in the biota system. In cultivated plants, induced genome instability can cause loss of cultivar properties.

Extensive morphological anomalies in the form of gigantism or microsomia of organs, which were observed in plants during the early post-accident years, have been also detected in recent years in areas with a particularly high radionuclide contamination density.

To date, an extensive body of experimental data have been collected, which indicate that internal radiation exposure involves a significantly more intense manifestation of radiobiological effects than the same external exposure dose. Hence, the notion of relative biological effectiveness (RBE) concerns not only different kinds of radiation, but also internal and external irradiation. One of the causes of difference between RBE values for external and internal irradiation is the difference in microdosimetry characteristics of internal irradiation, which results from irregular spread of radionuclides in cell ultrastructures.

Protracted realisation of latent, concealed radiation injuries of DNA in the sequence of cell generations has been proven for several species in the exclusion zone. Hence, new generations will comprise cells carrying previously accumulated defects in their genetic apparatus. The mutation process has intensified in elevated radiation zones. Whilst the identification of mutant forms in biota, particularly in animals, is a challenging task, there are reports that a mutant form of a swallow with partial albino features has become widespread in the exclusion zone.

Significantly more hazardous is the occurrence of mutations in micro organisms, viruses and pathogenic micromycetae. If a species has a short-lived cycle, the mutated gene can spread rapidly in the population. It has been estimated that cereal specific pathogenic fungi in consequence of chronic irradiation in the exclusion zone have generated new races with elevated virulence. This can be an extremely hazardous phenomenon because the spores of these fungi are transported by wind over great distances beyond the exclusion zone boundary.

Population effects caused by microevolution processes are instrumental in formation of remote radiation after-effects. Time-dependent increasing divergence in genome structures is indicative of an intense microevolution process, which, over an extended period, can cause dramatic changes in the biodiversity in territories contaminated with radionuclides.

6.2. Agricultural aspects of recovering radiocontaminated territories and radiation protection of the population

The ChNPP accident unfolded the gravest scenario with the following consequences for Ukraine's agricultural sector: more than 5 Mha of land was contaminated where crops are cultivated and where approximately 3 million people live, and a great number of cattle was lost. In the early post-accident years, sheep breeding, hop-growing and flax cultivation was effectively terminated in the

Ukrainian Polissia, and the exclusion zone was withdrawn from land usage. The involvement of scientists for planning and organising adequate countermeasures was delayed significantly, which had an adverse impact on the effectiveness of prohibitory and organisational decisions during the critical initial period.

The radiation exposure of Polissia's population living on land with a high factor of ^{137}Cs transfer from soil to plants (70–95%), is primarily attributed to internal irradiation due to intake of radionuclides with food. External exposure, inhalation of radioactive aerosols and contact irradiation due to contamination of the skin, clothing and working surfaces did not exceed 20% of the total dose [9].

Strontium-90 had a critical radioactive impact only in territories adjacent to the exclusion zone, in particular, the northern part of the Kyivska Oblast and the western part of the Chernihivska Oblast. ^{90}Sr fallout was associated with fuel particles that gradually decay in the soil. In acidic soddy-podzolic soils, 80–90% of ^{90}Sr was converted to soil-exchangeable forms, in neutral soils this proportion is 40–80% [10]. ^{90}Sr contributed substantially to human integral exposures in the following Kyivska Oblast settlements: Hubin, Strakholissia, Gornostaipil', Medvyn, Dytiatky, Zorin, Laput'ky, as well as those in the Chernihivska Oblast: Mnyov, Dniprovske, Vasylova Guta, Tuzhar, Mykhailo Kotsiubynske, and Loshakova Guta.

The radiation situation in contaminated territories is defined, primarily, by the intensity of radionuclide transfer in the food chain (soil – vegetation – animals – husbandry products) which varies substantially according to the soil and environmental conditions. Predicting radiation changes in time is especially critical. Changes in the radiation situation in plant cultivation depend on variation in several factors. Primarily, this is the density of radionuclide contamination of the key link in the food chain – soils – A_s (kBq/m^2), their agronomic properties, intensity of radionuclides accumulation by the root systems, crop rotation, and the technology of plant cultivation. In husbandry, the critical indicators are as follows: daily intake of radionuclides by the organism of animals with the ration defined by its composition, and the technology of keeping and feeding cattle. The final result relies heavily on the level of processing agricultural products, basically, milk. The radiation situation depends to a great extent also on the technology and scope of countermeasures taken.

6.2.1. Soil contamination levels

The key indicator for making decisions on alienating or incorporating land from/to production is contamination density. As early as 1986, a technique was developed, and existing agronomical and agrochemical agencies of the State Committee of Agriculture of the UkrSSR and the sanitary-epidemiological agency of the Ministry of Health of Ukraine monitored the soils of arable lands [11 and 12]. This allowed the critical administrative regions of Ukraine to be identified in short time, as early as the summer of 1986, without setting up special departments, and to focus the attention of the authorities and experts on these regions. An aerial gamma survey of the entire territory of Ukraine was carried out in the following years. Due to significant irregularity of the spatial distribution of Chornobyl radioactive fallout, interpolation of aerial survey made data very uncertain. Therefore, 1:100 000 maps proved to be useless for substantiating specific countermeasures to be taken in inhabited localities, farming land, or in natural landscapes.

To ensure a timely and detailed assessment of the radiation situation in agricultural lands, the agencies of State Committee of Agriculture of Ukraine, with methodical support of scientists of the Southern Division of All-Union Academy of Agricultural Sciences and the Ukrainian Branch of the All-Union Research Institute for Agricultural Radiology, conducted a combined stepping gamma survey with field radiometers in 1987 [13]. This team built ^{137}Cs and ^{90}Sr contamination cartograms for all the farming land in about 800 farms in Ukraine, and submitted them to state and local administrative bodies. Generalised maps scaled down to regions were published in the regional press in 1994. Data on contamination of agricultural lands in 12 Oblasts of Ukraine were presented in the year 2001 National Report.

It should be stressed that the surveys conducted so extensively in the early post-accident years could not be worked out in detail. Reviewing many-year data on radiation control of product quality, which was conducted on a very wide scale (up to hundreds of thousands of samples taken annually), allowed to identify the most critical farms, and even separate fields and lands.

In different time intervals after the accident, depending on self-cleaning processes and density of soil contamination, the changing radiological status of land, and the identification of further land-usage and recovery strategies had emerged. However, in critical localities where taking countermeasures is obligatory further, it is still necessary to conduct additional surveys of soil contamination, with representative sampling in each field, with particular focus on meadows and pastures. Without target financing such activities cannot be performed by the Oblasts alone. Additional surveying also demands

methodical support from specialised research organisations. Although this work is underway, it has not yet been supported by centralised financing and methodical tools.

Over the past 20 years, radioactive decay has resulted in soils contamination decreasing by approximately 35%. For example, in areas where soil ^{137}Cs contamination density was 555 kBq/m^2 (15 Ci/km^2) in 1986, it has dropped currently to 370 kBq/m^2 (10 Ci/km^2). Changes in A_s due to decay have to be accounted for when building new maps.

Vertical migration in the meadows and pastures results in embedding of nuclides in soil, though their migration below the root layer is minimal. Direct observations of ^{137}Cs content in the topsoil have shown that, actually, this indicator has decreased by no more than 15–20%. Evidently, this results from every-year mixing of the topsoil during tilling and cultivation.

Outflux of strontium and caesium radionuclides with plant harvests is within fractions of per cent annually, and cannot be considered as a key factor of radiation status change in time.

Rate of self-cleaning of territories from radioactive contamination due to erosion processes has been estimated to be within 0.1% to 1.0% for ^{90}Sr, and within 0.01% to 0.1% for ^{137}Cs annually depending on their abundance in the soil [14]. It has been demonstrated that resuspension has no influence on secondary contamination of inhabited localities, and that effective doses during inhalation of radionuclides is lower by an order of 1 to 3 than the doses of external exposure for machine-operators when servicing towed implements.

Territory self-cleaning due to processes of deflation, surface water runoff, and diffusion and convective transfer inside the soil profile during 20 years after the territory was contaminated with ^{90}Sr and ^{137}Cs makes a lesser contribution to improvement of the radiation situation than immobilisation due to physico-chemical fixation by soil, and subsequent reduced bioavailability for plants [9].

6.2.2. Scientific support

Immediately after the ChNPP accident, Ukraine set up an infrastructure for scientific support of monitoring and agricultural recovery of contaminated territories. Based on the scientific staff of UAAN, NASU, a specially set up Ukrainian Research Institute for Agricultural Radiology (UIAR), and with active involvement of scientists and experts of the Ministry of Health of Ukraine, the Ukrainian Scientific Centre for Radiation Medicine, and Ukrainian Committee of Hydrometeorology, a radioecological scientific school was soon set up in Ukraine. It provided methodical support for monitoring contaminated land and delivered timely objective estimates of radiation situation; assessed and adapted environment-specific recommendations for crop, forest and water management; and validated radiation standards and reference levels of contamination of soil and water, and agricultural and forestry products.

The scientific support program united over 50 scientific institutions (NASU, UAAN, UIAR, and others). This allowed for integrated resolution of a wide spectrum of radiological problems. These research activities have proven that the radiation situation in a contaminated territory depends not only on contamination density, but to a greater extent on the landscape and environmental conditions. At the same density of radionuclide contamination, the content of radionuclides in products can differ by 100 and more times.

Countermeasures have been developed and implemented in all farming sectors. In crop farming, these are special technologies of recultivating contaminated land, viz. soil treatment, applying lime materials and mineral fertilisers in unconventional ratios and doses, usage of local minerals, etc. In so doing, product radioactivity is reduced by 1.5 to 3-fold. Particularly high effectiveness is achieved by ameliorating grasslands and pastures, making it possible to reduce radioactivity of fodder and husbandry products by 4 to 16-fold.

In husbandry, high effectiveness has been achieved by introducing sorbents (ferrocines and zeolites) into the ration of cattle, allowing to reduce product radioactivity by 2 to 10-fold, as well as by follow-up fattening of meat cattle with clean fodder (the content of radiocaesium in muscular tissue was reduced by 5 to 8-fold). Making use of clean fodder at the final stage of fattening cattle allows using fodder from natural pastures practically without any constraints.

The content of radionuclides in food has been reduced by developing technologies of processing milk and other farming products. In the acute period of the accident, processing milk with high radioactive iodine content by implementing respective technologies at dairy plants allowed to reduce dairy products contamination by 7 to 10 times in the city of Kyiv and its suburbs. Getting rid of contaminated milk has not been registered in Ukraine. Processing milk, even by employing conventional technologies, allows eliminating roughly 65% of radiocaesium even today.

Two versions of the concept of farming in territories contaminated with radionuclides have been developed for different post-accident periods [15]. Based on research conducted in UIAR, UAAN and NASU, every 2–3 years «Recommendations on crop and forest management in radioactive contamina-

tion conditions» were issued. Their implementation allowed improving the situation dramatically, and reducing the level of product contamination and the population's internal exposure rate. Unfortunately, the last revision was published in 1998 for the period of 1999–2002 [16], and there have been no more orders for developing such recommendations.

The introduction of feeding additives, follow-up fattening of meat cattle with clean fodder, and surface and radical improvement of meadows, has ensured that collective farms have stopped producing milk and meat with a radiocaesium content exceeding standard levels. To provide scientific follow-up on implementing countermeasures, Radioecological Centres UAAN have been set up in the five most affected Oblasts, viz. Volynska, Rivnenska, Zhytomyrska, Kyivska, and Chernihivska [17]. These Centres have accumulated information on the radiation situation; adapted countermeasures to specific conditions of the Oblasts; and delivered consultancy services to producers of farming products. Financing of Oblast centres has been so low over recent years that this has hindered execution of their key functions. Scientific research results have been presented in different publications and methodological materials, monographs and reports at international and national scientific conferences. The prestige of the Ukrainian scientific school in agricultural radioecology has been acknowledged by the International CEC program, IncoCopernicus and others, which involved the research staff of NASU, UAAN and UIAR, and were executed jointly with leading research institutions in Europe, the USA, and Canada.

With the collapse of the USSR, research efforts in «Agricultural radioecology» were financed by Ministry of Chornobyl of Ukraine via NASU, UAAN and the Ministry of Agricultural Policy of Ukraine within the framework of the program for scientific follow-up of ChNPP accident recovery operations. The programs were managed and supervised by respective scientific divisions of NASU, UAAN and the Directorate of the Ministry of Agricultural Policy and the Ministry of Emergencies of Ukraine. The Scientific-and-Technological Council of the UAAN Presidium provided scientific management. Sections of Scientific-and-Technological Councils of the Ministry for Agricultural Policy and the Ministry of Emergencies of Ukraine were set up, but they ceased functioning since 1998 because of absence of a target program and lack of financing.

Since 1996, scientific developments were financed only as part of the scientific program of the Ministry of Emergencies of Ukraine, and since 1997, their implementation has been financed selectively.

6.2.3. Pattern of radionuclides transfer in food chains

Accumulation of radionuclides by root systems is the key factor that defines radiation safety in the contaminated territory. The key parameter that characterises behaviour of radionuclides in the «soil-plant» system is the transfer factor (TF, kg/m^2). Post-accident investigations in Ukraine and Russia have demonstrated that, over time, selective fixation of ^{137}Cs and ^{90}Sr in soil takes place. This involves a reduction in content of readily exchangeable forms of nuclides and, as a result, biological availability of nuclides for accumulation by plants.

A linear dependence between the specific activity of plants and soil has been demonstrated on the radioactive traces. This allows inferring that there is no «Chornobyl» phenomenon and to extend data to other cases [18].

In the first 5–6 post-accident years, there was a significant (5 to 15-fold) reduction in the specific activity of ^{137}Cs in plants in all types of soils investigated, and in the next 12 years, it decreased only by a factor of 1.5 to 2.5 [9]. Without exception, for all crops investigated and irrespective of the type of soil, the reduction of the ^{137}Cs transfer factor (TF) in time after ^{137}Cs has entered into the soil can be appropriately approximated by a sum of two exponents.

The «tailing» component of the curve is an exponent that characterises slow reduction of the «zero» transfer factor (TF_0^s) with the ecological semireduction period T_e^s. Extrapolation of the «initial» component prior to 1986 (at time $t = 0$) allows the quick component with the semireduction period T_e^q to be distinguished. At the time of fall-out, the contribution to TF_0 of ^{137}Cs forms with different rates of reduction in the soil is evaluated by parameters a_0^q and $a_0^s = 1 - a_0^q$. A reduction of $TF(t)$ ^{137}Cs from soil to plants due to soil processes of conversion of radionuclide forms in time is described by formula:

$$TF(t) = TF_0 \cdot \left\{ a_0^q \cdot \exp\left(-\frac{0{,}693 \cdot t}{T_e^q}\right) + a_0^s \cdot \exp\left(-\frac{0{,}693 \cdot t}{T_e^s}\right) \right\}$$

$$TF_0 = TF_0^q + TF_0^s.$$

The biological features of crops are characterised by the value of the «zero» ^{137}Cs transfer factor TF_0, which demonstrates the capacity of the given crop to accumulate the element at an equal total amount of radiocaesium forms in soil that are available to plants (Table 6.2.1).

Table 6.2.1

Accident year values of transfer factors (TF) of ^{137}Cs forms that bind with soil quickly TF_0^q and slowly TF_0^s [18]

Crop group	Peaty		Soddy-podzolic		Grey forest		Chernozem	
	TF_0^q	TF_0^s	TF_0^q	TF_0^s	TF_0^q	TF_0^s	TF_0^q	TF_0^s
Natural herbage hay	218	22	25	0.78	10	0.49	–	–
Cultivated grass hay	89	4.7	6.0	0.38	4.8	0.11	3.7	0.019
Green fodder (corn, lucerne, clover)	35	1.4	3.4	0.37	1.5	0.18	1.9	0.039
Vegetables (cabbage, tomatoes, cucumbers)	–	–	3.3	0.17	2.0	0.031	1.4	0.014
Roots and tuber crops (beets, potatoes), onions	11	0.84	1.5	0.10	0.55	0.064	0.56	0.017
Grain crops (winter wheat, barley and rye)	6.6	0.81	0.80	0.10	0.57	0.048	0.35	0.019
Change multiplicity	33	27	31	7.8	18	10	11	2.8

In order of decreasing ^{137}Cs TF, crops, irrespective of the type of soil in which they are cultivated, can be arranged as follows: natural herbage hay, cultivated cereal grass hay, green mass of forage crops, vegetables, beetroots, onion, potatoes, and grain of cereal crops. Irrespective of the post-accident period, with regard to availability of ^{137}Cs for accumulation by crops, soils form the following descending series: peaty, soddy-podzolic, grey forest, and chernozem soil.

In the radioactivity fallout year, over 90% of radionuclides were in the exchangeable physical-and-chemical forms, which were gradually transformed to strongly absorbed forms that are not readily available for plants. The ^{137}Cs TF decreases most rapidly with time in organic peaty soil (T_e^q – 0.89 a year). This process is retarded in the following series of mineral soils: in chernozem by 1.3 a year; in grey podzolized soil by 1.7 years, and in soddy-podzolic soil by 1.8 years.

The differences of T_e^s values for various soils are more significant. The highest rate of fixation of ^{137}Cs forms available for plants belongs to peaty soil T_e^s = 6.6 years. For soddy-podzolic soil, the mean value T_e^s = 20 years; for grey podzolized soil it is equal to 44 years; and for chernozem the value is equal to 112 years.

Milk contamination. In inhabited localities where the annual effective equivalent population exposure rate approaches or exceeds 1 mSv, approximately 600 000 people reside, including 180 000 children up to age 17. In current farming conditions, over 90% of potatoes and 60% of milk is produced by private farms and delivered to Ukraine's consumer market. In these inhabited localities, the annual collective dose is 200–400 man-Sv. This is because the majority of the population, especially after allocation of shares took place, used peaty soil with an extremely high factor of radiocaesium transfer from soil to plants for vegetable gardens, pastures and hayfields.

The pattern of plant contamination correlates with the pattern of ^{137}Cs content in cow milk. According to the measured concentrations of ^{137}Cs in milk within the framework of the program of certifying rural inhabited localities in the Zhytomyrska, Kyivska and Rivnenska Oblasts of Ukraine during 1987–1997, the «short» and «long» periods of semi-cleaning of milk from the nuclide were estimated to be 3 and 15 years, respectively [19]. These estimates are averaged for different soil conditions, and they demonstrate a good fit with the average values of parameters T_e^q and T_e^s for natural herbage and cultivated grass in peaty soil and soddy-podzolic soil found for the soil-plant system [18].

These data show that the factor of radiocaesium transfer over the soil-plant-milk chain will decrease very slowly, viz. by 2-fold in 6 to 20 years. Allocation of shares involved critical peaty soils, for which the radiocaesium – plants transfer factor is 30 to 100 times higher than that for mineral soil. At the same time, section 3.22 of the «Concept of agricultural management in contaminated territories, and their overall rehabilitation during 2000–2010» states that «safe utilisation of such lots can be warranted only if they are owned by collective farms or allotted to the state reserve» [15].

Unfortunately, even today the population is being allotted pasture land for cattle grazing and hayfields with high ^{137}Cs – grass transfer factors. Due to flooding conditions, melioration of much of this land is impossible and it will remain critical. If radical or surface improvement of such land is not carried out in the future, then hay should only be used for feeding of young dairy and meat cattle. In extreme cases, when the cattle owner cannot provide clean hay for cows during the lactation period, measures should be taken to provide clean hay, or to collect milk for processing.

The influence of allocating shares of critical land on the radiation situation has been confirmed by investigating the levels of contamination of farming products in 50 households (20% of the total num-

ber) in village Yel'ne of the Rokitnivsky Raion in Rivnenska Oblast during September-October 2003. All of the milk, cattle meat and cabbage produced in village Yel'ne exceeded permissible state levels PL-97 with regard to ^{137}Cs content. PL-97 norms, with regard to radiocaesium content, have been exceeded in the following cases: 85% for meat of calves; 88% for meat of pigs; 86% for potatoes; 50% for beets; 70% for carrots; and 40% for pumpkins [20]. Such high levels of contamination of plant products were not observed even in the early Chornobyl post-accident years. The high level of milk contamination can be attributed, primarily, to grazing cattle on share-allotted non-rehabilitated pastures in peaty lands. High pork contamination levels are the result of feeding pigs mainly with contaminated milk and potatoes. A dramatic increase in the level of contamination of milk and meat can be expected because lack of fodder will be compensated by the farmer's usage of hay from marshes and the woods.

6.2.4. Countermeasures for improving the radiation situation

In general, recommended practices of cattle keeping are not implemented in private household farms, livestock yield is dropping and ever increasing amounts of contaminated milk are used in the children's diet. Notably, in 2004–2005, in the villages of the Rivnenska Oblast, 44% of children aged up to three ate at home. Thus, the achievements of the «Program on elimination of the ChNPP accident consequences» in the first post-accident decade have practically come to naught.

In 2005, the individual population exposure dose reached or exceeded 5 mSv/annually in 15 inhabited locations. The content of ^{137}Cs in the milk of cows in these villages varies between 413 and 827 Bq/l (Table 6.2.2). There is a clear trend of decreasing milk contamination level over time, which corresponds to the rate of fixation of the nuclide by peaty soil. The same behaviour is also observed in the inhabited localities where milk and meat contamination levels exceed PL-97 requirements (Table 6.2.3). In 45 inhabited localities, the levels of radioactive contamination of milk still exceed PL-97, and in many cases, the requirements of the old standard TPL-87, which is a gross violation of the Laws of Ukraine. The countermeasure needs of most critical inhabited localities have not been met.

Table 6.2.2

Content of ^{137}Cs in milk produced in villages of the Rivnenska Oblast with the individual population exposure rate of 4–6 mSv/year during 2001–2004 [21]

Raion, village	Density of soil contamination with ^{137}Cs, kBq/m^2	^{137}Cs content in milk, Bq/l			
		2001	2002	2003	2004
Rokytnivsky, Vezhytsia	95	827	704	671	584
Rokytnivsky, Drozdyn'	53	772	704	719	628
Zarichniansky, Sernyky	81	766	633	427	604
Rokytnivsky, Yel'ne	95	745	657	555	568
Dubrovytsky, Velykyi Cheremel'	144	701	526	495	413

Table 6.2.3

Inhabited localities where milk contamination levels exceed PL-97 standards [21]

Oblasts	2001	2003	2004
Volynska	166	166	166
Zhytomyrska	90	57	61
Rivnenska	156	111	89
Chernihivska	3	0	0
Kyivska	4	0	1
Total	419	334	317

The bulk of Polissia region soils lack nutritive substances, in particular, potassium. Very acidic soils with pH< 5 account for roughly 9% of contaminated land. Due to the countermeasures taken in 1986–1999, over 1.5 Mha of contaminated land was rehabilitated in Ukraine. Introducing lime jointly with fertilizers in the early post-accident years allowed reducing the content of radionuclides in products by 2.5–5 times. However, in spite of the well-grounded necessity of taking countermeasures, only 1/10th of the land was fertilized, 1/20th was limed, and 1/4th of the pastures were improved, on average, annually during 1994–2000.

After 2000, a continuing decline in financing has resulted in reduced implementation of countermeasures. Table 6.2.4 shows that, during 1999 through 2004, annual meadow improvement and repeated meadow improvement was carried out in only 1,500–5,700 ha, whilst production of combined fodder with sorbent additives was 150 to 3,900 tonnes. Land improvement activities were reduced to such levels that decline in soil nitrogen, phosphorus, and potassium balance has been observed. This will inevitably result in increasing levels of radioactive contamination of plant cultivation products.

Table 6.2.4

Scope of major countermeasures taken in radio-contaminated territories, which prevent transfer of radionuclides into farming products, '000 ha / '000 hrivnas

Measures	1999	2000	2001	2002	2003	2004
Meadow improvement and repeated meadow improvement	12.7 / 3586	3.5 / 1829	4.4 / 1810	1.5 / 576.6	5.7/2360.3	4.0/2810
Liming of acidic soil	4.2 / 539	2.1 / 293	3.8 / 335	0.06 / 6.7	6.0/655.7	6.2/840.0
Applying of increased amounts of mineral fertilisers	6.6 / 920	–	–	–	–	/ 473.7
Applying of sapropels and peat composts	2.4 / 610	1.5 / 566	2.8 / 735.0	0.3 / 221.3	2.9/907.5	–
Producing and applying of the combined fodder with radioprotective additives, '000 tonnes	2.9 / 1190	1.2 / 960	2.5 / 1301	0.15 / 110	3.9/1586.8	1.2/805.0

Which countermeasures should be the highest ranking ones in the future? Radical improvement of natural forage lands will allow reducing transfer of radionuclides from the soil to meadow grass, and will ensure a decrease in the radiocaesium transfer factor by 4 to 10-fold [22]. Experiments in different regions of the contamination zone have shown that repeated radical improvement of meadows will reduce transfer of radionuclides from the soil to meadow grass only by 2 to 3-fold [22].

Consolidated data on effectiveness of measures taken in meadow and pasture lands is summarised in Table 6.2.5.

Table 6.2.5

Effectiveness of countermeasures taken in meadow and grazing land [22]

Radioprotection measures	Multiplicity of reduction of ^{137}Cs concentration in plants, times	
	Mineral soil (sandy and loamy soil)	Organic soil (peaty)
Drainage	–	2–4
Disking or rotary cultivation	1.2–1.5	1.8–3.5
Ploughing	1.8–2.5	2.0–3.2
Ploughing with turnover of chunk and displacement it to the depth of 35 to 40 cm	8–12	10–16
Liming	1.3–1.8	1.5–2.0
Nitrogen and increased amounts of phosphorus-potassium fertilizers	1.2–3.0	1.5–3.0
Surface improvement	1.6–2.9	1.8–14.0
Radical improvement	3.0–12.0	4.0–16.0

The condition of pastures and meadows, along with the content of radionuclides in the grass stand, has a dramatic impact on the contamination of husbandry products. During grazing of cattle and small cattle on infertile natural pastures where the grass stand is poorly developed or has been trampled, the level of radionuclide contamination of milk and meat can be several times higher than that on meadows with a good grass stand. **Melioration, and surface and radical improvement of grazing land and hayland must be carried out in all critical lands.**

The significant effects of sorbents addition to fodder and fattening animals with clean fodder prior to slaughter have been confirmed. At the final fattening stage, contaminated fodder might be replaced

with clean fodder. In so doing, the content of ^{137}Cs in muscular tissue dropped by 6 to 10 times during 2–3 months due to the high rate of ^{137}Cs excretion from animals' organism [23].

Implementation of the technology of fattening with clean fodder under life-time control of ^{137}Cs content in animals' bodies allows fodder to be used with few constraints [16]. In 1996, in the Zhytomyrska and Kyivska Oblasts, 1,600 cattle with the intramuscular ^{137}Cs content of 3,000 Bq/kg were fattened. The intramuscular ^{137}Cs content was reduced in 2–3 months to 130 Bq/kg, i. e. more than by a factor of 20. The effectiveness of this measure was enhanced by addition of sorbents. In the Rivnenska Oblast, salt-licks containing mineral nutritive elements and ferrocine also proved to be very effective [23].

After the accident, the following substances were used extensively as sorbents in Polissia: zeolites – natural minerals with a high caesium-binding capacity – vermiculite (Zaporizhia Oblast), palygorskite (Cherkaska Oblast), and clinoptilolite (town of Khust, Zakarpatska Oblast). As regards effectiveness of enterosorption, the minerals form the following series: palygorskite, vermiculite, and clinoptilolite, and allow to reduce radiocaesium transfer to milk by 3–9.7 times. The effectiveness of zeolites increased with increasing preparation dose and decreasing granular size. Modifying zeolites with ferrocines and other substances increased selective sorption of ^{137}Cs by several-fold. Using zeolites when fattening prior to slaughter reduced the accumulation of ^{137}Cs in the muscular tissue of animals by 2.0–2.4 times [23].

The Sokyrnytsky Zeolite Plant of the Ministry of Emergencies of Ukraine has manufactured and delivered 1,362 tons of zeolite powder to provender mills in three Oblasts. Action has been taken to reprofile farms in five Oblasts to «meat husbandry» and «reproductive pig breeding». During this period, the brood stock of the meat cattle has been renewed and replenished; the material and technical basis of farms has been strengthened; and scientific and methodical support has been delivered. However, the support for these highly effective measures was insignificant, during 2001–2004, they were funded with only 1.5 million hrivnas.

After the accident, there were no reported cases of contamination of the meat of geese and ducks over standards. In recent years, providing the poultry population with feed grain has become a problem. So, in the summer, in the Volynska and Rivnenska Oblasts, geese flocks now feed on flood lands, i.e. the most critical natural landscapes. Naturally, the concentration of radioactive caesium in goose meat exceeds the concentration of this nuclide in beef. A family living in the Polissia eats several dozen geese over winter, i. e. poultry meat has become a critical component in the diet of large cohorts of the population. This problem can be resolved by fattening poultry with clean fodder in 2–2.5 months prior to slaughter.

Developing fodder production will become a base for producing clean milk and meat. Dairy husbandry should be provided with combined fodder with additives of ferrocines and zeolites. In the course of implementation of the project «Ensuring radiation protection of children in Ukraine on territories affected by the ChNPP accident» within the framework of the program «Children of Ukraine» it has been demonstrated that comprehensive countermeasures taken in fodder production and husbandry (improvement and repeated improvement of pastures and usage of combined fodder with sorbent additives) have ensured production of milk and meat with a radiocaesium content lower than that specified in PL-97 at almost all critical farms and settlements in Ukrainian Polissia.

Radiation monitoring system. A comprehensive radiation monitoring system has been set up and it is functioning within the contaminated territories. In 2,139 inhabited localities, milk and potatoes are sampled and analysed for caesium-137 and strontium-90 content. In inhabited localities where annual certified population exposure rates are in excess of 3 mSv, and in certain inhabited localities in the absolute resettlement zone, milk is sampled and analysed six times every year. In inhabited localities in the zone of assured voluntary relocation, this is done twice a year. In settlements in the zone of intensified radioecological control, this is done once a year. During 2001–2004, more than 63,500 samples of milk and potatoes were taken and analysed.

Every year, there are a decreasing number of inhabited localities, in which the human annual exposure rate can exceed 1 mSv. In 1991, the number of such inhabited localities was 826, and in 2004, this number was 207. Continued action has to be taken to ensure there is no critical change in the radiation situation in such localities.

Laboratories and stations, subordinate to central executive power bodies, are implementing a wide-scale program of radiation control of food at all stages of its production. As a whole, the radiological services annually take more than 800,000 measurements of the content of radionuclides in food during production and processing. Permissible levels are exceeded in 1.5–2% of samples taken. The bulk of measurements are taken by the laboratories of the Ministry of Agricultural Policy, which, unfortunately, lack equipment and financing; and the monitoring service has not been assigned the status of a state service.

Effectiveness of countermeasures. When planning a system of countermeasures, it is necessary to be governed both by the terminal level of product contamination and the amount of radionuclides in the given kind of product as a whole (radionuclide flux). For instance, the amount of radiocaesium carried out from soil by the net grain crop yield in Polissia conditions does not exceed 1–2% of the total outflux of the radionuclide with plants. Using grain for cattle fodder and in bakeries accounts for a cumulative dose of about 10–20 man-Sv. At the same time, usage of contaminated hay for cattle fodder accounts for a dose that is 50 to 70 times higher. Hence, however high the radiological effectiveness of countermeasures for cultivating grain crops, they cannot reduce the total collective dose by more than several per cent.

Three components were identified to assess the effectiveness of countermeasures and thus make up subsequent decisions on their adoption [24]. The first one is *radioecological effectiveness*, which shows by how many times the level of product contamination can be reduced by taking a countermeasure. However, the key criterion of effectiveness of agricultural countermeasures is not the reduction of the radionuclide concentration in the products achieved, but the integral (total) dose whose formation was prevented by the countermeasures taken. It is known as the *dose effectiveness*. Evidently, the second component (dose effectiveness) depends on many factors, including the amount of products made, and the time and mode of their consumption. For instance, if improvement of meadows contributed to producing hay with low ^{137}Cs content, and it was used for feeding the calves rather than milk cows, the dose effectiveness of such a countermeasure will be nil. The general strategy of countermeasures is defined by the dose effectiveness, though the radioecological effectiveness can be of critical importance when making decisions on taking countermeasures if the radionuclide concentration in the products exceeds the standard level.

Similar exposure dose reductions can be achieved by different countermeasures whose cost can differ significantly. Therefore, the third component of overall effectiveness is *cost efficiency* whose quantitative measure is the cost of unit dose averted by countermeasures – hrivna of additional expenditure per one averted man-Sv.

Analysis has shown that, at an approximately equal radiological effectiveness due to taking all the above countermeasures, which, for instance, reduce the products contamination level by a factor of two, their dose effectiveness in husbandry is significantly higher than in crop production, whilst the cost effectiveness differs on the whole by up to 1,000 times. In other words, the countermeasure effectiveness increases with increasing trophic level, at which it is effected in the soil – plant (vegetative organs – productive organs) – animals (meat and milk) – processing chain. The next 5 to 10 years will be critical for identifying priorities.

The countermeasures taken and fixation of ^{137}Cs in the soil has significantly improved the radiation and sanitary conditions of population's residence in ChNPP accident-contaminated territories. In the greater part of the contaminated territory, collective agricultural enterprises, farms and private households cultivate food products whose ^{137}Cs content meets tight national standards, i. e. permissible levels (PL-97). In many forestries, the wild food products also meet radiation hygiene standards.

Essentially, the countermeasures taken over recent years in the scope mentioned have no critical effect on the radiation situation. With aim of implementing monitoring of radiation situation in Ukraine's agriculture, developing recommendations on its improvement, providing scientific and methodical support for the units of the Ministry of Emergencies of Ukraine and the Ministry of Agricultural Policy, which are responsible for control of the radiation situation,– a state program for implementing protective countermeasures and scientific follow-up in the agriculture has to be developed and realized in practice.

The International Forum «Chornobyl's Legacy: Health, Environmental and Socio-Economic Impacts» held in Vienna (5–6 September 2005) found that the measures taken by the governments of the affected CIS countries to mitigate the accident consequences were, as a whole, timely and adequate. Current research has shown that the focal point of efforts has to be changed by placing priorities on economic and social development.

6.3. Migration of radionuclides from the Chornobyl fallout in irrigated land

Due to the ChNPP accident, the bulk of airborne radioactive fallout hit the Dnipro River and its tributaries. In addition, there is annual intake to date of long-lived radionuclides from the catchment basin to the water system.

Intensive activities in monitoring the major water bodies of Ukraine were launched immediately after the accident. As early as May 1986, the Ukrainian Hydrometeorological Service performed a gamma-survey for radioactive contamination of all water reservoirs of the Dnipro Hydro cascade. This survey was repeated in June and September.

Fallout of ^{137}Cs and ^{90}Sr from the ChNPP accident release into the Dnipro water, and further onto irrigated land has entailed two aspects of the problem:

1) determining the levels of ^{90}Sr and ^{137}Cs transfer with sprinkling water to irrigated land (especially to rice paddies) to develop a long-term forecast of the behaviour of this process. The importance of this aspect is that transfer of radionuclides with water to irrigated land contributes significantly to additional land contamination [25];

2) quantitative assessment of the parameters of radioactive contamination of crop harvests and studying the behaviour of this process to develop a long-term forecast of contamination of food products obtained from irrigated land.

The basic processes of transfer of radionuclides to crops cultivated by irrigation were known before the Chornobyl accident. Sprinkling is known to carry radioactive elements with water to the leaves, stems, flowers and fruit of plants, which absorb these elements directly, in other words, non-root (airborne) transfer of radionuclides to plants. With such a transfer path, radioactive substances are not absorbed by the soil solid phase and there is no barrier to their uptake by plants.

Concurrently with this process, the roots of plants also accumulate radionuclides. However, the share of ^{137}Cs transferred along this path is negligible (by 2–3 orders less), therefore, in practice (e. g. at the post-accident change in the content of this radionuclide in the Dnipro water), non-root transfer of this radionuclide for all crops during irrigation will prevail. The contribution of root transfer of ^{90}Sr (at constant concentration of radionuclides in water) will be comparable to its transfer via overground organs of plants as early as in 2–16 years (depending on the crop species and the regime of land irrigation).

The influence of irrigation water quality. The species of radionuclides in water, water ion composition and pH, presence of competing ions and the content of suspensions affects the mobility of radionuclides in water and their further transfer to the yield. Radionuclide accumulation is the least in crops cultivated when irrigating with highly mineralised water (ratio: Inhulets River water – 80% + Dnipro River water – 20%, and mineralisation – 590 mg/l).

Crop irrigation regime (standard and number of waterings). Depending on the weather and climate conditions, and the biological features of crops, different amounts of water are required to ensure yields. The irrigation norm provided by sprinkling during the vegetation period is delivered in several stages with the irrigation norm value of 400–600 m^3/ha. It has been established that, when employing overhead irrigation with an increasing number of waterings containing radionuclides, their transfer to the crops cultivated also increases, however, this dependence is not directly proportional.

Irrigation methods. The most widespread irrigation methods in Ukraine are overhead irrigation (sprinkling) and flooding in paddies. Drip and subsoil irrigation have just started to be implemented and are used in a small area.

Sprinkling is the most contaminating method because radionuclides come into contact with plants, and are absorbed by the surface tissues. As a result, radionuclides are accumulated in the crop 4–33 times more than during subsoil irrigation; 2–8 times more than during furrow irrigation; and 2–14 times more than during drip irrigation [26].

In 1987–1988, transfer of ^{137}Cs into crops was higher when the irrigation source (water reservoir) was closer to the accident site [26]. Thus, its content in crops irrigated with water from the Kanivske reservoir was 2–3 times higher than when irrigating with water from the Kakhovske reservoir, and up to 6 times higher than when irrigating with water taken from sources other than those linked to the Dnipro River (Table 6.3.1). Since the content of radionuclides in the Kanivske reservoir water was also 2–3 times higher than that in the Kakhovske reservoir [27], this regularity can be attributed to the directly proportional dependence of radionuclide accumulation in the yield on radionuclide concentration in irrigation water.

In the first 10 post-accident years, transfer of ^{137}Cs to crops changed insignificantly, and in 1996 it was practically at the 1988 level (Table 6.3.2). Over several years, ^{90}Sr has demonstrated a distinctive increase in root transfer [26].

Over time, the content of ^{90}Sr in the rice yield dramatically increased due to root transfer. Its content in rice grain in 1996 (in 10 years after the accident) had increased, as against 1986, by 18-fold. The amount of accumulation of ^{137}Cs in rice grain stabilised at the level of 1 Bq/kg. Further accumulation of this radionuclide in rice grain will correlate with its content in water (Table 6.3.3).

Based on generalising an extensive body of data collected during pre-accident and post-accident research in accumulation of radionuclides in the yield of major crops cultivated with irrigation, the averaged values of coefficients that characterise the level of ^{137}Cs and ^{90}Sr transfer to crops can be calculated and used for forecast estimates (Table 6.3.4).

Table 6.3.1

Content of ^{137}Cs in the commercial yield of crops during irrigation with water from different sources (Bq/kg aerated-dry mass)

Crop	Years	Dnipro Hydro cascade water reservoirs				Water from other sources	
		Kanivske	Kremen-chutske	Dnypro-dzerzhinske	Kakhovske	Kharkivska Oblast	Donetska Oblast
Winter wheat	1987	11.85	1.85	0.92	1.11	0.29	0.37
	1988	21.11	1.48	0.37	1.11	0.37	0.37
Corn	1987	0.37	0.37	0.18	0.22	0.07	0.07
	1988	0.37	0.18	0.22	0.11	0.04	0.07
Lucerne hay	1987	22.2	22.2	13.7	11.8	2.96	3.70
	1988	14.8	14.8	11.1	7.40	3.33	3.33
Cabbage	1987	0.22	0.26	0.11	0.11	0.04	0.04
	1988	0.22	0.22	0.07	0.11	0.04	0.04
Tomatoes	1987	0.74	0.74	0.37	0.37	0.22	0.18
	1988	0.74	0.37	0.37	0.74	0.22	0.18
Cucumbers	1987	1.48	1.48	0.74	0.74	0.37	0.37
	1988	1.11	1.48	0.74	0.37	0.37	0.74

Table 6.3.2

Content of radionuclides in yield of major crops cultivated by irrigating with water from the Kakhovske reservoir, Bq/kg aerated-dry mass

Crop	^{137}Cs		^{90}Sr	
	1988 p.	1996 p.	1988 p.	1996 p.
Winter wheat, grain	1.10–1.91	0.50	0.12–0.31	0.90
Corn, grain	0.13–0.42	0.30	0.07–0.19	0.11
Lucerne, hay	11.1–22.8	12.0	3.70–11.10	3.10
Cabbage, head	0.11–0.30	0.16	0.004–0.015	0.19
Tomatoes, vegetable	0.31–0.72	0.89	0.02–0.04	1.92
Cucumbers, vegetable	0.60–1.51	1.10	0.40–1.50	1.13
Red beets, storage root	0.43–0.71	1.53	0.001–0.004	2.60
Carrots, storage roots	0.37–0.74	1.10	0.11–0.22	1.51
Squash, vegetable	0.19–0.26	0.52	0.07–0.11	2.40
Onion, head	0.74–1.11	0.71	0.01–0.11	2.00

Table 6.3.3

Transfer of radionuclides the rice yield

Survey years	Radionuclide content, Bq/kg aerated-dry mass			
	Sr-90		Cs-137	
	Grain	Straw	Grain	Straw
1972	0.33	4.1	2.4	5.6
1982	0.30	3.0	0.7	1.6
1985	0.11	1.2	0.6	1.0
1986	0.07	1.1	1.0	1.8
1987	0.15	1.5	1.6	2.9
1988	0.19	2.1	1.5	2.2
1989	0.37	2.8	1.2	2.0

Continuation Table 6.3.3

Survey years	Radionuclide content, Bq/kg aerated-dry mass			
	Sr-90		Cs-137	
	Grain	Straw	Grain	Straw
1990	0.56	3.5	0.9	2.2
1991	0.69	4.3	1.1	1.9
1992	0.81	4.9	1.0	2.1
1993	1.12	5.5	0.9	1.5
1994	0.70	3.8	2.0	3.5
1995	1.27	5.2	1.1	2.8
1996	1.30	5.3	0.8	2.3

Table 6.3.4

Averaged factors, which characterise the amount of ^{137}Cs and ^{90}Sr transfer to crops cultivated with overhead irrigation [25–27]

Crop, organ or its part which is used	^{137}Cs		^{90}Sr	
	TF*	TF_a **	TF	TF_a
Winter wheat, grain	0.11	24	1.33	2.90
straw	0.53	110	4.42	11
Spring wheat, grain	0.15	32	–	–
Barley, grain	0.08	15	–	–
Peas, pea	0.19	38	1.37	3.1
Millet grain	0.05	9	–	–
Corn: grain	0.25	47	0.42	0.9
silage	1.25	290	1.33	2.7
Rice***: grain	0.13	80	0.55	13
straw	0.88	530	2.65	51
Lucerne, hay	3.80	920	21	64
Fodder beets, storage roots	0.63	170	2.20	5.9
Carrots, storage roots	0.18	37	0.39	0.8
Potatoes, potato	0.05	9	0.33	0.7
Cucumbers, vegetable	0.42	86	0.11	0.3
Tomato, vegetable	0.28	39	0.17	0.4
Sweet pepper, vegetable	0.13	27	0.22	0.7
Squash, vegetable	0.02	4	0.17	0.5
Pumpkin, vegetable	0.06	10	0.17	0.5
Cabbage, head	0.08	15	0.47	1.6
Onions, onion	0.27	37	1.86	5.8
Egg-plant, vegetable	0.11	23	0.25	–
Greens	0.21	40	1.40	3.3

* TF – proportionality factor (Bq/kg mass of yield with moisture content used)/(kBq/m^2 soil).
** TF_a – accumulation factor (Bq/kg mass of yield with moisture content used)/(Bq/l water).
*** Irrigation of paddies by flooding.

Root intake of radionuclides to crops during irrigation. As early as 8–10 years after starting irrigation with contaminated water, the soil transfer of ^{90}Sr to vegetables and certain other crops becomes predominant, whilst intake of ^{137}Cs over a very extended period of time (up to 200 years) will be associated

predominantly with the water (non-root) path. In clayey types of soil, such a ratio between the root and non-root paths of ^{137}Cs transfer will persist until its concentration in water drops by 2–3 orders as compared to the initial one.

For crops of different species, the time interval during which there is equilibrium in plant intake of ^{90}Sr via the root and non-root paths, varies from 2 to 16 years depending on the irrigation regime and species of crop. This time interval was as follows: for cereal crops – 14–16 years; for vegetables – 8–10 years; and for lucerne – 2–6 years. For corn, this equilibrium occurs later than the 16th – 20th year.

Intake of ^{137}Cs from water in case of sprinkling of clayey soil will prevail over the soil path until the density of soil contamination will not become 1,000 times more than current one due to the annual irrigation.

Regularities of radionuclide contamination of irrigated land. The pattern of accumulation of these radionuclides in irrigated land depends on two processes: migration of radionuclides with water into soil, and a process involving loss.

The amount of radionuclides taken in depends on their concentration in water and the irrigation norm during the vegetation period. The loss process is associated with physical decay of radionuclides and their carryover below the root soil layer during vertical soil migration, as well as with removal at harvest.

Observation data have shown that, at chronic intake of ^{137}Cs and ^{90}Sr with irrigation water to irrigated land, represented by claly soil, the upper 20-cm soil layer retains within 53 to 85% of the gross amount of radionuclides introduced during one irrigation season [27]. In this case, the crop intake was less than 10%.

In analysing the pattern of intake of radionuclides with irrigation water by the soil of irrigated paddies in the Khersonska Oblast in 1987 through 1997, the content of ^{137}Cs and ^{90}Sr in the soil of rice paddies increased by 1.7 and 2.7 times, respectively.

Estimates made using the parameters of migration of radionuclides in irrigated land allow a long-term forecast of the quantitative parameters of soil radionuclide intake with water. At a constant specific concentration of radionuclides in water, the process of ^{90}Sr accumulation in soil takes 70 years, and that of ^{137}Cs requires 200 years. After this, the process of radionuclide intake with water will match the processes of their out flux.

Provided the content of these radionuclides in the irrigation water source demonstrates a steady trend, there is a need to develop a long-term forecast of the additional contamination of irrigated land with ^{137}Cs and ^{90}Sr radionuclide intake with water. Note, however, that, since 1996, monitoring surveys were terminated in irrigation areas, making it impossible to predict correctly the radiation situation in this region.

Predicting the exposure rates for the population in the Dnipro River basin. Over 8 million people use Dnipro River water. The predicted values of exposure from accident radionuclides for this cohort of people is 3,000 man-Sv, including 2,500 man-Sv due to ^{90}Sr and 500 man-Sv due to ^{137}Cs [27]. For the population in other regions, the exposure from consuming water from different sources will be significantly lower, and it can be ignored in the exposure load. The expected population dose of Ukraine's population from the Chornobyl accident over 70 years will be as much as 55,000 to 70,000 man-Sv, of which the water component will account for only 4–5%.

6.4. Forest management under radioactive contamination conditions

Forests in 18 Oblasts of Ukraine were radio-contaminated due to the ChNPP accident. In 1991–92, the density of contamination with ^{137}Cs exceeding 37 kBq/m^2 (1 Ci/km^2) was found in territories with the area of 1.23 Mha. The Polissia forests of Ukraine were the most heavily radio-contaminated.

Beyond the 30-km ChNPP zone, due to high levels of contamination of forests with ^{137}Cs, many economic activities were prohibited on territories exceeding 157,000 ha, and 110,000 ha of forests managed by the Chornobylsky and Novo-Shepelytsky state forestries were included in the ChNPP exclusion zone. The total direct losses incurred by the forest management enterprises due to radioactive contamination by 31.12.1986, were 65 million USD; and annual losses due to reduced volumes of timber cutting and associated forest utilisation amount to 7.15 million USD.

Beyond the limits of the exclusion and absolute resettlement zone, the main radionuclide is ^{137}Cs, and this is the focus of attention. However, in forests adjacent to the exclusion zone, as well as in separate «spots» in the Zhytomyrska, Kyivska, Cherkaska and Vinnytska Oblasts, the share of ^{90}Sr in contamination of the components of the forest ecosystem is growing. This calls for in-depth studies in its behaviour in the forest cenosis. In the long term, parts of the exclusion zone forests will recover and be incorporated into a normal management scheme. The presence of transuranium elements in the radioactive contamina-

tion of these forests can also present certain challenges, and requires an in-depth examination of the situation.

After airborne transfer of ^{137}Cs to the forest ecosystem, 70 to 90% of its total activity will be contained by the tops of coniferous trees. Intensive migration of radiocaesium as early as in the first vegetation period, will result in significant redistribution of ^{137}Cs among the components of the forest ecosystem. In 3–4 months, up to 80–90% of ^{137}Cs migrated to the surface of the moss cover and the forest floor, and the vegetation root system started to gradually absorb radiocaesium. In 3–4 years, a period of quasi-equilibrium of this radionuclide in the ground and vegetation cover of forests had occurred, which has continued to the present [28]. Its distinctive features are as follows: 1) domination of the root path of radionuclide uptake by plants, which depends primarily on the landscape and geochemical conditions of the territory; 2) gradual redistribution of ^{137}Cs among the components of forest ecosystems; and 3) quasi-equilibrium of annual transfer of ^{137}Cs from the soil to vegetation, and reverse transfer of radionuclide to the soil with vegetation defoliation and falling. Thus, the share of total ^{137}Cs activity contained by the components of forest ecosystems is predictable (Table 6.4.1).

Table 6.4.1

Share of total ^{137}Cs activity in components of forest ecosystems in different types of forest and vegetation conditions (% of total contamination)

Ecosystem component	Share of total content of ^{137}Cs in ecosystem, %					
	Fresh subor		Damp pine forest		Damp sudubrava	
	1994	2004	1994	2004	1994	2004
Timber stand	**7.3**	**8.5**	**12.1**	**16.7**	**1.8**	**2.9**
Timber	2.7	4.6	4.0	5.8	0.7	1.7
Bark	3.0	2.4	3.0	3.6	0.8	0.9
Branches	1.4	1.3	4.7	6.9	0.2	0.2
Needles	0.2	0.2	0.4	0.4	0.1	0.1
Regrowth	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.3**
Herb and shrub layer	**1.2**	**0.7**	**2.0**	**0.9**	**0.3**	**0.1**
Moss layer	–	–	**3.1**	**1.1**	–	–
Forest floor (Ao)	**52.5**	**33.7**	**59.3**	**46.5**	**18.8**	**17.8**
Leaf horizon (AoL)	0.4	0.1	3.2	1.9	0.2	0.1
Fermentation horizon (AoF)	36.1	12.8	44.1	24.0	7.2	6.1
Humus horizon (AoH)	16.0	20.8	12.0	20.6	11.4	11.6
Mineral soil (0–30-cm)	**38.9**	**57.0**	**23.4**	**34.6**	**78.8**	**78.9**
0–2 cm	29.6	39.8	11.2	16.7	50.2	47.1
2–10 cm	6.9	10.4	10.6	14.8	25.5	27.5
10–20 cm	1.6	5.0	1.6	2.2	2.8	3.5
21–30 cm	0.8	1.8	0.2	0.9	0.3	0.8

The shares are peculiar to each type of forest and vegetation conditions and depend on the age of the stand, and its stock composition, and so defines the forest management regime and the possibility of using certain kinds of forestry products [29]. Presently, the bulk of total activity of the radionuclide (81–96%) is concentrated in the soil. Depending on the environmental conditions, the forest floor retains 17–46% of the total ^{137}Cs activity, whilst the mineral part of the soil retains 50–64%. Accordingly, the plant components retain from 3.5% of the store of ^{137}Cs in the forest ecosystem as a whole in more abundant conditions of the damp sudubrava to 19.3% in lean conditions of a damp pine forest [30].

Depending on environmental conditions, the timber stand can play a different role in the share of ^{137}Cs in forest ecosystems. In so doing, its edificator and relative geochemical role is most prominent in conditions close to optimal ones for growth of the basic forest-forming stock (pine, oak and birch), viz. fresh and humid subors, sudubravas and clusters, and it diminishes in unfavourable conditions of dry pine forests and wet pine forests where the share of other vegetation layers in retaining ^{137}Cs activity exceeds

that of the timber stand [31]. The geochemical role of different forest vegetation layers varies significantly and correlates positively with the phytomass per unit area. The past decade has demonstrated an increasing total content of radioactive elements in forest stock timber. This entails an increasing probability of obtaining contaminated products, which exceeds the «Sanitary standard of specific activity of ^{137}Cs and ^{90}Sr radionuclides in timber and timber products» (GNPAR-2005) [32].

Presently, eight industrial radiological laboratories of the State Forest Management of Ukraine are performing radiation monitoring of forestry products. The major share of timber products complies with the sanitary standard, however, this situation can change in parts of territories contaminated with radionuclides (the northern parts of the Zhytomyrska and Kyivska Oblasts) due to introduction of new, tighter standards. Primarily, this concerns firewood, construction timber and domestic products. According to their data, the conditions in the levels of radioactive contamination of mushrooms, berries and medicinal herbs in the forests of the Polissia region are critical.

The current share of radionuclides in forest ecosystems is indicative of predictability and stability of the radiation situation. In turn, this allows for actively taking countermeasures and rehabilitation of forest territories contaminated with ChNPP accident releases. Estimates based on the «Methodical guide for rehabilitation of forests in territories contaminated with radionuclides due to the ChNPP accident» (2005) have shown that, due to declining density of contamination of soil with ^{137}Cs (as against 1991), forest management can be resumed on 105,000 ha of forests without any constraints [33].

Studying the long-term behaviour of ^{137}Cs content in forest ecosystems has led to several major findings. First, the dynamic trends in the specific activity of radionuclides in different components of forest ecosystems have been clearly identified. Second, in almost all components of ecosystems, there is a close connection between ^{137}Cs content and the number of years that have past after the Chernobyl accident [34]. For pine bark, the bilberry phytomass, the live part of moss, and part of mushroom species, there is a steady trend to decline of specific ^{137}Cs activity in the post-accident period. Increasing specific activity has been found in bast and timber, as well as in the dead part of moss [35].

Hence, forest ecosystems are demonstrating opposing processes of migration of ^{137}Cs in ecosystem components,, in other words, cleaning of some components and increasing radioactive contamination of others. These processes have allowed the content of ^{137}Cs and other radionuclides in forest ecosystem compartments to be predicted, in addition to the rehabilitation of certain forest areas [36]. In Ukraine, a forest typology base is being used for the active development of a computerised model of ^{137}Cs migration in forest ecosystems of coniferous forests. It will allow predicting radioactive contamination of any component of the forest ecosystem with acceptable accuracy [37].

The content of ^{137}Cs in pine timber since the time of the accident had increased until about 2002. Presently, this indicator has reached a plateau, which will persist, according to estimates, until 2007–2008, after which the timber will gradually clean. Though, as a whole, the behaviour of the above indicator in the mycothallus of edible mushrooms of different kinds is similar, the peak of the content of the radionuclide mentioned was observed in different periods. Chanterelle demonstrated a peak accumulation in the early '90s, and, in the following years, ^{137}Cs content gradually declined. In the mycothallus of cepe, the content of ^{137}Cs had increased since the time of the accident until 2005. After this, a certain plateau is predicted until 2015, followed by steady decline of specific activity of ^{137}Cs in the mycothallus. In bilberries, since the early '90s, the specific activity of ^{137}Cs has demonstrated a monotonous decline in contamination [37].

The behaviour of ^{90}Sr radically differs from that of ^{137}Cs migration features. This radionuclide is characterised by increasing mobility due to leaching from «hot particles», whereas ^{137}Cs is subject to fairly rapid ageing. In virgin soil, the pattern of ^{90}Sr distribution in the ground profile is similar, on the whole, to radiocaesium, however, it migrates down the ground profile significantly faster, and its bulk is found in the crust of the unsaturated 0–10 cm layer of the soil. The high bioavailability of ^{90}Sr has resulted in high levels of its accumulation by the forest cenosis representatives. The magnitude of transfer factors (TF) for the components of the overground phytomass of a pine stand is 5 to 20 times greater than that for ^{137}Cs. ^{90}Sr is most actively absorbed by bast, leaves, 2–3-year old needles and timber. Foliage trees are characterised by an elevated level of ^{90}Sr accumulation as compared to ^{137}Cs [30]. Among berry plants, wild strawberries demonstrate excess accumulation of ^{90}Sr. The majority of macromycetae do not accumulate ^{90}Sr. An exception is chanterelle and sponk mushrooms, hlyva being the basic edible one [36].

Low biological mobility is a feature of transuranium elements. The TF for these radionuclides is mainly 0.01–0.005 and less. An exception is ^{241}Am whose content in vegetation is increasing steadily. However, this radionuclide is found almost exclusively within the exclusion zone limits, and has minimal impact on forest territories adjacent to this zone [28].

Forests are critical landscapes from the viewpoint of forming internal exposure doses for the population of regions with abundant areas of forests, in particular, the Ukrainian Polissia. In conditions when

the majority of the population uses forest food products in their diet, their contribution to formation of the internal exposure dose is 50–60% of the dose received from all food products [33].

Forest management personnel are a critical cohort of population with regard to dose formation. Forest management activities often involve elevated dusting, and the forest is the initial link for a multitude of food chains.

Forest rehabilitation after radioactive contamination relies exclusively on the rate of self-repair processes. Nowadays, the following, mainly passive countermeasures, can be implemented in forests: restrictive, organisational and technological ones (Table 6.4.2).

Table 6.4.2

Countermeasures implemented in forest management

Types of countermeasures	Type of countermeasures	Focused on
Nationwide-restrictive	Introducing state sanitary standards for content of radionuclides in forest food products, medicinal herbs, timber and timber products (PL-97; GNPAR-2005)	Preventing making products with content of radionuclides exceeding admissible levels
Industry-restrictive	Introducing radiation monitoring of forestry products	Preventing spread of radio-contaminated forestry products
Organisational	Phasing out forest management of forest stands with contamination density exceeding 555 kBq/m2	Preventing follow-up exposure of industry personnel and local residents
Radiation-sanitary	Introducing personal dosimetry monitoring for personnel; dosimetry monitoring of work places, devices and equipment	Maintaining admissible personnel exposure rates
Radioecological	Providing radiation monitoring of forests; radiation monitoring of sites for stocking forest food products and medicinal herbs	Providing radioecological information for administrative bodies, enterprise managers and local residents.
Technological	Sorting timber by specific activity of radionuclides; employing special timber handling processes	Producing forestry products having a radionuclide content within standards

Primarily, it is necessary to develop criteria and methodological bases for forest rehabilitation. The organisational basis for rehabilitation activities should be a stagewise conversion from respective forest areas with a restricted management regime to areas with a more extended forest management level. Based on this plan, once in five years, or after another substantiated period, the regime of forest management in contaminated areas can be revised. All activities in ensuring rehabilitation of radio-contaminated forests should be performed within the framework of the National Program for mitigating the ChNPP accident impact, and be guaranteed state financial support.

Conclusions

The condition of biota in territories contaminated with radionuclides requires dedicated monitoring focusing on pre-emptive assessment of the risks, and the development of methods of preventing adverse changes in the flora and fauna gene pool. To ensure such monitoring, it is necessary to clarify governing rules for safety of biota in territories contaminated with radionuclides.

Special emphasis should be placed on monitoring race formation of phytopathogenic and zoopathogenic microbes and viruses. This is necessary with account of emerging trends in occurrence of especially virulent forms of micromycetae and viruses.

In 20 years after the Chornobyl catastrophe, in Polissia there are over 40 inhabited localities where radioactivity in milk invariably exceeds the permissible level of 100 Bq/l (PL-97) by 5–15 times; and there are over 200 inhabited localities where the level of radioactive contamination of milk in a significant number of private households (roughly 70%) invariably exceeds the requirements specified in PL-97.

These facts are a gross violation of the Laws of Ukraine. A challenging problem is providing children with clean food products.

A forecast of the behaviour of radionuclides in the soil – plant system has shown that, without taking comprehensive countermeasures in agriculture, this situation will persist over many decades to come. In the past decade, countermeasures focused to producing clean agricultural products were implemented in less than 10% of the required cases, and in significantly smaller volumes as compared to those in Russia and Belarus. The number of inhabited localities with the annual population exposure rate exceeding 1 mSv has been changing very slowly since 1994, and, mainly, due to processes involving natural rehabilitation of soils.

The top-priority immediate countermeasures should be in animal husbandry, including using fodder additives (the effectiveness of ferrocine in reducing radioactive contamination of products is 2 to 7-fold); fattening cattle with «clean» fodder (effectiveness up to 10); and employing agricultural methods, such as surface and radical improvement of meadows (effectiveness of 3 to 5-fold), introducing increased amounts of mineral fertilizers (effectiveness of 1.5 to 2-fold), soil liming (effectiveness up to 1.5 to 2-fold), and land development and changing land utilisation schemes.

The radiation situation in irrigated lands has stabilised. Agricultural products in irrigated lands contain less radionuclides by an order of 1–2 as compared with products from northern contaminated regions of Ukraine. The forecasted estimates of exposure to accident radionuclides, which get into water, for this cohort of population are 3,000 man-Sv, including 2,500 man-Sv from ^{90}Sr and 500 man-Sv from ^{137}Cs. However, the water component in the expected population dose of Ukraine's population from the Chornobyl accident over 70 years will be only 4–5 %. This requires conducting follow-up monitoring surveys in the behaviour of carryover of radionuclides to the soil of irrigated land because, at an invariable content of radionuclides in water, their long-term accumulation in soil takes place.

The current radiation situation in Ukraine's forests is stable. In the forests, one can observe a slow redistribution of radionuclides between the ecosystem components. The intensity of this process depends basically on the landscape and geochemical conditions.

In the most heavily radio-contaminated Oblasts of Ukraine, the content of ^{137}Cs in timber products as a whole complies with the permissible levels (TPL-91). At the same time, an excess of levels in non-timber forest products (wild mushrooms and berries) over those specified in PL-97 has been found in 60% of samples. The content of ^{90}Sr in components of the forest biomass has also been found to increase.

Forests are still the critical landscapes with regard to formation of internal exposure doses in the population of Ukrainian Polissia. They account for up to 50% of the exposure dose from all food products owing to a high content of ^{137}Cs in forest food products.

From the viewpoint of dose formation, forest management personnel are the most critical occupational group among the population in contaminated areas.

7. ESTIMATION OF ECONOMIC LOSSES FOR UKRAINE CAUSED BY THE CHORNOBYL CATASTROPHE AND FINANCING OF CHORNOBYL PROGRAMS

The Chornobyl catastrophe caused serious social and economic losses in economics and social field as in the former USSR so beyond its boundaries.

The catastrophe ruined normal activity and production in many regions of Ukraine, Belarus and Russia. It led to a decrease of electrical energy production, considerable damage was incurred to agriculture production; forestry and the water industry were affected by contamination (5120 sq. km of agricultural lands, the use of 4920 sq. km of forests was limited).

In 1986, about 116 000 people were evacuated, hence the construction of additional houses for the evacuated people arose. In 1986–1987 about 15 000 flats, hostels for over one thousand people, 23 000 buildings, and about 800 social and cultural establishments were built for re-settlers. The town of Slavutych was built for Chornobyl NPP personnel as a replacement for the evacuated town of Prypiat.

The measures, which were taken by the executive power immediately after the catastrophe, were directed first of all on the protection of the population from the radiation and on minimizing of the direct threat to people's life and health. Alongside the evacuation, measures aimed at public and economic assistance to the population and enterprises were taken.

The help to the contaminated regions in Russia, Ukraine and Belarus was given at the expense of the centralized all-Union (of the former USSR) financial and technical resources and was mainly concentrated on measures concerning activity, production recovery, decontamination, social support of the population which continued to live in the contaminated regions, provision with uncontaminated products, medical services.

Material losses were partially compensated to victims (lost private property, sown cereals, houses etc.) connected with the evacuation. Industrial and agricultural enterprises were compensated for lost financial, material and technical resources. Conditions for organization of production and assurance of jobs for evacuated people were created.

7.1. Estimation of economic losses connected with the Chornobyl catastrophe for the USSR

By the order of the government of the former USSR, the Ministry of Finance of the USSR analyzed the information of ministries and departments, branch departments of the Council of Ministers of the Union Republics of the USSR concerning the direct losses caused by the catastrophe at the Chornobyl NPP. For the period of 1986–1989, the total sum of direct losses and expenses from all sources of financing was about 9200 million rubles[1], i. e. about US $ 12.6 billion.

In 1990, the expenses from the USSR state budget for financing the measures concerning elimination of the consequences of the catastrophe were 3324 million rubles. In addition, about 1 billion rubles were given from the republican budgets of Russia, Ukraine and Belarus. In 1991, some 10300 million rubles were set aside for these purposes in the state budget of the USSR. However, due to the collapse of the USSR, financing was realized only partially from the union budget, and at the end of the year it was exclusively from the state budgets of the three most affected countries, which were formed following the collapse of the USSR.

These expenses and losses, as mentioned above, are related to the loss of the permanent and circulating assets of industrial production and agriculture, the necessity of realization of measures concerning control and minimization of the consequences of the catastrophe. These included building and deactivation programs, realization of counter-measures in the woodlands and water industry, social and compensation programs. They were financed from many different budgets of the USSR, Ukraine, and Belarus, State insurance funds, voluntary contributions of natural persons and organizations (about 544 million rubles), which were transferred to account No. 904920 of «The fund of assistance to elimination of the consequences of the Chornobyl NPP catastrophe». During 1988–1989, resources in foreign currencies were received and used. The total sum was 2.97 million rubles including 2.2 million in converted currencies.

[1] This information was officially presented at the meeting of the Economic and Social Council of the UNO by delegations of the USSR, Belarus and Ukraine (the letter to UNO General secretary No.a/45/342, E/1990/102).

7.2. Estimation of total economic losses of Ukraine

7.2.1. Direct losses. Direct costs and indirect losses, including additional losses due to the early closure of the Chornobyl NPP

Estimation of direct losses

Losses of infrastructure on the territory next to the Chornobyl NPP and in the exclusion zone (including the towns of Prypiat and Chornobyl) are taken into account in calculating the losses due to the Chornobyl catastrophe.

The estimation of the value of losses of capital objects to the national economy in the exclusion zone is 11 010.6 million rubles according to valuation calculations (Table 7.2.1) [1].

Table 7.2.1

National economy capital losses in the exclusion zone on the territory of Ukraine, which were taken out of use due to the catastrophe in 1986

The name of the capital object lost due to the Chornobyl catastrophe	The year of estimation of key assets and the material circulating asset value	The value of production key assets and of material circulating assets	
		thousands of rubles	$ thousands
Objects and expenses concerning the stopped building of the Chornobyl NPP (III turn)	1986*	99.028	136.120
The fourth block of Chornobyl NPP	1964**	201.000	223.330
The object «Chornobyl - 2»	1984***	97.700	137.027
Enterprises of the communication industry (1)	1986	51.070	70.199
Enterprises of metallurgy industries (1)	1986	44.700	61.443
Enterprises of the building materials industry (1)	1986	7.750	10.653
Enterprises of river transport (2)	1986	21.050	28.935
The highways with hard surfaces (353 km)	1986	60.550	83.230
Enterprises of the woodworking industry (1)	1986	4.720	6.488
Enterprises of the feed mill industry (1)	1986	4.550	6.254
Enterprises of primary processing of agricultural raw materials(1)	1986	4.900	6.735
Enterprises of the food industry	1986	5.010	6.887
Enterprises of repair of tractors and agricultural machines (1)	1986	760	1.045
Enterprises of woodlands (1)	1986	4.700	6.460
Collective farms (14)	1986	79.693	109.544
State farms (2)	1986	18.659	25.648
Co-agricultural enterprises	1986	18.694	25.696
Infrastructure and network of water-supply	1986	4.405	6.055
Infrastructure and networks of sewerage	1986	3.850	5.292
Electrical networks for lighting	1986	315	433
Infrastructure and networks of heat supply	1986	3.390	4.660
The available housing:			
– state (402)	1986	209.750	288.316
– private (2.278)		7.101	9.761
– rural houses (9.050)		28.200	38.763
Recreation departments (10); medical stations (44); Schools: trade schools (3); secondary schools (34); musical schools (2); Palaces of culture (16); cinemas (2); clubs (39)	1986	29.104	40.005
TOTAL		1010.649	

* Course in April of 1986: $1 – 72,75 kop.
** Course in October of 1984: $1 – 71,3 kop.
*** Course in 1964: $1 – 90 kop.

In addition to the considerable losses of infrastructure in the exclusion zone, there were also losses of the technologies, means and mechanisms, which were used to eliminate the consequences of the catastrophe. These were contaminated with radionuclides, and are buried at the sedimentation area «Rozsokha» and the station for wastes burial «Buryakivka». These losses were 33,482 thousand rubles or US $ 46,024 thousand.

Thus, the direct losses (material & property and individual economic objects) only in the exclusion zone on the territory of Ukraine were in total 1,044,131 rubles or US $ 1,385,003.

Moreover, one should take into account other losses connected with re-settlement of people and loss of the assets of basic production after 1986. These measures were taken after the precise definition of the radiation situation on the territory of obligatory evacuation during the 1990s.The value of lost housing and private property beyond the boundaries of the exclusion zone is estimated as 0.2 billion rubles (at 1984 prices). The losses of the assets of basic production beyond the boundaries of the exclusion zone are about 0.4 billion rubles (at 1984 prices).

The total direct losses of capital objects and economic objects beyond the boundares of the exclusion zone are 0.6 billion rubles or US $ 0.84 billion.

7.2.2. Estimation of direct expenses

The cost of the measures for elimination of the consequences of the catastrophe is determined, proceeding from the total amount of financing for the following:

– The work on the direct elimination of the catastrophe in the exclusion zone;
– Social protection of victims and the costs of corresponding medical programs;
– Costs of implementation of scientific research program;
– Costs of the environmental radiation monitoring programs;
– Costs of the decontamination work and handling of radioactive wastes.

Complete data on the real amounts of financing of this work is given in Table 7.2.2 [1].

Table 7.2.2

Data of the real costs of financing the work related with the elimination of the consequences of the Chornobyl catastrophe and social protection of population for 1986–1997.
For 1986 – September 1, 1991 this was at the expense of the USSR state budget resources; since September 1, 1991 this was at the expense of Ukraine state budget resources.
Costs are given in US $ millions

№ з/п	Name	Years						
		1986–1991	1992	1993	1994	1995	1996	1997
1	Social protection of people	6606.55	197.33	196.51	478.07	383.97	545.65	639.93
2	Special medical help	53.62	6.32	2.99	8.83	22.81	19.02	8.21
3	Scientific research	57.76	3.23	4.45	4.99	5.92	7.04	10.54
4	Radiation control	63.79	1.99	1.64	2.28	3.15	4.44	5.4
5	Environment and ecological recovery costs	–	–	0.01	0.37	0.36	0.19	0.23
6	Rehabilitation provision and burial of radioactive wastes	0.17	0.27	0.08	0.20	0.13	0.16	0.29
7	Investments. Re-settlements and ensuring proper living on the contaminated territories costs	3173.62	276.07	197.78	205.28	167.44	194.10	89.87
8	Conducting work in the exclusion zone	8923.75	19.70	25.84	46.45	44.95	52.08	56.1
9	Other costs	228.97	17.72	15.88	25.91	41.94	43.36	37.0
	Total for Ukraine *	19108.23 5732.47	510.81	436.01	755.72	638.30	835.19	844.6

* Taking into account the fact that in the period of 1986–1991 the Ukrainian share of expenses of the all-Union budget was 30%, total Ukrainian expenses due to the catastrophe can be estimated in the same proportion.

Since 1998, the following sums were financed from the state budget of Ukraine in the same proportion according to the expenses' items for solving problems of minimization of Chornobyl Catastrophe:

Years	US $ millions
1998	584.72
1999	371.76
2000	332.64
2001	358.34
2002	376.00
2003	259.09
2004	450.11
2005	343.55 – 1 734 905 thousand hryvnas

We should mention that since 2001, because of the early closure of the Chornobyl NPP Ukraine additionally suffers a loss, as the closed energy blocks of the Chornobyl NPP must be kept in a safe state and the object «Shelter» (Sarcophagus) must be kept in an environmentally safe condition. The sum of annual expenses is about US $ 50 million.

The state budget of Ukraine estimates, for 2005, the following costs for measures to minimize the consequences of the Chornobyl catastrophe:

«Keeping energy blocks and the object «Shelter» of Chornobyl NPP in the safe state and decommissioning of the Chornobyl NPP» to the amount of 283 400.0 thousand hryvnas;

«Contribution of Ukraine to the Chornobyl fund «Shelter» for implementation of SIP program» to the amount of 346 870 thousand hryvnas.

The costs for 2005 were 318 087 thousand hryvnas (US $ 63 million).

The integrated and national programs of decommissioning the Chornobyl NPP and transforming the object «Shelter» into an environmentally safe state for 2006–2020 note that it will take about one hundred years to complete these tasks. These programs therefore consist of the highest priority measures, which must be realized during the period 2006–2010. Concerning this, financing from the state budget is estimated to be for the following main tasks:

– decommissioning of the Chornobyl NPP;

– transforming of the object «Shelter» into an environmentally safe system;

– handling from Chornobyl NPP of the radioactive wastes, which have been accumulated during the period of its exploitation and will be created during the decommissioning works and stabilization of the object «Shelter»;

– handling of the spent nuclear fuel of the Chornobyl NPP;

– social support of the Chornobyl NPP workers and residents of the town of Slavutych in connection with the early decommissioning of the Chornobyl NPP.

Approximately 3.5 billion hryvnas have been budgeted for these tasks for the period 2006–2010 taking into account that the work amount and financing by the directions are determined within the budget destinations, which are envisaged by the state budget for every year.

It is clear that money will need to be allocated from state budgets for decommissioning of the NPP and the «Shelter» over a period of several decades.

7.2.3. Analysis of indirect losses

Losses due to abandoned contaminated agricultural lands, and losses of water and timber resources

Economic activity was completely stopped on territories with contamination density of over 555 kBq/m^2 (15 Ci/km^2) and was partially stopped on territory with contamination density of 185 to 555 kBq/m^2 (5–15 Ci/km^2). Recovery of the production to levels existing before the accident will only be possible in several ones. Forestry also suffered considerable losses. There is only limited use of approximately 5000 km^2 of woodlands. The losses of primary forest resources amount to approximately 100 million rubles. The total losses of timber resources and the related timber industry for 1986–1991 are about 1.8–2.0 billion rubles (according to 1984 prices).

The contaminated territories of Ukraine comprise the richest forests where, in addition to wood, dozens of thousands tons of hay, many mushrooms and berries were produced. The resources comprised 6% of the total all-Union amount of pine, 50% of the total amount of turpentine, gathered in the former USSR, and every year about 60 thousand tons of coniferous flour were produced with a value of 15 million rubles.

The economic losses in the water and fish industries of the Dnipro and the Black Sea basins due to contamination of the reservoirs with radioactive isotopes were 2.3–3.1 billion rubles in the first few years after the catastrophe.

The average estimation of the total amount of losses due to misuse of contaminated agricultural lands, water and forest resources is 8.6 + 10.9 = 19.5/2 = 9.75 billion rubles for the period 1986–1991 (six years). These indirect losses were recalculated for one year as 9.75/6 = 1.625 billion rubles.

For thirty years (to 2015) the indirect losses of these kinds of economic activity will be $1.625 \times 30 = 48.75$ billion rubles.

7.2.4. The losses due to the reduction of electrical energy production and related with it production of goods and services, and also other indirect losses

Among all the losses related with the Chornobyl NPP, there were losses corresponding to the reduction of electrical energy production and related setbacks in production of goods and service. The amount of underproduced electric energy during the misuse of the resource of the fourth block and shut down of other blocks of the Chornobyl NPP in 1986 were 62 billion kW·h-1. At an average value of electrical energy, which was produced by the Chornobyl NPP, of 1.5 kop./kW/h, the direct losses were about 1 billion rubles. According to economists' calculations, the units of electric energy value, which would have been delivered to other fields of the national economy, provide an increase of 20 units of the national income. The failure to deliver this energy considerably reduces the production in such fields as machine-building, light industry, food industry and other fields of processing industry.

The electrical energy, which was produced at the Chornobyl NPP, was distributed according to a scheme of consumption. The total value of losses due to the failure of delivery, if it was corrected to account for the above increase, may exceed 20 billion rubles (according to the prices of 1984).

Due to the decision to halt new atomic power plants, the national economy lost almost 6 million kWB of the electrical energy which otherwise would have been produced. According to the estimates of experts, a one-year delay in implementation of 1 million kW of electrical energy would lead to a 2 billion ruble reduction of national income, provided this delay is protracted for a long time. The value of the losses due to the moratorium on the new atomic energy units at existing electric power stations for a four years period is 48 billion rubles (according to 1984 prices).

Hence, summarizing the indirect losses, one can say that the total amount of the irretrievable losses of the national economy of Ukraine due to the Chornobyl NPP catastrophe is 116.75 billion rubles (according to 1984 prices). The composition of indirect losses is given in Table 7.2.3.

Table 7.2.3

The composition of indirect losses of Ukraine due to the Chornobyl NPP catastrophe

	Losses	Billions rubles
a)	Losses due to misuse of agricultural lands, water and forestry resources	48.75
b)	The value of the deficiency of electrical energy production	20.0
c)	Losses due to the moratorium on new reactor units at existing atomic power plants	48.0
	Total	116.75

Taking into account that in 1984 the US $ exchange rate with the USSR. ruble was about 71.3 kop., one can estimate the indirect losses due to Chornobyl NPP as US $ 163.74 billion or 3.4 times the annual Gross domestic Product of Ukraine in 1997. We should mention that here are given the estimations of indirect losses on the most seriously impacted fields of the national economy.

7.2.5. Estimation of summary economical losses of Ukraine

The direct losses (of material & property complexes and individual objects of economics) only in the exclusion zone on the territory of Ukraine were in total 1044 million rubles or US $ 1385 million.

The direct expenses of Ukraine for elimination on the Chornobyl catastrophe consequences at the expense of all the sources of financing during the period from 1986 till 1991 were about US $ 6 billion. During the last fourteen years, when Ukraine independently financed the costs of elimination of the catastrophe consequences, i. e. since 1992 to 2005, the costs were US $ 7.35 billion.

However, it is difficult to determine exactly the amount of indirect losses caused by misuse of contaminated agricultural lands, water and forest resources [2], and also by reduction of electric energy production, as by goods production and services provision, reduced as a consequence of the former.

According to the Ukrainian specialists' calculations, the total economical losses of Ukraine by 2015 will have form some US $ 179 billion.

So, the total economical losses of Ukraine due to Chornobyl catastrophe are of such amounts and structure (Table 7.2.4).

Table 7.2.4

The structure of the total economical losses of Ukraine in 2005

No	Name	Value in US $ millions
1.	Direct losses of the material objects and the objects of economics	
1.1	in the exclusion zone:	1385
1.2	beyond the boundaries of the exclusion zone:	840
2	direct costs of financing the work and measures concerning the catastrophe consequences' elimination:	
2.1	– in 1986–1991 (the part of Ukraine in the expense part of the USSR budget)	5732.5
2.2	– in 1992–2005 (the costs of Ukraine after it became an independent state)	7357
3	Indirect losses according to Table 4 (counting on 30-year period to 2015)	163 740
	Total	179 054.5

These losses are not exhaustive as they don't take into account all the indirect losses of Ukraine's economy, for example:

– losses of health and ability to work of present and future generations of people;

– future costs on rehabilitation of the contaminated territories and water basins;

– future costs on decommissioning of Chornobyl NPP, transformation of the object «Shelter» into an ecological safe system, burial of radioactive wastes from the object «Shelter» and SNF of ChNPP.

7.3. Efficiency of the realized counter-measures

Population protection under the conditions of radiation catastrophe is based on the system of measures (counter-measures), which are practically always interfer with the everyday (habitual) life of people, and also in the sphere of the normal, social & common, economic and cultural functioning of the territories.

Depending on the scales and phases of the radiation catastrophe early (acute) or late (recovery phase), as on the levels of the predicted breakdown doses of irradiation, the counter-measures are conditionally divided into urgent, pressing and long-term.

• Urgent counter-measures are those, which are aimed at prevention of such levels of acute and/or chronic irradiation of population, that create the menace of appearing radiation effects, which become clinically apparent.

• Counter-measures are classified as pressing ones when their realization aimed at prevention of determinative effects.

• Long-term counter-measures are those, which are aimed at prevention or reduction of the doses of chronic irradiation, value of which are usually lower than the thresholds of determinative effects of induction.

The basis of the decision concerning expediency (inexpediency) of conducting one or other counter-measure is estimation and comparison of the loss, which is caused by the intervention, well founded by this counter-measure, which is good for health due to the dose, which can be prevented by this intervention.

So, the estimation of the efficiency of the realized protection measures is of a big scientific and practical value. The structure of the realized counter-measures and those which will be realized, concerning the minimization of the Chornobyl catastrophe consequences, are given in Fig. 7.3.1.

The estimations concerning the efficiency of the taken counter-measures, conducted for the previous period, allow to confirm quite surely that the following counter-measures were **undoubtedly effective**:

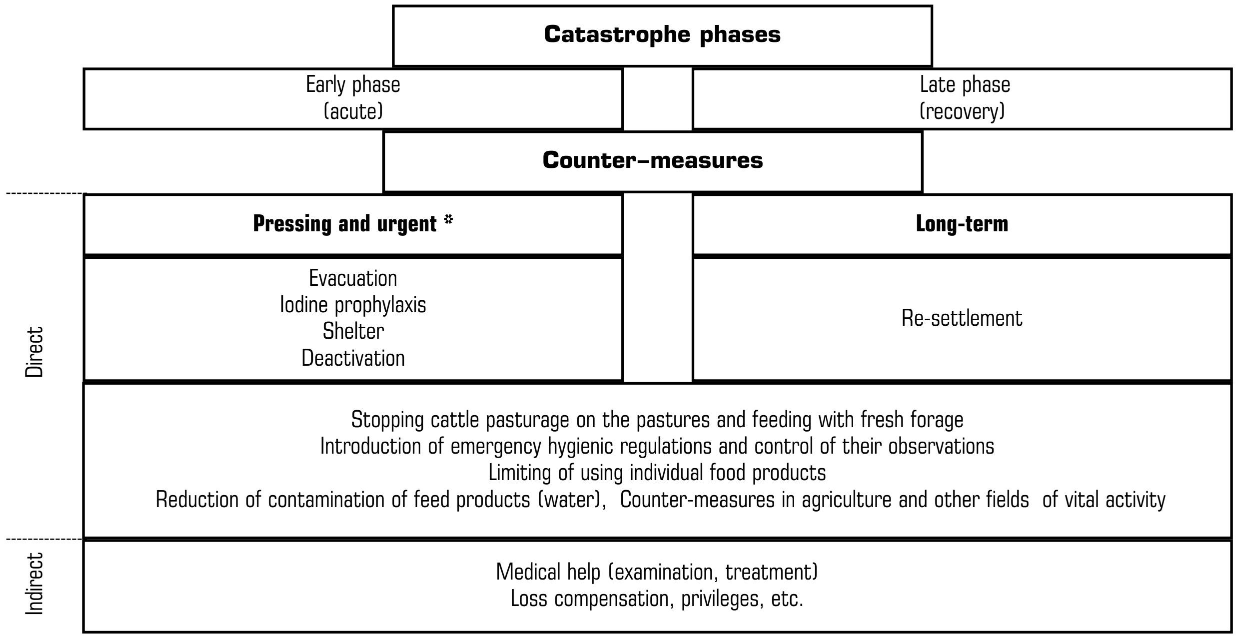
During the acute period:

1) evacuation;

2) iodine prophylaxis.

The acute and further periods:

1) deactivation of the school territories (taking down the upper layer of the soil, repair of the hard coatings of playgrounds, deactivation of buildings with the use of surface active agents, etc.);



* the work on the source, which is in the state of catastrophe, is not given in this scheme

Fig. 7.3.1. The structure of counter-measures at the different phases of the catastrophe

2) deactivation of the surfaces of buildings and roads in the towns (everyday washing of roads, pavements and yards with the hard coating, etc.);

3) substitution of contaminated food for clean ones;

4) liming of soils: simultaneously with reduction of radioactive cesium accumulation, it led to reduction of heavy metals (lead and cadmium) accumulation;

5) introduction of increased doses of fertilizers;

6) radical improvement of meadows;

7) deep repeated ploughing up of the soils (where humus layer thickness allows)

A number of factors reduced the efficiency of using counter-measures:

1) preferable conducting of counter-measures in the collective sector of agriculture production;

2) delayed conducting the radical improvement of meadows for private sector;

3) incomplete fulfillment of recommendations concerning liming of soils (microelements were not introduced along with lime).

The following counter-measures were less effective:

1) re-settlement – low dose efficiency (in many cases re-settlements were conducted to the territories with the increased natural ionizing radiation background), the social & psychological factors were not taken into account;

2) usual repeated ploughing of soil with the aim of reduction of the dose of irradiation (repeated ploughing conducting reduced the efficiency of using a number of the land-improvement measures).

At the current stage of the catastrophe (late phase) the main doses of internal irradiation are formed by means of usage of contaminated food.

During this period the following counter-measures directed to internal irradiation doses reduction might be effective:

1) technological processing of milk at the enterprises of low power;

2) usage of various ferrocine additions to cattle's fodder;

3) radical improvement of meadows for private sector of economy;

4) liming of soils;

5) introduction of increased doses of potassium fertilizers;

6) reduction of irregular usage of growing wild mushrooms and berries.

The less known, but very important from the point of view of reaction in case of radiation catastrophe counter-measures, are indirect ones; they are aimed not only to reduce or prevent the catastrophe doses of irradiation, but also to save and/or raise the level of common health of people who live in the contaminated zones.

Here, first of all, it's worth mention the estimation of the efficiency of money and material compen-

sations, various privileges, measures on improvement of population health, and also that of informing with political decisions and legislative basis.

The work concerning the estimation of counter-measures influence on psychical & social mood of population is of great importance. At the current stage of the catastrophe the measures directed to the social & psychological rehabilitation of the suffered population and recovery of its normal status must be of the priority

Conclusions Summary and Proposals

1. The catastrophe demonstrated that the expenses on nuclear plants safety assurance are considerably inferior to those on elimination of the possible catastrophes' consequences; antropogenic catastrophes caused enormous economical losses to the countries, which are situated in the zone of their influence.

2. Chornobyl catastrophe caused enormous social & economical losses first of all to the three of the most affected countries: Ukraine, Belarus and Russia.

Due to the direct losses of the material objects and economic objects, as to those of the financial area, provoked by the minimization of the catastrophe consequences, the total sum of losses in Ukraine consisted of US $ dozens of billions.

Chornobyl Catastrophe is also characterized by considerable indirect losses, i. e. the losses because of: an incomplete delivery of production in power engineering, agriculture, forest, water industry, fish breeding and other losses.

The direct losses, financial costs and indirect losses caused by the Chornobyl Catastrophe were US $ dozens of billions for Ukraine for the years after the catastrophe.

3. The amounts of the social & economical losses for Ukraine don't correspond to the real economic abilities of the country as far as elimination of consequences in the nearest future is concerned; that's why the assistance of the international community is of a vital importance.

4. The burden of the economics connected with the Chornobyl Catastrophe is one of the most important consequences of this catastrophe. The costs, which are connected with minimization of the Chornobyl Catastrophe consequences will be the real burden for the country's economy for many years.

8. THE EXCLUSION ZONE AND THE ZONE OF ABSOLUTE RESETTLEMENT

8.1. Radiological situation of the zone

The Ukranian law «About the legal regime of the territory, subjected to radioactive contamination as a result of the Chornobyl catastrophe» determines the *Exclusion Zone* as the territory where the population was evacuated in 1986. This zone and the *zone of absolute resettlement* (EZ and ZAR hereinafter referred to as the Zone) are the territories, which lands have been removed from the economic usage. They are managed by a State department – *Administration of EZ and ZAR of the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe*.

The territory EZ and ZAR, under this administration is about 2600 km^2. Before the catastrophe about 40% of the territory was devoted to forestry, approximately 28% was used for arable production, and 18% was meadows and grass marshes. The reclaimed areas took about 10% of the whole territory. The population evacuation and cessation of the economic activities initiated the process of changes in the plant cover of the Zone territory, as a result of both forestation, supported by special actions, and transformation of arable lands to meadows and fallow lands. Today, the lands covered with forests comprise about half of the zone territory. The lands without forests comprise about 30%, water surfaces (rivers, lakes, canals, the Prypiat, artificial reservoirs, ChNPP pond-cooler) comprise about 10% of the Zone area [1]. The soils within the Zone territory are characterized by mixed character; zonal types of soils – both soddy-podzolic ones with different granulometric composition and gley degree and peaty soils – occupies more than 95% of the Zone territory. The Zone territory includes many types of landscapes; the Zone flora and fauna are characterized by high variety of plants and animals including those listed in the Red Book [2, 3]. Industrial and engineering structures in the Zone are the Chornobyl NPP, Object «Shelter», Points of Radioactive Wastes Disposal (PRWD), Points of Temporary Localization of Radioactive Wastes (PTLRW), Complex «Vector», Storage of spent nuclear fuel (SSNF-2), liquid Radioactive Wastes Processing Plant (RLRW), the solid Radioactive Wastes processing Complex (CRSRW), the irrigation and drainage network facilities, Pond-cooler etc.

The radioactive contamination of the Zone is characterized by its being highly spatially heterogeneous; by a number of physical-and-chemical forms of fallout, different long-term dynamics of biological availability and migrative mobility of radionuclides within migration chains on various tracks of fallout.

The stock of main radiological significant radionuclides in the components of terrestrial ecosystems of the Zone consists of: ^{137}Cs 5.5 PBq, ^{90}Sr 2.5 PBq, transuranium elements (TUE) 0.1 PBq. Approximately 4.5 PBq of ^{137}Cs, 3.5 PBq ^{90}Sr and 0.1 PBq. TUE are concentrated in the Points of Radioactive Waste Disposal and Points of Temporary Localization of Radioactive Waste. Object «Shelter» contains approximately 340 PBq of radionuclides, including those with half-life period superior to 5 years. Contamination density of the Zone territory with the long-lived radionuclides varies within broad limits: ^{137}Cs – from 3.7 kBq/m^2 to 460 MBq/m^2 and more, ^{90}Sr – from units kBq/m^2 to 185 MBq/m^2 and more, $^{239, 240}$Pu from parts of Bq/m^2 and more [1].

The physical, chemical and biological migration of the radionuclides into the environment slowly modify the general character of its contamination. The redistribution of radionuclides in the soil cover is observed, in the majority of cases, so on the places of anthropogenic influence as on those of a regular flooding (by 20–40% of total stock). On the rest of the Zone territory the radionuclides activity is mainly (90–95%) located in the upper (5–10 cm) soil layer (including forest litters) [5].

Estimations of radionuclide stocks in various plant communities of the Zone are presented in the Table 8.1.1.

The basic ways of radionuclide migration to out of the Zone are: river transport (the river Prypiat) – 84–96%; air (wind) transfer – 3.5–14%, in case of forest fires – up to 20%; biogenic outflux – 0.4–1.5%, technogenic migration – up to 0.5% from the total flux of radionuclides out of the Zone borders [1]. Approximately the same quantity of radionuclides as that of the transported out of the Zone by the river flux, is accumulated annually in the forests plants due to growth of its biomass. Estimations of radionuclide fluxes in the Zone and out of its borders are given in Table 8.1.2.

Nowadays the Zone is an open plane source of radioactivity with its own structure of distribution, different forms and types of deposited radioactive nuclides. As a consequence, the radiation factor keeps on being one of the basic for determination of a possible danger for both the population residing on the adjacent to the Zone territories and for Ukraine's population as a whole.

The Zone's environmental radiation state characteristics have drastically changed comparing with

Table 8.1.1

Radionuclide stocks in various plant communities of the Zone

Угруповання	Area, km^2	^{137}Cs, PBq			^{90}Sr, PBq		
		Soil	Plants	Sum	Soil	Plants	Sum
Highly productive pinery	137	0.43	0.015	0.44	0.14	0.009	0.15
Low productive pinery	477	0.77	0.022	0.79	0.28	0.012	0.29
Highly productive mixed forests	552	1.18	0.038	1.22	0.45	0.037	0.49
Highly productive deciduous forests	42	0.13	0.005	0.14	0.074	0.007	0.081
Low productive deciduous forests	91	0.46	0.019	0.48	0.23	0.021	0.25
Bushes	22	0.20	0.003	0.20	0.13	0.004	0.14
Meadows and fallow lands	359	1.07	0.010	1.08	0.53	0.010	0.54
Swamps	22	0.04	0.001	0.04	0.007	0.001	0.008
Total	1702	4.28	0.12	4.40	1.84	0.10	1.94

Table 8.1.2

Estimates of radionuclide fluxes in the Zone and out of its borders

Flux	Activity, TBq/year	% of stock in the Zone
Outflux by river Prypiat out of the Zone borders (max.)	17.6	0.21
Outflux by river Prypiat out of the Zone borders (min.)	4.4	0.05
Biological transfer outside of the Zone (animals)	0.07	0.00086
Biological transfer inside the Zone (forests and meadows)	6.15	0.076
Technogenic migration	0.016	0.0002
Wind transfer	0.7	0.0086
Depositation in geologic medium	37	0.46
Release from the object «Shelter» (normal conditions)	0.0116	0.0000016
Release from the object «Shelter» (accidental conditions)	155	0.02

the first post-accidental year. After the decay of the short-lived radionuclides the main dose loadings on the landscape components, personnel and population are formed nowadays by, to a different extent, ^{137}Cs and ^{90}Sr with half-life of about 30 years, and also transuranium elements.

Gamma irradiation exposure dose rate

During the first days after the accident some very high levels of exposure dose of the gamma irradiation were fixed near by the ruined 4 unit reactor and its industrial site, as they come to some 1000 R/hour; some impermissibly high for the population were determined on the large adjacent territories (the town Prypiat – up to 1.5 R/hour, the town Chornobyl – up to 24 mR/hour). Since 1988, dose rates in the Exclusion Zone have been monitored by means of the automatized system for control of radiation situation.

During the time after the accident total radiation situation in the Zone has been stabilazing. In comparison with June 1986, the gamma dose rates on undisturbed areas reduced in dozens of times, and on the areas where deactivation measures were conducted they reduced hundreds of times. After decay of the short-lived gamma-irradiated radionuclides, changes in dose rate reduced considerably. The soil surface is now the primary source of radiation.

Maximum values of gamma dose rate are measured on the ChNPP industrial site near the liquid and solid wastes storage. In the 10 kilometer zone around the ChNPP the highest levels are measured in the town of Prypiat. In the remote zone (10–30 km) the maximum values of dose rates are found in the former settlements of Usiv and Buryakivka, which were on the north and west traces of radioactive fallout. The lowest dose rates are at the periphery of the Exclusion Zone.

Average values of gamma dose rate are: at the ChNPP industrial site – 0.3–25 mR/hour; the town of Chornobyl – 0.02–0.05 mR/hour; at the radiation control point «Dytyatky» – about 0.02 mR/hour. Seasonal behaviour of gamma dose rate and irregularity of distribution on the territory is observed against a background of overall reduction of gamma dose rate.

From April 1986, radiation state of surface air in the Exclusion Zone was predetermined by heterogeneous surface contamination of the territory with radioactive materials of Chornobyl releases, meteorological conditions, anthropogenic factors, and activities at the Chornobyl NPP.

During the post-accident period the total concentration of radionuclides in the air gradually reduced due to radioactive decay, natural autopurification processes, and decontamination measures. Contamination of the air with ^{137}Cs was characterized by a rapid reduction in 1986–1988 and a slower decrease during the following years (Fig. 8.1.1).

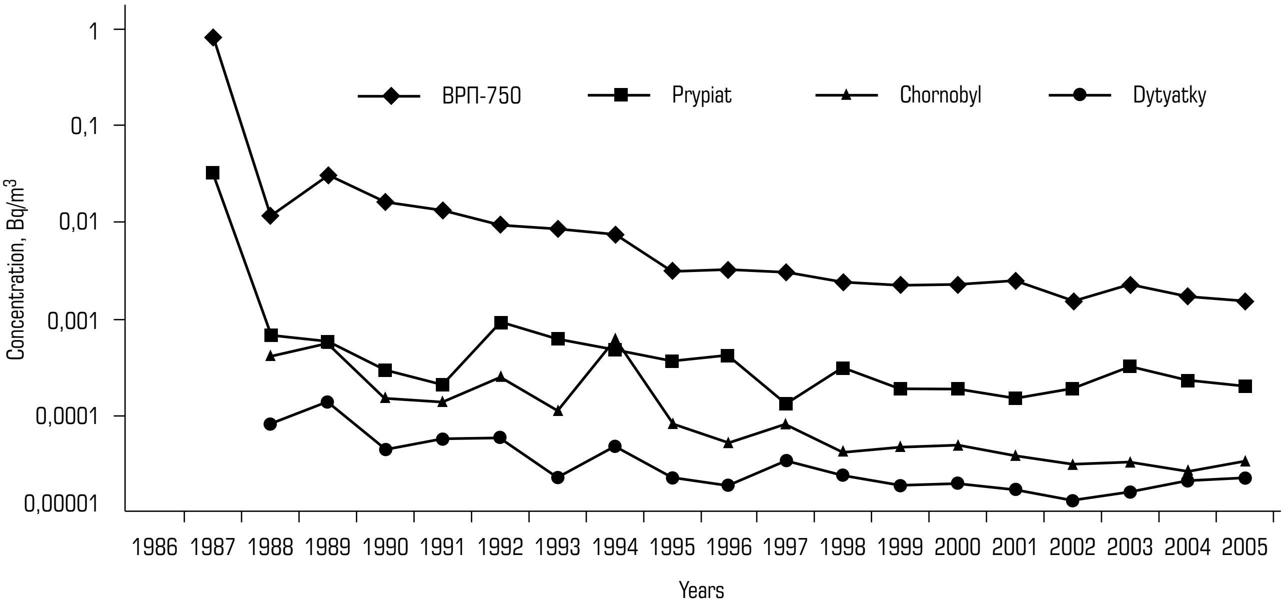


Fig. 8.1.1. Dynamics of ^{137}Cs concentration in the air of control points of the Zone

Maximum values of radionuclides concentration in the air have been constantly measured in the zone close to the ChNPP. The concentration of radioactive caesium in the air of the industrial site reduced from values 3–59000 mBq/m^3 in 1987 to 0.1–11 mBq/m^3 in 2005, and in the remote zone it has varied during last time from 0.01 to 2.9 mBq/m^3.

At the control points of the remote zone (10–30 km) the largest radionuclides concentrations were registered in the areas of high surface contamination: with the construction work carried out on them or with a dense traffic. The average concentration of radioactive aerosols during the warmer seasons is generally 1.5–2 times as high as that during the cold season. Lately, surface air radionuclide concentrations at the most of the control points have approximately equilibrated; variations being caused by meteorological conditions, human activity or fires. If in 1987, the maximum concentrations of radionuclides in the air were 25 times as high as the average value at the ChNPP industrial site, then in 2004 they were only 5 times higher. In the town of Chornobyl during the forest fires in July 1992 ^{137}Cs concentration in the air increased to 17 mBq/m^3, an increase of approximately 90-fold compared to average concentrations. The dry weather in September 1991 resulted into the intensification of wind resuspension of radionuclides and an increase in the air concentrations to 3 mBq/m^3 (16 times higher than average). The frequency of increases in the air concentrations decreased with time: in May 2002, the concentration of radionuclides in the air in the town of Chornobyl under the same meteorological conditions only 2.5 times exceeded monitoring indicators. In 2004 the maximum coefficient of CR excess for the town of Chornobyl was only 1.4.

Calculated from monitoring data, the values of the resuspension coefficient of ^{137}Cs (i. e. its concentration in air normalized to the soil contamination density) for the town of Chornobyl are given in Fig. 8.1.2. There was a high rate of reduction in the resuspension coefficient until 1992, after this year it considerably reduced. The maximum values of the real observations are 1 or 2 orders higher than the average annual levels. During every year two periods of increase in resuspension are observed: the first one at the end of April/at the beginning of May; and the second one in the middle of July.

According to the monitoring data of ChNPP and «Ecocentre», the surface air is permanently enriched with radionuclides, which contain releases from the ChNPP and are flied out from the object «Shelter». The spectrum of radionuclides ejected through the vent stacks into the environment is typ-

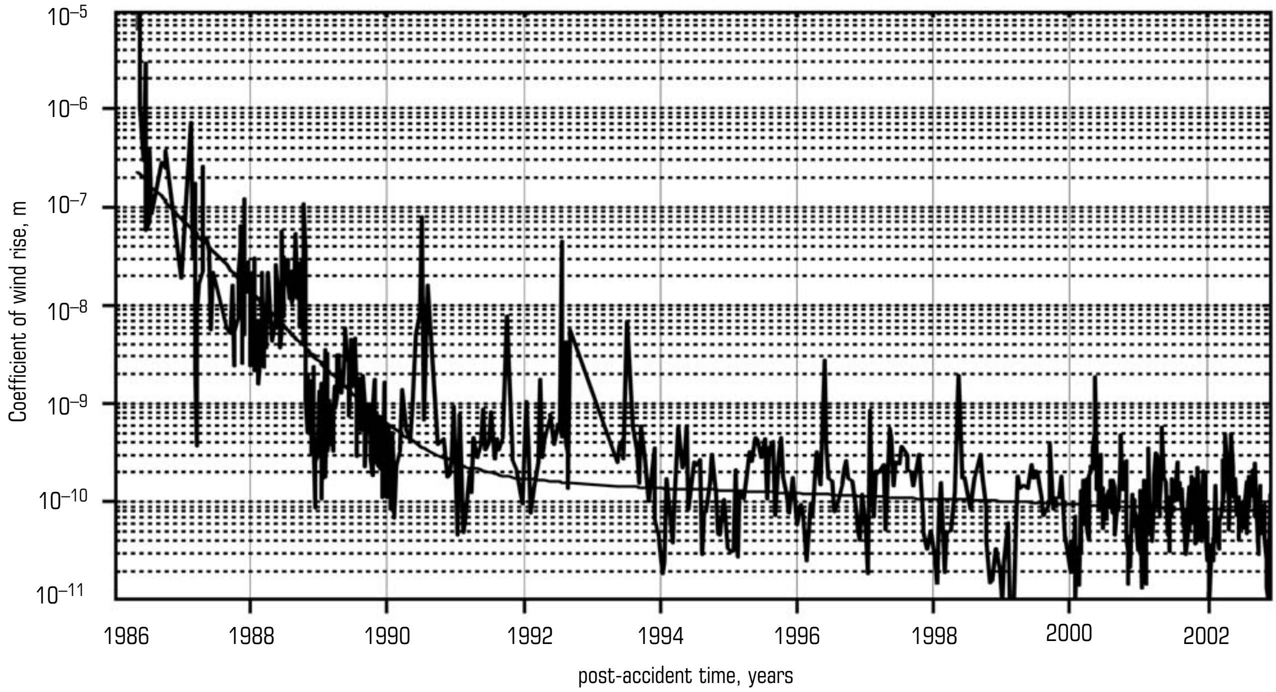


Fig. 8.1.2. Coefficient of ^{137}Cs wind dust rise observed in the town of Chornobyl in 1986–2002

ical for the ChNPP releases, the number of radionuclides varies within the wide limits, but their maximum concentrations are 4–6 orders of magnitude less than permissible levels.

After the ChNPP closing the numbers of ^{137}Cs and ^{90}Sr, which come into the atmosphere, reduced annually, except ^{90}Sr releases through vent stack 2, concentration of which remained practically constant.

The Control levels of radionuclides in the air of the Zone observation points, thus set on November 1, 2001 by the Sanitary norms «The basic control levels, levels of exemption and levels of action concerning radioactive contamination of the Exclusion Zone facilities» (SN 6.6.1.076-01) were annually exceeded by the various causes: human activities, meteorological conditions and fires. The maximum quantity of cases (22) of excess of ^{137}Cs permissible levels was observed in 2002. This was due to long periods of dry and wind weather, which intensify deflation processes, such splashes of near-ground air layer contamination arose (13 of the 22 cases) and anthropogenic causes (intensive construction and transport works on soil movement at the ChNPP industrial site; 9 of the cases).

The analysis of the monitoring results and information published on the processes of spontaneous dust creation in object «Shelter» indicates increasing amounts of radioactive particles in inhalation fractions. As a consequence the role and importance of radiation monitoring of the surface air in the Exclusion Zone and adjacent territories increases. It especially, relates to recovery places at the Exclusion Zone facilities.

Radiation state of surface waters

During the early stage of the accident radioactive contamination was formed on the large drainage territories of the river Dnipro (including inside the Zone), and directly in water bodies (rivers, lakes, reservoirs), which are used for industrial and drinking water supplies in the system of the Dnipro reservoirs. For the first two weeks after the accident the total beta-activity of water of the river Prypiat at its mouth reached values of the order 10^8 Bq/m^3, the predominant contribution to this was ^{131}I (70–90% of total activity), the ^{90}Sr concentration activity was $1.5{\cdot}10^4$ Bq/m^3. When deposition had stopped and short-lived radionuclides decayed, a considerable reduction of the river Prypiat contamination was observed. The isotopes ^{137}Cs and ^{90}Sr began to predominate as the source of radioactive contamination of surface waters. From 1988, ^{90}Sr has dominated the total activity of river waters; for the recent years it has contributed 60–75% of the activity. The radiological condition of closed and low-flow reservoirs not improved to the same extent (Table 8.1.3). The most strongly contaminated water bodies of the Zone are reservoirs on the right and the left bank of the river Prypiat floodplain. Levels of water contamination, for example, of Glyboke lake reach the values of concentration activity of ^{90}Sr 130–160 kBq/m^3, ^{137}Cs is 6–8 kBq/m^3.The corresponding values for the ChNNP pond-cooler nowaday is about 2 kBq/m^3.

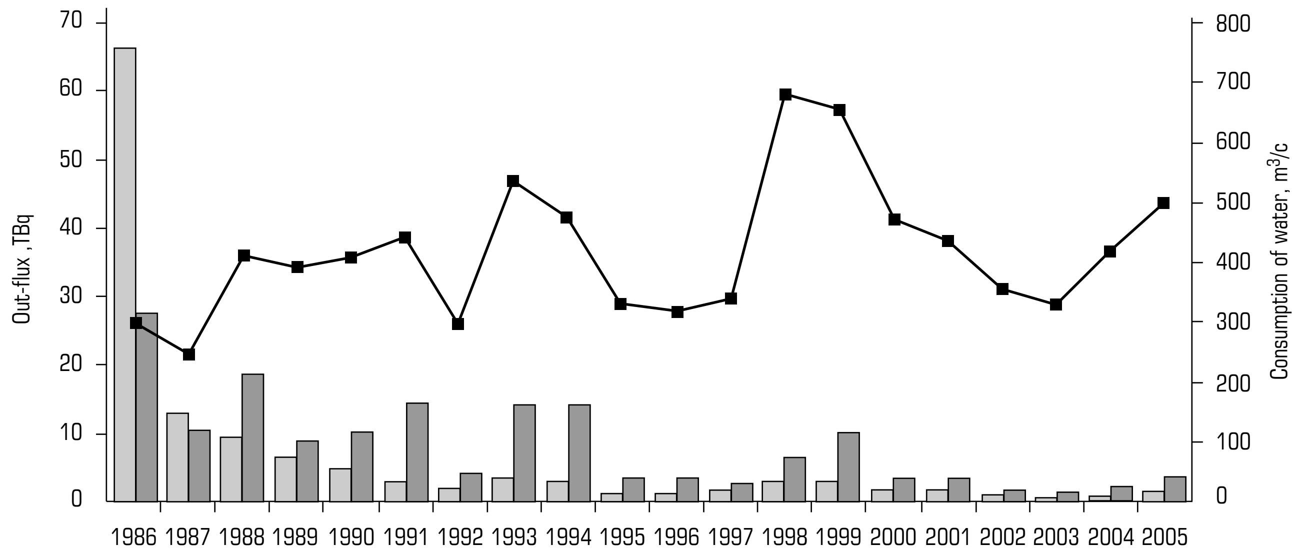
Table 8.1.3

^{137}Cs and ^{90}Sr concentration activity in surface waters of the Exclusion Zone in 2004, kBq/m^3

Facility and control point	^{137}Cs						^{90}Sr		
	suspension			solution					
	min.	max.	average	min.	max.	average	min.	max.	average
River Prypiat – the village Usiv	0.01	0.11	0.02	0.01	0.04	0.03	0.02	0.13	0.04
River Prypiat – the town of Chornobyl	0.01	0.06	0.02	0.01	0.06	0.03	0.10	0.35	0.18
River Uzh – the village of Cherevach	0.01	0.06	0.02	0.01	0.08	0.04	0.09	0.32	0.17
River Braginka – Dam 39	0.01	0.20	0.04	1.3	4.5	2.3	2.1	5.7	3.7
River Sakhan – the village of Novoshepelychi	0.01	0.05	0.02	0.08	0.49	0.22	0.51	5.5	2.1
Reservoir-cooler of the Chornobyl NPP	0.02	2.9	0.34	0.20	4.3	1.8	0.59	5.1	1.6
River Glynytsya	0.01	0.17	0.04	0.18	0.60	0.42	3.5	6.9	4.8
Semykhodsky creek	0.01	0.27	0.11	0.77	2.7	1.2	10	20	14
Prypiatsky creek	0.02	0.19	0.08	2.3	3.9	2.8	15	23	19
Lake Azbuchyn	0.05	2.7	0.44	1.1	12	6.7	38	72	56
The duct branch of ChNPP 3rd turn	0.32	4.3	2.2	110	160	130	36	40	38
The left-bank polder tale pool of GTC7	0.10	0.78	0.33	0.90	8.1	2.0	11	25	18
Lake Glyboke	0.06	0.98	0.34	4.5	8.2	6.2	97	160	135

In the last decade, ^{90}Sr concentration activity in the water of the river Prypiat in the area of the town of Chornobyl did not exceed the established permissible level (PL-97) for drinking water (2 kBq/m^3), the maximum value of 1.6 kBq/m^3 was determined during the largest post-accident spring flood in 1999. During periods of mean water, levels of activity are of the order of 0.3 kBq/m^3. The concentration activity of ^{137}Cs is two or three times less than for ^{90}Sr

The maximum river outflux of radionuclides via the river Prypiat into Kyiv reservoir was determined in 1986 to be about 66 TBq of ^{137}Cs and 27.6 TBq of ^{90}Sr (Fig. 8.1.3). Subsequently ^{90}Sr outflux via the river Prypiat was 10–14 TBq in years of average water and 3–4 TBq in the low-flow years.



	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
^{137}Cs	66,2	12,8	9,48	6,44	4,63	2,89	1,92	3,48	2,96	1,15	1,3	1,7	2,95	3,05	1,71	1,54	0,87	0,49	0,69	1,4
^{90}Sr	27,6	10,4	18,7	8,97	10,1	14,4	4,14	14,2	14,2	3,4	3,42	2,68	6,37	10,5	3,36	3,14	1,65	1,4	2,23	3,67
Consumption	302	246	411	392	409	442	295	537	476	330	3,19	340	681	656	470	437	358	330	419	498

Fig. 8.1.3. River flow of radionuclides with the water of the river Prypiat to Kyiv reservoir in 1986–2005, TBq

About 70% of ^{90}Sr transported by river Prypiat originates from the Exclusion Zone (Table 8.1.3). From 1988, the annual outflux of ^{137}Cs rarely exceeded half of ^{90}Sr. About 90% of the total river outflux of ^{137}Cs is formed outside of the Exclusion Zone.

An additionally, 0.6 to 1.2 TBq of ^{90}Sr entered the Kyiv reservoir via the river Uzh in 1987–1994, in 1995–2000 it was of 0.1 to 0.5 TBq a year; the river Brahinka contributed 0.1 to 0.5 TBq a year.

Among the water-protection measures conducted in the Exclusion Zone was the construction of protective dams on the floodplain of the river Prypiat. Left-bank complex was constructed in 1992 and right bank in 1999–2004. The majority of specialists believe that these constructions positively reduced the volley wash-off of radionuclides from the most contaminated parts of the floodplain during the spring flood as well as water rise caused by mashing events. As a whole, for the post-accident period according to the computations of Ukrainian Hydrometeorology Institute, «Ecocentre» and others, the water-protective measures prevented the possible additional ^{90}Sr outflux by surface waters to the Kiev reservoir by about 17–20 TBq (450–550 Ci).

At the same time, the dams construction intensified the processes of over-moistening and swamping of flood land territories that leads to intensification of radionuclides migration processes, first of all, of ^{90}Sr and its coming with ground waters to the surface waters of the river Prypiat.

Over recent years radionuclides flow into the river Prypiat via ground waters of quaternary water-bearing complex become an important contributor.

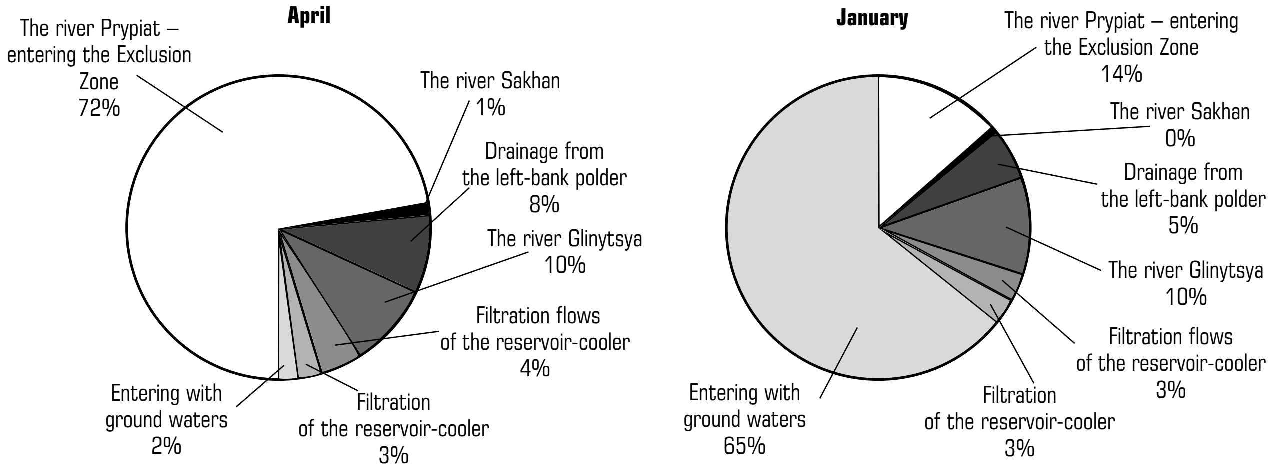


Fig. 8.1.4. Typical distribution of the sources of forming ^{90}Sr flow by the river Prypiat at flood and mean water (2003)

As we can see in Fig. 8.1.4, during the period of mean water levels, when the underground component dominates contributions to the river, over 60% of ^{90}Sr come with underground waters

Specialists believe that in the near future the contributions of different sources to the radionuclides outflux by rivers will remain the same.

Radiological state of underground waters

During the significant period of time since the Chornobyl catastrophe investigations have shown that, generally, the processes of radionuclide migration within the aeration zone and water-saturated beds, are characterized by moderation and passivity in contrasting with radionuclides behaviour in air and surface water.

The system of radiation monitoring covers the underground waters of quaternary, Eocene and Cenomanian and Lower Cretaceous water-bearing complexes. Radiation state of underground waters of water-bearing complex of Eocene sediments (the sources of the centralized water supply system of the Chornobyl NPP) were monitored on the acting ChNNP water supply unit, the town of Prypiat, Cenomanian and Lower Cretaceous ones (sources of the centralized water supply of the town of Chornobyl) was monitored at the acting water supply unit of the town of Chornobyl. The water-bearing complex of quaternary sediments, which is the first from the surface ground, is the facility of the direct impact of technogenic radiation contamination.

The results of investigations of 1986–2005 do not give grounds for single-valued assertion on their contamination with radionuclides of the ChNPP releases. The concentration activity of ^{137}Cs and ^{90}Sr in water at the ChNPP water supply units and the town of Chornobyl do not exceed 10 Bq/m^3.

Taking into account the character of different hydrogeological conditions of the separate sites of the Zone, since 1990 the radioactive contamination of the ground waters, mainly, by ^{90}Sr has been increasing. The results of underground water monitoring are evidence of progressing contamination with ^{90}Sr, both temporally and spatially, in water-bearing complex of quaternary sediments. This is due to radionuclide migration from the surface Points of Temporary Localization of Radioactive Waste-trenches (clamps) and industrial site of the object «Shelter». Radionuclide migration into the hydrogeological environment is caused by infiltration of atmospheric precipitation, and by direct constant or seasonal flooding of the RW – trenches by ground waters. The specific activity of ^{90}Sr in the pore solutions under and around the burial areas exceeds 100–1000 times the allowable permissible limit for drinking water (PL-97). The water-bearing complex is contaminated to some tens meters down along the flow of ground waters.

The maximum radionuclide migration has been determined at observation boreholes within the «Red forest» areas of the «Old Construction Base» and Yanivsky creek, 220–240 kBq/m^3 and 350–400 kBq/m^3 (Table 8.1.4).

Table 8.1.4

Concentration activity of ^{137}Cs and ^{90}Sr (Bq/m^3) in ground waters within the «Red forest», areas of the «Old Construction Base» and Yanivsky creek

The districts of PTLRW	^{90}Sr			^{137}Cs		
	min	max	average	min	max	average
Old Construction Base	21 000	230 000	70 000	120	1100	400
Yanivsky creek (except Borehole K-4)	6300	400 000	82 000	28	220	100

At boreholes close to the pond-cooler radionuclides contamination due to underground flow of the river Prypiat was observed. The average concentration activity of ^{90}Sr in the water of these boreholes is 5200 Bq/m^3 with a range from 100 Bq/m^3 to 31000 Bq/m^3, the respective values for ^{137}Cs are 40, 8 and 160 Bq/m^3. ^{90}Sr concentration in the water of 24 boreholes from a total of 32 exceeded 2000 Bq/m^3.

The results of investigations in the near zone of the Chornobyl NPP where the basic PTLRW are («Red forest», «Construction Base», the Station of Yaniv and others), the ChNPP industrial site, the Object «Shelter», Points of Radioactive Waste Disposal «Pidlisny», «Complexny» and other show that in the long-term trends the lateral spreading of ^{90}Sr from the trenches will be limited to the first hundreds of meters below the burial sites along the flow of ground waters. The local hydrogeological conditions and natural geological barriers provide rather reliable retention and inhibition of radioactive Strontium and Caesium migration, and thus, they confine the underground migration of radionuclides to surface hydrosphere.

However, underground waters around PTLRW will remain a constant potential source of radiation risks in the near zone of the Chornobyl NPP for a long time. The burial trenches in the area of Yanivsky creek are the really danger ones as a potential source of surface water contamination. Maximal levels of radioactive contamination are observed in boreholes near PTLRW «Old Construction Base» and Yanivsky creek, respectively, 400 kBq/m^3 и 250–270 kBq/m^3.

The dominating factor controlling intensity of radionuclides fluctuation in the river are the geological, hydrogeological and climatic conditions, together with the specifics of construction of different burial trenches and of the interconnection of surface waters, reservoirs and underground waters. Beyond the bounds of RW burial areas the radioactive contamination of ground waters is determined by migration of deposited radionuclides. ^{90}Sr contamination of the water in the boreholes of the regional observation network is 80–250 Bq/m^3, whilst ^{137}Cs is in the range 30–50 Bq/m^3.

The latest investigations have determined the progressing of ^{90}Sr migration from PTLRW «Pishchane plato» to the area of Semyhodsky creek. The ^{90}Sr concentration activity in the water of the observation borehole at Semyhodsky creek is 100 kBq/m^3.

According to the data of the Institute of Geological Sciences of National Academy of Sciences of Ukraine about 40 TBq (~ 1000 Ci) of ^{137}Cs penetrate annually into the geological environment with taking into account of local sites – PTLRW, PRWD, the object «Shelter». The amount of ^{90}Sr, which comes annually into the geological environment, is considerably more than ^{137}Cs. The total activity of ^{137}Cs and ^{90}Sr, which is transported to the geologic environment, is 4–20 times more than the annual outflux transported by the river Prypiat to outside the Exclusion Zone. According to the data of ISTC «Shelter», about 120 MBq Uranium and Plutonium and almost 1.5TBq (40.5 Ci) ^{137}Cs and ^{90}Sr annually penetrate into the geological environment via water flux at the object «Shelter».

As a result of the Chornobyl catastrophe the distribution of radioactive contamination of the Exclusion Zone territory at the initial stage was characterized first of all by the release composition and atmospheric processes. When radioactive releases from the damaged unit stopped and the Object «Shelter» was built, subsequent changes in the radioactive contamination of soils were determined mainly by the following factors: radioactive decay, deactivation work, radionuclides wash out and transfer by rain and flood waters, radionuclides migration in soils, wind transfer of radionuclides.

Investigations have shown that the generally in the majority of the Zone soil 92–98% of ^{137}Cs is localised in the 0–15 cm upper layer. Below this radionuclide concentration activity sharply decrease less than 1% of the total deposit being below 20 cm. In the 20th year after deposition, the maximum depth of penetration of the majority of radionuclides into the soil varies from 20 to 25 cm (Fig. 8.1.5). However, in soils of the flood plain ^{137}Cs migration is 2–3 times higher in comparison with watersheds and terraces. In these soils a more smooth reduction of radionuclide concentrations with depth is seen, there is no measurable deposit in the upper layer. For the soil of the flood plains the maximum intensity of ^{137}Cs migration is observed on technogenicaly changed soil. The relatively quick vertical migration of radionuclides in the soils of the flood plain mean that they may have more rapid penetration of radionuclides into the ground waters, that required the rating of these landscapes to the category of critical ones.

The vertical distribution of ^{90}Sr in soil profiles is similar to that of ^{137}Cs, but the depth of ^{90}Sr penetration is generally greater. The most considerable differences in ^{90}Sr distribution are observed in soil of flood-land landscapes. The hydrologic regiment of theses soils considerably influences the intensity of ^{90}Sr redistribution. After displacement of the basic mass of radionuclides to the underlying horizons, ^{90}Sr migration acceleration along the vertical profile and its larger penetration into the ground waters is observed. In forest soils a gradual increase of ^{90}Sr in the upper litter layer (AoL) horizon is observed. Falling foliage (in particular needles) has higher ^{90}Sr concentrations in comparison with ^{137}Cs. In time, it will lead to the enrichment of the forest litter with ^{90}Sr.

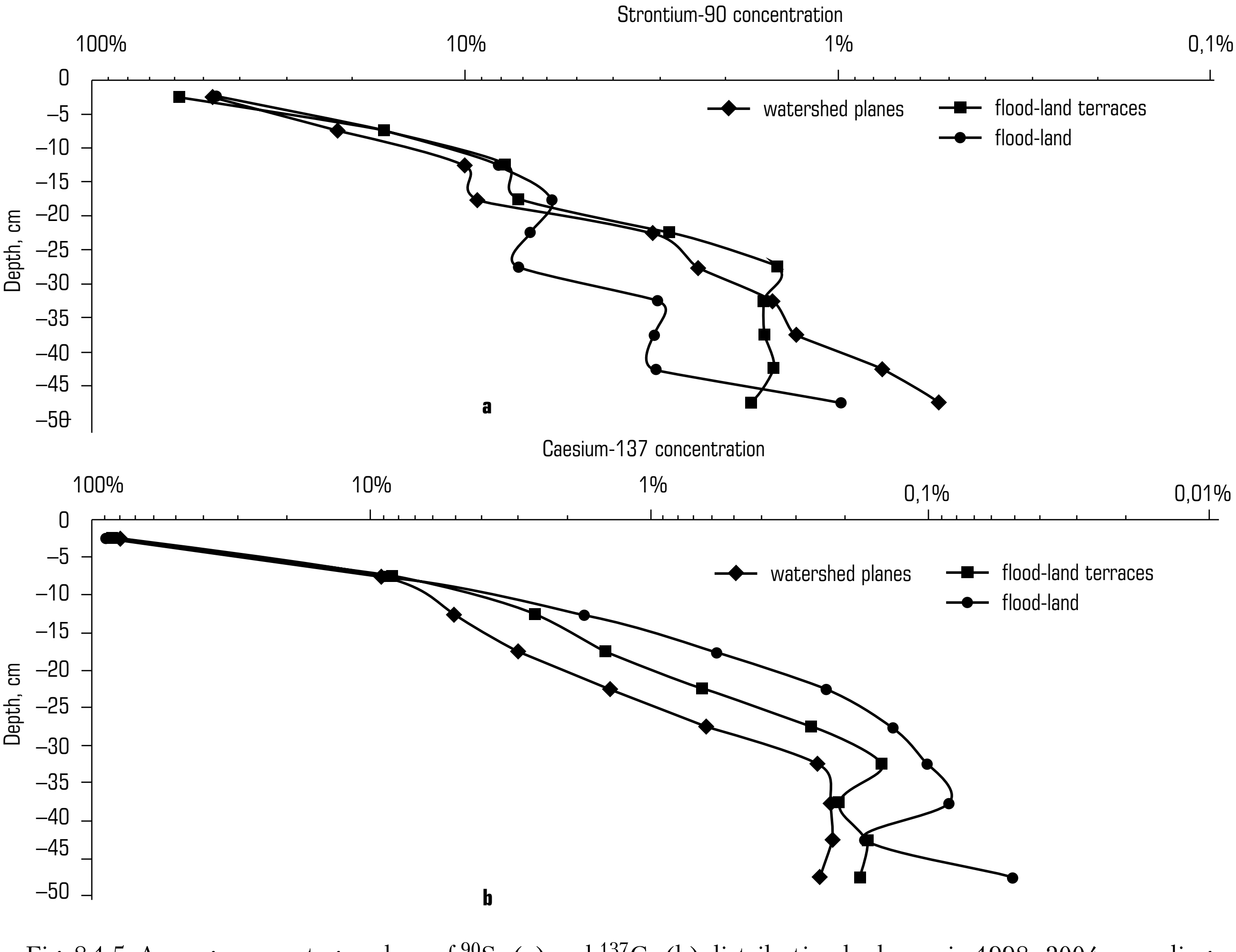


Fig. 8.1.5. Average percentage values of ^{90}Sr (a) and ^{137}Cs (b) distribution by layers in 1998–2004 according to the observations at typical landscapes

One of the most urgent problems after the Chornobyl accident was estimation of radioactive contamination of topsoil in the places of human activities and workers residence. The first assessments of the radiation situation in the area of the town of Prypiat were conducted in July-September 1986; ones in the area of the town of Chornobyl were conducted in June 1986. They showed considerable variations of the soil contamination by radionuclides, ^{137}Cs concentration on the soil surface in the town of Prypiat varied from 2,6 to 24 MBq/m^2; in the town of Chornobyl it was of 180–920 kBq/m^2. Average and maximum values of contamination of the soils in the town of Chornobyl during 1987–2005 ranged from: ^{137}Cs – 150–480 (average) and 250–4800 kBq/m^2 (maximum); ^{90}Sr – 75–210 and 130–2100 kBq/m^2; $^{239+240}Pu$ – 1.3–6.7 and 2.9–67 kBq/m^2; ^{241}Am – 2.2–4.2 and 5.4–11 kBq/m^2. The corresponding values for the town of Prypiat were: ^{137}Cs – 580–960 and 1200–15000 kBq/m^2; ^{90}Sr – 280–480 and 570–6500 kBq/m^2; $^{239+240}Pu$ – 4,1–13 and 7,7–210 kBq/m^2; ^{241}Am – 6,1–15 and 15–96 kBq/m^2.

Radiation situation in the places of unauthorized residence

Now over three hundred people (so-called self-settlers) reside in the some settlements of the Zone. They are concentrated in the south and southwest sectors of the Exclusion Zone. On October 1, 2005 209 persons lived in 11 villages of the Exclusion Zone, in the town of Chornobyl they were 148 people (in addition to personnel).

Radiometric measurements on farmsteads show an approximate stabilization or reduction, in the levels of external gamma and beta radiation. Over the last decade of observations, beta flow density in the farmsteads has not exceeded 70 parts/(min.·cm^2), they were 150–900 parts/(min.·cm^2) in fire ashes. The levels of gamma radiation in the village gardens have been determined in the range 8–30 μR/hour.

Concentrations of ^{137}Cs and ^{90}Sr in drinking water from wells have not exceeded permissible levels 2 Bq/l (PL-97) over the whole period of observation.

Settlements, which were directly on the «traces» of radioactive fallout have soil contamination densities with ^{137}Cs near tens - hundreds (sometimes thousands) of kBq/m^2 and with ^{90}Sr of tens – hundreds. The largest density of topsoil contamination with TUE units is of the order tens of kBq/m^2 or less.

In 2003–2005 the specific activity of ^{137}Cs and ^{90}Sr in fruit and vegetable products of many zone settlements exceeded permissible levels for entry into the human food chain. The concentration activity of ^{90}Sr and ^{137}Cs in potatoes, which dominate the food of «self-settlers» in some farming exceeds, respectively, 9 and 3 times the permissible levels. Contamination of products of the «self-settlers» with radionuclides due to results of the last three years is given in table 8.1.5.

Table 8.1.5

Concentration activity of ^{137}Cs and ^{90}Sr in foodstuff, made by «self-settlers» , Bq/kg, Bq/l, Bq/unit

Contamination, Bq/kg, Bq/l, Bq/unit	Product				
	Potatoes	Vegetables	Milk	*Eggs	Fruit
^{137}Cs					
PL-97	60	40	100	6	70
Observed	1.1–160	1.3–220	12–340	0.1–0.6	3.4–87
^{90}Sr					
PL-97	20	20	20	2	10
Observed	2.2–190	1.7–3600	1.3–36	0.1–0.7	2.4–50

* Units.

Over the last seven years the concentration activity of ^{137}Cs in milk has been the gradually reduced, however, in some homesteads the levels of milk contamination are high, and exceed PL-97 several times. The specific activity of ^{90}Sr in milk exceeded PL-97 (20 Bq/l) only in the village of Lubianka. The concentration activity of TUE in all the samples of milk are below the limits of detection.

The products, which «self-settlers» take from the nature (fish, wild animals, mushrooms and berries), contribute an important fraction in their total dose formation. These products are often in considerable excess of ^{137}Cs and ^{90}Sr activity concentrations as defined in PL-97, and can't be used as a food.

Radiation state of forests

Over 20 years the processes of ^{137}Cs accumulation in the components of the forest ecosystems have stabilized with the gradual reduction of the total level of contamination. At the same time, ^{90}Sr has not

reached a maximum, and contamination of radioactive strontium in individual components of the phytomass continues to rise. Over recent years the range of variations of the concentration activity of phytomass fractions of the forest has been practically unchanged. The causes of changing these indicators are conditioned by a complex of natural factors, and they cannot be always predicted. It is the evidence of potential hazard of non-monitored movement and application radioactively contaminated biological forest products.

The traditional application of wood wastes as fuel can result the contamination of land surrounding the dwelling sector. For example, in the former settlements of the Exclusion Zone «self-settlers» use the firewood of local origin, heating boilers function at some enterprises (Table 8.1.6). The growing accumulation of ^{90}Sr in trees and using these trees for heating already leads to ashes of with levels of contamination, corresponding to RW.

Table 8.1.6

Contamination of pine firewood and ashes with radionuclides during burning, kBq/kg

Territory	Wood, ^{137}Cs	Bark, ^{137}Cs	Ashes	
			^{137}Cs	^{90}Sr
Southeast sector of the Zone	30...90	700	15 000	59 000
Northwest sector of the Zone	140...570	1500...8600	36 000	300 000

The basic kinds of the forest food products, wild mushrooms and berries in the Exclusion Zone are accumulators of ^{137}Cs, and the particular species of them accumulate ^{90}Sr. The many year observations are evidence of the small changes of ^{137}Cs concentration in blackberries. The average values of the transfer factor (TF) in blackberries considerably depends on the ecological conditions and are in the range of 2.0 to 16.0 Bq·kg^{-1}/Bq·m^{-2}. With increasing soil moisture, TF value for berries rises: in subors in the fresh conditions the berry TF is 8.2 Bq·kg^{-1}/kBq·m^{-2}, in the moist conditions it is 11.0 Bq·kg^{-1}/Bq·m^{-2}, and in the fresh ones it is 16.0 Bq·kg^{-1}/Bq·m^{-2}. The general tendency is reduction of intensity of radioactive caesium coming into blackberries with increasing the soil richness. TF of fresh higrotopes in pineries is 10.0 Bq·kg^{-1}/kBq·m^{-2}, in subors it is 8.2 Bq·kg^{-1}/kBq·m^{-2}, and in sudubravas it is 2.0 Bq·kg^{-1}/kBq·m^{-2}, i. e. the difference between the extreme trophotopes is 5 times.

Mushrooms continue to be the leaders of accumulation of radioactive caesium, but the dynamics of its content considerably depends on biological peculiarities of a species and the weather conditions of vegetation periods. The intensity of ^{137}Cs accumulation by mushrooms increases when the moisture is rising and soil richness reducing. The dominating accumulation of radioactive Strontium is typical for wild strawberries, birch sap, tree-destroying fungi. All this makes forest products the source of additional internal irradiation of population for a long time.

The specialized system for forests supervision and support of stability and vital activity of forest plantations with complete preservation of their protective functions is developed and realized.

State of fauna

The basic result of the accident for the fauna of the Zone was the gradual recovery of its natural condition. For today, the zoocenoses of the Exclusion Zone can be characterized as stable ones. The basic transformations of species structure due to the radioactive contamination and removal of the anthropogenic load with rapid increase in quantity and disappearance of some species occurred in 1986–1991. Changes of quantity of species are caused by their own variations («waves of life») and the gradual transformation of the landscapes into those, which are typical for this natural and geographical zone. According to the observation results during the post-accident period the constant or seasonal stay has already been proved for 313 kinds of vertebrates, among them 20 species are from the Red book. 409 species of vertebrates, among their number 73 kinds of mammals, 251 kind of birds, 7 kinds of reptiles, 11 kinds of Amphibians and 67 kinds of ichthyoids can live on the territory of the Exclusion Zone. Besides, two migration flows of birds, the north (Dnipro) one and the west (Prypiat) one nest on the territory of the Exclusion Zone. Every year during the period of spring and autumn migration dozens of millions birds (to 5000–6000 tons of total mass) fly over the territory of the Exclusion Zone, among them about 5 million (mostly small birds) stay for nesting. The part of migrant birds stays on the Zone territory for the periods of 1–2 days to a month.

The basic characteristic of animals' radioactive contamination is the considerable variations of the values caused by the well-known space heterogeneity of the primary fallout as well as soil and plant conditions, specific for the species and individual territorial behaviour of animals, trophic specialization of the species, seasonal changes of feeding and physiology (Table 8.1.7).

Table 8.1.7

^{137}Cs concentration activity in the samples of the typical kinds of the Exclusion Zone fauna, Bq/kg (the period of observations is 2000–2005)

Samples	Minimum	Average value	Maximum	PL-97
The river Prypiat mouth				
Aquatic birds	30	**300**	**1800**	200
The Zone territory				
Wild boar	100	**600**	**5200**	200
Roe	**410**	**695**	**6900**	
Deer	–	–	**730**	
Beaver	–	–	**1300**	
Przevalsky's horse	70	–	**100**	
Elk	**750**	**635**	**1500**	

Примітка: the data, which exceed PL-97, are given in the bold type.

It attracts attention that for the last four years in the majority of samples of eatable bioresources of animal origin 1.5–50 times exceeding of ^{137}Cs concentration activity values, which are regulated by permissible levels PL-97, is systematically determined. Cosntamination of the basic kinds of game on the territory of the former game-preserve «Birch haycock» near the Zone south bound considerably exceeds PL-97 norms. The results exclude the possibility of using the Zone territory as the game preserve.

Autorehabilitation processes in the Zone

The predicted estimations of radiological conditions of the environment, the same way as planning and realization of rehabilitation measures in the Zone must obligatorily take into account the processes of autorehabilitation of radioactive contaminated ecosystems.

Autorehabilitation processes on the radioactive contaminated territories play the ambiguous role [2]. The estimation of the rate of autorehabilitation processes on the Zone territory requires complex calculations of the rate of abiogenic and biogenic migration of radionuclides on the contaminated landscapes. But one can form a number of recommendations today.

It is necessary to support the development of autorehabilitation processes, which lead to binding, precipitation or local circulation of radionuclides in that part of the Zone where human habitation is impossible during the next 100 years. Reforestation, bushing and creation of weak-drainage, waterlogged parts are assumed here.

It is necessary to provide the measures or support the conditions, which give opportunities not resulting worsening of soil fertility, current radiation conditions and the conditions of possible human residence, in the areas, which have the perspective of returning to the economical use. Besides, it is necessary to stimulate the natural processes, which lead to purification of the landscape to be used, i. e. carrying out or dissemination of the contaminated substances. The degree and intensity of intervention into autorehabilitation processes must be determined by the real terms of returning land to the economical use. At the same time, the measures concerning rehabilitation must not be contrary to the basic strategic tasks concerning the Zone, which is minimization of radioactive contamination dissemination beyond its bounds.

Rehabilitation of the abandoned territories

Rehabilitation of the abandoned territories has its own peculiarity, as due to the stopping of human activity for a long time, the considerable changes of natural and man-made environment have occurred: the economic activity is stopped, the infrastructure is damaged, the condition of terrestrial and water ecosystems considerably changed (ground water level rose, landscapes changed, soil fertility changed, biovariety rose, insects-parasites and diseases of plants and wild animals expanded, etc.) The planning of the possible scenario of using some parts of the abandoned territories and grounding of making of corresponding decisions should be based on not only the estimations of radiation factors (possible levels of exposure dose on the re-evacuated population), but on the estimations of social and economic and psychological factors. For the recent years, the conceptual and methodological bases of rehabilitation have been developed; they include the general step-by-step approach to the safe recovery of the excluded territories with regard for radiation, economical, ecological, psychological and social aspects, the previous estimations of the possible directions of the rehabilitation activities have been made and zoning of areas of the Zone territory has been made in the directions of activities with regard to the notions of the full

and partial (limited) rehabilitation. The methodical supplying of the abandoned territories rehabilitation being developed, the previous forecast estimations of the possible exposure doses on the hypothetically re-evacuated population for various scenarios of rehabilitation of some parts of both the Exclusion Zone, and the zone of absolute resettlement have been made [6].

Unsolved radioecological problems

Among unsolved radioecological problems of the Zone or questions, which require the further developments, it is necessary to mention the following directions [7]:

–continuation of the investigations, aimed at the estimation of the radiological significance of natural and technogenic objects of the Zone;

– complex research of the long-term dynamics of radioecological processes;

– complex research of the barrier function of natural and technogenic components of the Zone, development of algorithms for its optimization;

– conduction of the detailed investigations of autorehabilitation processes of the Zone ecosystems;

– estimation of the influence of the technogenic objects complex (Object «Shelter», Chornobyl NPP, Storage of Spent Nuclear Fuel-2, Complex «Vector», Plant for Liquid RW Processing etc.), the complex of technological processes connected with movement and processing of nuclear fuel and RW as integrated distributed long-term technogenic source of radionuclides on the radiological situation in ecosystems of the Exclusion Zone and the adjacent territories;

– radioecological research of the former urbanized territories;

– continuation of research of the problems connected with rehabilitation of the Zone territory, etc.

8.2. Tends of the Zone territory usage and obligatory measures

According to the Legislation of Ukraine and the resolutions of the Cabinet of Ministers of Ukraine, the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the consequences of Chornobyl catastrophe provides the usage of different parts of the Zone, i. e.:

A. Creation and operation of the current enterprises concerning handling of RW, their infrastructure provision, particularly: construction and operation of the depositories of low- and middle active RW of the complex «Vector», operation of PRWD and PTLRW.

B. Creation and operation of the current enterprises connected with decommissioning of the Chornobyl NPP and conversion of the object «Shelter» into the ecologically safe system, their infrastructure provision.

C. Realization of measures on rehabilitation of the Zone ecosystems, water-protective measures.

D. Carrying out of the specialized forest economic activity as to management of the Zone forests including recovery of existing special reserved territories and creation of the new ones.

E. Prevention of radionuclides carrying out beyond the borders of the Zone and conversion of radioactively danger facilities of the Zone to ecologically safe systems.

The activity in the Zone, first of all is aimed at realization of the obligatory measures determined by the legislation in force, especially:

– protection of the adjacent territories from distribution of radioactive substances beyond the bounds of the Exclusion Zone, minimization of ecological hazard for population of Ukraine with regard to the extreme situations possible under the conditions of the region in the scope, it can be possible and economically profitable;

– monitoring of environment conditions, medical and biological monitoring;

– keeping the territory in proper sanitary and fire-safe conditions;

– fixation of radionuclides in the region;

– provision of the measures on the Chornobyl NPP decommissioning, conversion of the object «Shelter» to the ecologically safe system and handling of the spent nuclear fuel.

All kinds of activities in the Zone are carried out with limiting the total collective dose of ionizing irradiation, and confining the quantity of the involved people. Such kind of work doesn't worse the radiological situation, increases the level of investigation of its natural and technogenic complex and does not prevent the rational use of the Zone territory in future. Any activity in the Exclusion Zone aimed at improvement of the radiological situation is realized with maximum natural factors use and with minimum intervention in the natural environment.

The obligatory measures are conducted on the basic directions:

1. Support of available conditions of safety and conversion of the object «Shelter» into the ecologically safe system.

2. Creation of technologies, technical means and enterprises for handling of technogenic wastes, construction and operation of the complex «Vector».

3. Monitoring of RW burial units, RW transportation and burial, deactivation of territories, facilities, materials and equipment.

4. Provision of water-protecting measures.

5. Regional radiation and ecological monitoring of the environment, and dosimetric control.

6. The territory rehabilitation and its scientific supervision.

7. Conduction of the specialized forestry activities, provision of fire-prevention measures in the forestlands of the Zone, support of the special natural and reserved fund.

8. Scientific investigations by the tasks of the National program on minimization of the Chornobyl catastrophe consequences.

9. Data ware of the obligatory measures and population.

10. Realisation, keeping in the constant readiness and improvement of the operation of all the links of a regional sub-system of the United national system of prevention and response to emergences of technogenic and natural character in the Exclusion Zone.

The general strategy of the activities is to determine the ways of long-term maintenance of the Exclusion Zone and the priorities of the activities in it in the basic directions, which provide reduction of ecological risk and minimization of its influence on the radiological situation and the health of population of Ukraine.

The conception of the activity in the territory of the EZ and ZAR is based on the results of generalization of the real data and conclusions of domestic and international scientific research devoted to investigation of the state of facilities, consisting the radioactive materials, and the environment of the Exclusion Zone, taking into account the predictions of the possible ecological consequences of the Chornobyl catastrophe.

The complete achievement of the aims and tasks of the general strategy cannot be reached in the short terms. Their accomplishment with regard to the priorities of the activity in the Exclusion Zone is conditioned by technical and economical possibilities of the state.

Conclusions

In 20 years after the catastrophe, the Zone is an open flat source of radioactivity with the immense stocks of radionuclides, heterogeneous structure of their distribution in components of the environment and technogenic facilities, the presence of various forms and species of precipitated radioactive nuclides. Because to it, the radiation factor continues to be the basic factor in determination of potential hazard both for population residing on the adjacent to the Zone territories and for Ukraine's population, as a whole.

Creation of the Chornobyl Exclusion Zone was a justified measure not only in connection with the necessity of evacuation of the population from the most strongly contaminated territory. The Zone is the most strongly contaminated territorial complex and the largest source of radiation hazard for the surrounding populated territories. Continuation of activities on investigate, support and strengthen the barrier role EZ and ZAR is the most important direction of the efforts to minimize accident consequences.

On the background of the total stabilization of radioecological situation the tendency of further complication of radiation conditions in the components of the Zone environment, it remains to be a source of contamination of practically all its components. Due to the processes of redistribution and migration of the radionuclides, which are deposited after catastrophe in burials, landscapes, close water reservoirs, individual facilities the process of forming of secondary sources of radioactivity, which makes them potentially hazardous, occurs.

The basic way of radionuclides migration beyond the bounds of the Zone is water river drainage (the river Prypiat). Along with it for the last decade the concentration activity values of ^{90}Sr in the water of the river Prypiat in the in the area of the town of Chornobyl did not exceed the established PL-97 norm for drinking water, the concentration activity values of ^{137}Cs were 2–3 times less than ones of ^{90}Sr.

The construction of left-bank and right-bank protective dams in the flood-lands of the river Prypiat contributed the positive effect on reducing valley washout of radionuclides from the most contaminated parts of the flood-lands of the river during the flood and water levels rising. As a whole, for the post-accident period water-protection measures prevented the possible additional ^{90}Sr flow with the surface waters in the amount of about 17–20 TBq.

In 2003–2005, in the places of non-authorized habitation of the population the concentration activities of ^{137}Cs and ^{90}Sr in fruit and vegetables production considerably exceeded allowable levels, what makes the productions to be inedible. In spite of the gradual reduction of the levels of milk contamination with ^{137}Cs and ^{90}Sr for the last seven years, they remain high and several times exceed PL-97 in some places of the non-authorized habitation. The products, which are got by «self-settlers»

in the nature (fish, wild animals, mushrooms and berries), are mostly inedible, as specific activities of ^{137}Cs and ^{90}Sr considerably exceed the ones of PL-97.

For the last four years contamination of the edible natural resources of animal origin with ^{137}Cs systematically 1.5–50 times exceeds the values, which are regulated by PL-97 that excludes the possibility of using the Zone territory for as a game-preserve.

The development of consecutive and comprehensive strategy of the Zone rehabilitation is necessary with emphasis on rising safety of the available facilities for preservation and burial of radioactive wastes. It will require development of the method for determination of priority for rehabilitation of the areas, which is based of the results of the safety estimation. It will allow determine, from which areas the wastes can be taken and buried, and on which ones it is necessary to leave wastes for their decay on the spot.

For the further development of the system of environment protection from radiation it is necessary to continue the complex investigations of long-term consequences of radiation on flora and fauna facilities, directions and intensity of radionuclides migration and redistribution processes in the components of environment in the Zone, which provides the unique natural conditions for radioecological and radiobiological investigations. Except small experiments, such investigations are difficult or impossible to be conducted in any other region of the world.

9. THE SHELTER

Constructed under extreme post-accident conditions, the Shelter has been performing its protective functions for almost 20 years.

The key feature of the Shelter is its potential hazard, which is significantly greater than permitted by regulations and rules for facilities containing nuclear-hazardous and radioactive materials.

Generally, from the point of view of radiation safety, the Shelter is actually an open source of alpha, beta, gamma and neutron radiation, which, with respect to its radiation characteristics, has no analogous in the world practice. It can be considered as an interim barrier to fissile nuclear-hazardous materials and high-level wastes, with a practically uncontrolled situation inside the facility.

The current status of the Shelter is specified in Annex RSSU-97 «Radiation protection from sources of potential radiation» (RSSU-97/D-2000) – *sites for surface storage of non-arranged RW.*

9.1. Nuclear-hazardous materials inside the Shelter (integral assessments)

9.1.1. Fuel-containing materials (FCM) located currently inside the Shelter

Presently, inside the Shelter nuclear fuel is present in a variety of modified forms which were produced during the active phase of the accident. Such modifications are as follows:

• Reactor core fragments (RCF) in the form of fuel pellets, fragments of fuel elements, fuel rod assemblies and graphite;

• Lava-like FCM (LFCM) containing nuclear fuel. They contain a significant amount of uranium that was in the reactor core before the accident, and a significant share of radionuclides developed in the reactor.

The scenario of emergence of LFCM, their elements and radionuclide composition has been described previously [1].

Total amount of nuclear fuel in different rooms of the Shelter

An assessment of the current amount of nuclear fuel in different areas of the Shelter is summarised in Table 9.1.1.

Table 9.1.1

Assessment of the amount of fuel in Shelter rooms

Description (No.) of room	FCM modifications in the room	Detected fuel t (U) (estimate on 2004)	Remarks
Central room (914/2)	Reactor core fragments	More than 21	48 fuel assemblies with fresh fuel (5.5 t) LFCM can be present
Southern cooling pond (505/3)	Reactor core fragments	14.8	129 cooled SFA LFCM can be present
All upper rooms, including the CR (elevation +24.00 and higher)	Fuel dust	~5 on heap surface in CR ~30 in all	The 30 t estimate includes surface contamination inside the heap in the CR and in all other rooms
304/3	LFCM	6 ± 2	«Horizontal lava flow». LFCM in breach between rooms 304/3 and 305/2 is accounted for
301/5 + 301/6 + + 303/3	LFCM	4.5 ± 2.5	«Horizontal lava flow»
217/2	LFCM	0.4 ± 0.2	«Elephant's leg», «stalactites». LFCM from «horizontal flow»
Subapparatus rooms 305/2 and 504/2 to elevation 24 m	Reactor core fragments, LFCM, dust	85 ± 25	Estimates by 6 clusters of FCM. Source of all LFCM flows
RCR (210/5 + + 210/6 + 210/7)	LFCM	12 ± 6	«Big vertical flow» and «small vertical flow»
BB-2 (012/14 + + 012/15 + + 012/16)	LFCM	minimum – 3, maximum – 14	
BB-1 (012/5 + + 012/6 + + 012/7)	LFCM	1.9 (+1.0; –0.5)	

Continuation Table 9.1.1

Description (No.) of room	FCM modifications in the room	Detected fuel t (U) (estimate as of 2004)	Remarks
Fuel under cascade wall	RC fragments, dust	?	
Water in all areas of the reactor room	Dissolved uranium salts, suspension	~4 kg	
Fuel in Shelter site	RC fragments, dust	0.75 ± 0.25	

The specific activity of different types of radioactive emissions in the basic fuel storage facility of Unit 4 on 1st February 2005 is summarised in Table 9.1.2.

Table 9.1.2

Specific activity of different types of radioactive emissions in the basic fuel storage facility of Unit 4 on 1st February 2005, Bq/g uranium

Alpha emitters	Beta emitters	Beta-gamma emitters
$^{238}Pu - 6.7 \cdot 10^6$	$^{90}Sr - 7.60 \cdot 10^8$	$^{106}Rh - 1.29 \cdot 10^4$
$^{239}Pu - 5.0 \cdot 10^6$	$^{90}Y - 7.60 \cdot 10^8$	$^{125}Sb - 7.12 \cdot 10^5$
$^{240}Pu - 8.19 \cdot 10^6$	$^{106}Ru - 1.29 \cdot 10^4$	$^{134}Cs - 1.61 \cdot 10^6$
$^{242}Pu - 1.30 \cdot 10^4$	$^{147}Pm - 2.65 \cdot 10^7$	$^{137}Cs - 9.09 \cdot 10^8$
$^{241}Am - 1.95 \cdot 10^7$	$^{241}Pu - 3.89 \cdot 10^8$	$^{144}Ce - 1.20 \cdot 10^3$
$^{243}Am - 8.73 \cdot 10^3$		$^{154}Eu - 1.64 \cdot 10^7$
$^{244}Cm - 1.07 \cdot 10^6$		$^{155}Eu - 4.45 \cdot 10^6$
Total ≈ 80 Ci/kg uranium		

Hence, the total amount of fuel inside the Shelter is presently about 14 MCi.

Possible changes in FCM characteristics

FCM are the main source of environmental emission of radionuclides and, hence, the main source of radiological hazard within the Shelter.

It is well known that UO_2 pellets exposed into the air deteriorate in about 20 years [2]. However, the most critical factor for the Shelter can be deterioration of LFCM because the most radionuclides therein are in the form of FCM.

Currently, the LFCM are demonstrating clear changes in strength properties, which are manifested by their cracking, destruction of big LFCM fragments and enhanced dust-formation capacity [3–4]. Hence, a challenging problem is what critical changes can occur in LFCM over a prolonged period such as the next 50 years. Currently, there are two fundamentally different approaches [5–6] to predicting changes in LFCM characteristics with time. In [3 and 5], it is assumed a priori that LFCM characteristics are similar to silicate glass used for containing radioactive waste. Based on this assumption, a conclusion is drawn that radiation damages caused by alpha-decay will initiate LFCM strength property changes no earlier than in 10,000 years. The authors attribute the basic causes of evident changes in LFCM to temperature drops, interaction with water, dust-suppression compounds, and other factors including external influences.

In paper [6], the authors investigate the basic characteristics of LFCM, and the influence of these factors in causing changes in LFCM properties with time. The basic conclusion is that; there appear to be disordered areas created by recoil nuclei due to inner self-irradiation during alpha-decay of transuranium isotopes. The increasing concentration of disordered areas (which are a source of occurrence of micro fissures) can lead to sudden total destruction of LFCM. Such catastrophic destruction might procure in the next 50 years.

Besides, in [4 and 7] it was shown that submicron aerosols are generated on the surfaces of LFCM and irradiated nuclear fuel, which can present a serious radiation hazard. The mechanism responsible for this phenomenon in LFCM can be a Coulomb explosion, which occurs during deceleration of alpha-particles.

In spite of extensive investigations, to date there is no well-grounded prognosis on FCM behaviour. Hence, follow-up studies in this area are essential.

9.1.2. Monitoring nuclear safety

Accumulations of FCM in the inner rooms of Unit 4 are piles of nuclear-hazardous fission materials with uncertain mass, substance and geometric parameters. Initially, FCM are very subcritical, however, in the presence of a moderator (e. g. water), a self-sustained chain reaction (SCR) can occur in some FCM piles. Based on nuclear safety requirements, it is necessary to identify the sites of possible critical mass zones (CMZ), and ensure their secure monitoring. The sole characteristic that can be used to assess the current level of subcriticality to ensure nuclear safety is measuring the extent of neutron activity and the relative changes in neutron activity with time.

The scheduled monitoring functions are performed by the FCM monitoring system «Signal».

The information-and-investigation system (IIS) «Finish» was set up in March 1988. In December 1998, part of the IIS «Finish» – «Finish-R» was transferred to the scheduled monitoring mode.

As an example, Fig. 9.1.1 shows the averaged annual temperature, neutron and gamma activity trends registered in subreactor room 305/2 in 1988. The trends of decreasing absolute average annual values of the parameters being measured correspond to physical decay, primarily of ^{244}Cm, ^{240,242}Pu240, ^{137}Cs and other radionuclides.

Development of critical masses is only possible through moistening in the piles of FCM located in the central room and in the subreactor space (room 305/2).

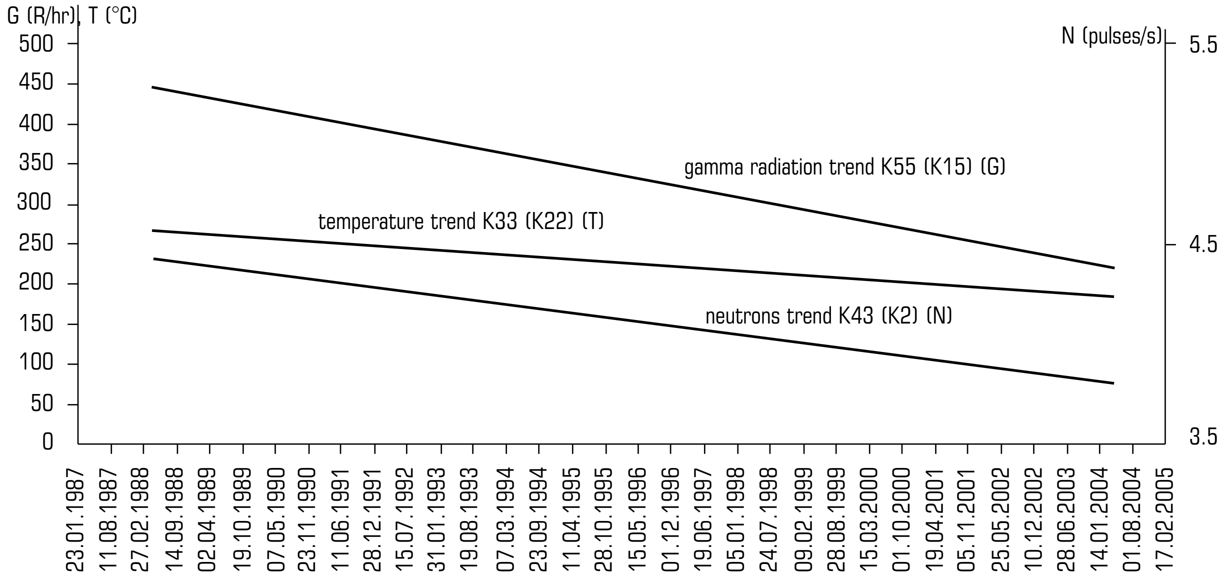


Fig. 9.1.1. Averaged annual temperature, neutron and gamma activity trends in subreactor room 305/2

Unfortunately, the bulk of FCM in the central room has not yet been monitored, and the neutron activity behaviour in the vicinity of the southern roll-back gate has not been investigated. Hence, the nuclear safety of the facility cannot be guaranteed. The subcriticality monitoring subsystem of the computer-aided integrated monitoring system «CIMS», the neutron detectors of which are located according to the principle of simple overlay around the periphery of full volumes of basic FCM piles, fails to meet its purpose because it does not ensure early detection of hazardous changes in subcriticality due to the presence of a local neutron background, and its remoteness from expected zones of critical mass risk.

9.2. Fuel in the industrial site around the Shelter

During the accident and recovery activities, a layer of soil contamination with released radioactivity appeared in the site surrounding the ChNPP Unit 4. It was only partially removed, and the contaminated ground was covered with clean materials. As a result, something resembling a «sandwich» was formed, in which the materials are arranged as follows (from depth of the surface): Primary ground (pre-accident) – active layer – covering materials.

Examination of the active layer is believed to be important due to the following reasons:

– It can contain a significant amount of fuel;

– Active layer movement due to natural factors can lead to contamination of ground water; and

– Converting the Shelter to an environmentally safe system involves activities in the industrial

site facility, which may disturb the active layer; hence, it is necessary to have adequate information about it.

A review of new data has shown that the thickness of the active layer in the local zone is mainly within a depth of 10–30 cm, and its volume (in quantity) is estimated 15,000 m^3.

Using borehole data for analysis, it is assumed that the amount of fuel in the local zone around the Shelter is (0.75 ± 0.25) t.

9.3. Water in the Shelter rooms

One of the main sources of radiation hazard in the Shelter is water. Water affects nuclear safety conditions, leading to changes in the «FCM + water» multiplication systems. In reacting with FCM, water dissolves and transfers radionuclides, which eventually may reach the environment.

«Hot particles» of the aerosol-condensation type determine to a great extent the level of surface contamination of inner Shelter rooms, the greatest contribution to activity being made to date by ^{137}Cs and ^{125}Sb isotopes. Dissolution of these particles contaminated water with caesium isotopes. Oxidised fuel particles (U_3O_8) are the main source of contamination of the «unit water» with fission elements and ^{90}Sr. The chemical stability of oxidised particles, with regard to water, is lower than of fresh fuel (UO_2).

Atmospheric precipitation, man made solutions and condensate, when draining from upper elevations to lower ones, leaches the most soluble concrete components, such as carbonates, bicarbonates, chlorides and sulphates of alkaline metals. Heavy metals also pass into the solution due to corrosion of metal structures. These processes contribute to formation of radionuclide, chemical and phase composition of «unit water». The averaged radionuclide composition and activity of the main water bodies and the Shelter flows is summarised in Table 9.3.1. Part of this activity is concentrated in deposited sludge, and as they dry up in the summer and autumn season, they present a hazard as a source of aerosols.

Table 9.3.1

Average concentrations of radionuclides and uranium in main bodies of the Shelter LRW

Point #	Elevation, m	Room No.	Volume, m^3	Component concentration, Bq/l				
				^{137}Cs	^{90}Sr	Σ Pu	^{241}Am	ΣU, mg/l
6	+2.20	012/16	60 м^3	$6.2 \cdot 10^7$	$9.9 \cdot 10^6$	4000	$1.7 \cdot 10^4$	48
–	+6.00	219/2	10 м^3	$4.0 \cdot 10^6$	$1.0 \cdot 10^5$	–	–	1.1
17	–0.65	017/2	7 м^3	$5.0 \cdot 10^6$	$1.0 \cdot 10^5$	–	–	8.9
18	–0.65	013/2	20 м^3	$4.0 \cdot 10^6$	$0.8 \cdot 10^5$	–	–	1.1
30	–2.60	001/3	270 м^3	$5.2 \cdot 10^6$	$1.0 \cdot 10^6$	360	$4.0 \cdot 10^3$	3.6
31	–0.65	012/5	20 м^3	$6.1 \cdot 10^7$	$8.9 \cdot 10^6$	3100	$1.3 \cdot 10^4$	43
32	–0.65	012/7	10 м^3	$1.3 \cdot 10^8$	$2.2 \cdot 10^6$	4200	$2.8 \cdot 10^4$	110
111	–6.00	0005	5 м^3	$6.8 \cdot 10^6$	$1.0 \cdot 10^6$	1600	$2.0 \cdot 10^3$	5.7

Investigations of the phase distribution of activity have shown that a significant share of LRW activity is concentrated on fine particles and colloids. The solid phase particles, in getting into water bodies at lower unit elevations, settle and form bottom deposits.

For example, the volume of bottom sedimentation in room 001/3 is up to 100 m^3 with a total mass of about 150 t, the gross amount of ^{239}Pu is 430 g, and that of ^{235}U is 860 g [8].

Due to disorganized water flow at low elevations of unit B and DSRV, medium-active LRW accumulate and flow beyond the limits of the Shelter along two main directions: northern and south-eastern [9].

Experimental research has shown that 300 to 900 m^3 of medium-active LRW annually flow out of the northern part of the Shelter in the DSRV room of Unit 3 [9]. The direction and intensity of LRW flow from the south-eastern part of the Shelter is currently being investigated.

The bulk of LRW formed in the northern part of unit B has accumulated in room 001/3. The maximum total volumetric activity of ^{137}Cs and ^{90}Sr in this major water body in 2005 reached $1.8 \cdot 10^{10}$ Bq/m^3; that of $^{240}Pu+^{239}Pu+^{238}Pu$ reached $3.0 \cdot 10^6$ Bq/m3, and the maximum uranium concentration was 28 g/m^3.

The radionuclide and chemical composition of this water body is formed due to low-activity inflow from the cascade wall and high-activity inflow from the northern side of the bubbler pond. Therefore, it would be practical to set up local purification of high-activity LRW prior to its inflow to room 001/3.

9.4. Radioactive aerosols in the Shelter

Air migration of radionuclides from the Shelter is one of the main sources of environmental contamination during normal operation of the NPP, and especially during accidents.

The main pathways of release of radioactive aerosols from the Shelter to the environment are as follows:

- Vent stack 2, into which a channel from the Central Room (the so-called ventilation system «Bypass»); and
- Leakages (cracks, process openings, and hatches) in external structures of the Shelter, whose area, for a maximum estimate of emission has been calculated 120 m^2.

Analysis of results of many years observations has shown [10] that the intensity of release of radioactive aerosols from the Shelter is determined by the combined action of natural and man made factors.

Fig. 9.4.1 shows the behaviour of random emission of radioactive aerosols through openings at higher Shelter elevations from 1992 to October 2005. As a comment on these data, note the following:

1. During 1992-1996, there was an increase of activity release, which changed to a period of small release variations.
2. In 1998, there was an increase of emission activity due to work on reinforcing vent stack.
3. A certain increase in radioactive aerosol activity in 2001 can be attributed to a combination of unfavourable weather conditions (dry hot and windy summer) and repair work being performed on the light roof.
4. Aerosol release from the Shelter is several per cent of the admissible value for a normally operating MW-capacity power unit.

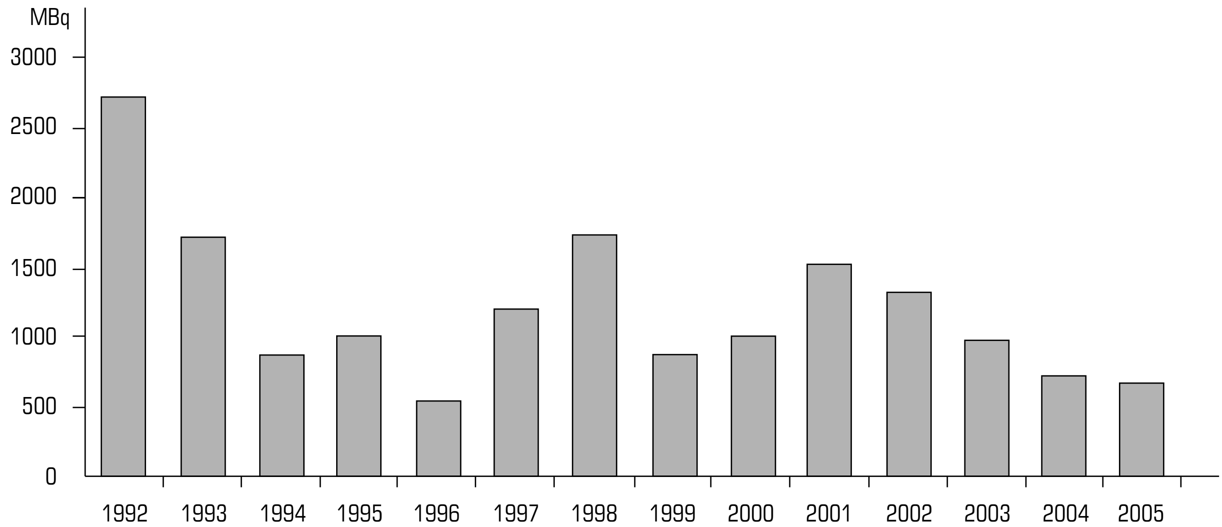


Fig. 9.4.1. Emission of radio aerosols through cracks in the Shelter roof according to data from accumulating flatbeds

The radioactive aerosols released from the Shelter have a wide range of sizes. However, particles with the median aerodynamic activity diameter (MAAD) of 2–6 μm are the most often entrained with air flow discharges. Aerosols of such size have a low rate of gravitational deposition. For example, about 1 hour is needed for particles with a diameter of 10 μm to precipitate by gravity from a height of 50 m. During this time, they will be carried away from the ChNPP to a distance of many kilometres. Therefore, their affect on the radiation situation in the local zone around the Shelter is minimal.

The surface air of the local zone of the Shelter has been monitored for contamination using three suction installations arranged along its perimeter.

The level of air contamination in a specific point of the local zone is a sum of the following natural and man made factors:

- Intensity of entrainment of radioactive aerosols from the Shelter;
- Intensity and periodicity of atmospheric precipitation;
- Weather conditions (temperature, humidity and wind direction and velocity); and
- The character and intensity of work performed in the local zone.

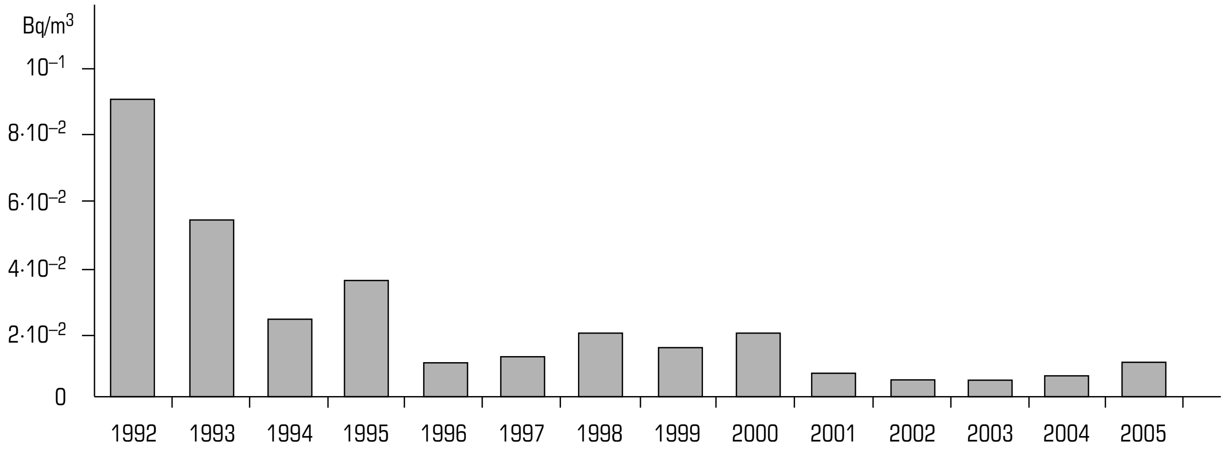


Fig. 9.4.2. Annual average spatial activity of near-ground air in the Shelter local zone according to data from suction installations

The data presented in Fig. 9.4.2 allow us to draw the following conclusions:

1. In 1992–1996, there was an intensive drop in the annual average spatial activity of the near-ground air in the Shelter local zone.

2. Since 1996 and to date, the annual average spatial activity in the local zone have stabilised at about 10^{-2} Bq/m^3.

The maximum air contamination level observed in 2005 was:

– $1.4·10^{-3}$ Bq/m^3 for total alpha-emitters; and

– $8.5·10^{-2}$ Bq/m^3 for total beta-emitters.

In late 1989, a stationary dust suppression system (DSS) was commissioned to reduce the concentration of aerosols in the Shelter and their entrainment to the atmosphere. To date, more than 1,000 tons of dust suppression solutions have been applied, making it possible to significantly reduce and stabilise aerosol entrainment from the Shelter.

Employing dust suppressing solutions with a high concentration of organic components (up to 23%) created a durable protective polymer film on the surfaces being sprinkled. Prior to applying the coating, the magnitude of beta-activity removed from surfaces located next to the western support of the «Mammoth» beam was 12,000–30,000 particles/cm^2·min. After the coating had been applied, this value was 150–1,200 particles/cm^2·min. Hence, the intensity of formation of radioactive aerosols when performing various works was reduced essentially.

9.5. Monitoring of the contamination and the level of ground water

Regular monitoring of ground water contamination in the local zone of the Shelter industrial site was initiated in 1992. Monitoring involves monthly sampling and radiochemical assay of water samples taken from boreholes 1G-6G located in the northern part of local zone below and along the water flow relative to the Shelter. In addition, the groundwater table level is measured twice monthly.

Character of changes of strontium concentrations during 2003–2005; gamma-ray logging, measurement of concentration of ^{238}Pu, $^{239+240}$Pu, ^{241}Am, ^{244}Cm and isotope composition of uranium in water taken from borehole 4G, all these data currently do not provide evidence of LRW leakage from the Shelter to the geological environment (or that it has occurred earlier).

The average groundwater table in the local zone in 2005 was 110.20 to 110.87 m. The maximum level at the beginning of 2005 exceeded the previously recorded maximum (110.61 m in June 2001) for the entire monitoring period since 1998. Furthermore, over the past years there is an evident trend of a rising groundwater table. The correspondence between the average annual groundwater table behaviour and the amount of atmospheric precipitation observed earlier is now not occurring.

9.6. Radiation parameters of the Shelter

9.6.1. General characteristic of the radiation situation in the Shelter's rooms

The exposure rate (ER) in the inner rooms and on the roofs of the Shelter varies widely, and is due to the spatial location of FCM in the rooms and the content of uranium and its fission products in FCM.

Now, Shelter rooms demonstrate the ER values shown in Table 9.6.1

Table 9.6.1

Exposure rate values in examined Shelter rooms

Radiation situation, R/hr	Units				
	Unit «B»	Unit «C»	Unit DRSV	Unit «G» (A–B)	Unit «G» (B–G)
below 0.5	66	17	59	59	140
0.5–1	13				1
1–5	70			6	1
5–10	7			1	
10–50	14				
50–100	7				
100–500	4				
> 500	7				
Inaccessible rooms	126		4	28	7

The Table shows that in the majority of accessible rooms in reactor unit B, the average gamma-radiation exposure rate is less than 1 R/hr.

9.6.2. Radiation situation on the Shelter roofs

After the Shelter was constructed the radiation situation on its roofs depended largely on gamma radiation that penetrated from the inner rooms and contaminated constructions. Over time, the exposure rate dropped significantly due to natural decay of radionuclides and because of an extensive range of deactivation work performed on the roofs. Currently, the exposure rate varies within 0.1–8 R/hr.

9.6.3. Radiation situation on the industrial site

The exposure rate on the territory adjacent to the Shelter is determined by two factors: gamma-radiation of the Shelter itself and radiation from radio-contaminated soils and objects located on the Shelter industrial site.

The most heavily contaminated territory is the closest to the ChNPP Unit 4, so-called Shelter local zone.

Radionuclide contamination of the local zone has a non-uniform pattern. Analysis of the exposure rate chart shows that there is a significant contribution of Shelter radiation from the area of the staircase-elevator unit. The influence of the Shelter on the spatial distribution in exposure rate above the industrial site is illustrated clearly in Fig. 9.6.1.

A sharp increase towards the unit is observed next to the row A. It can be assumed that the cause of this anomaly can be local intensive sources of gamma-radiation located on the roof of the turbine room and the deaerator stack. Therefore, before starting the confinement construction, it would be reasonable to remove or screen off these sources.

9.7. Condition of a building structures

The building structures of the Shelter are a combination of «old» structures of the ruined power Unit 4 and «new» protective structures constructed after the accident. This has led to a unique spatial construction where building structures perform the critical function of protective engineering barriers preventing the release of radioactive substances and ionising radiation into the environment.

The basis of such barriers will be external protective constructions, which were constructed after the accident.

The post-accident condition of the «old» structures of the ruined power unit are characterised by extensive damage of remaining elements and assemblies, and their overloading due to a supporting damaged constructions, equipment and materials used when elimination the accident. The open steel of reinforced concrete structures and metal structures are subjects to corrosion. Such critical defects require continuous monitoring of the condition of these structures, and taking required stabilising measures.

The «new» objects constructed after the accident (protective-isolating walls and the Shelter metal structures) were designed in compliance with construction regulations in effect at that time. However, this group of structures is also experiencing problems with robustness and durability.

Therefore, immediately after the Shelter had been erected, activities were launched to investigate

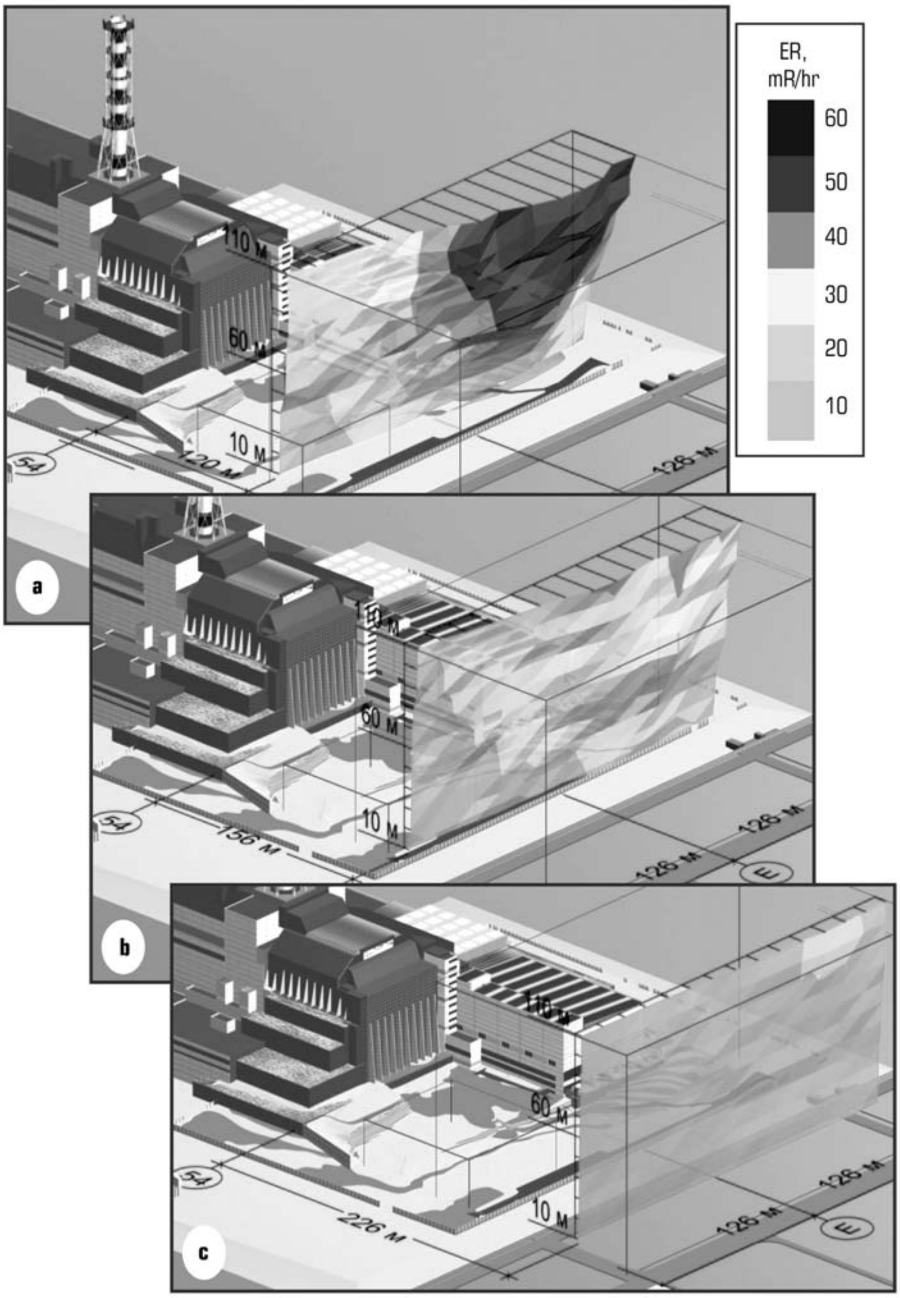


Fig. 9.6.1. Model of gamma field in NSC construction zone (June 2004):
a – section in axis 54 + 120 m; b – section in axis 54 + 156 m; c – section in axis 54 + 226 m

the condition of its building structures. In 1988–1989, projects focused on reinforcing the structures constructed under emergency-condition in the critical zones were implemented. Further regular in-site examinations identified other defects which had to be removed to increase the robustness of structures that affect Shelter safety. In 1998, the supporting frame of the vent stack, where 30 defects were detected, was repaired (Fig. 9.7.1). These efforts were managed by personnel of the Shelter. The work contractor was KSMP «Ukrenergobud». Experts from the USA and Canada delivered technical assistance and consultancy services, and performed general supervision of the project. The vent stack repair was the first international project that enhanced the SHELTER safety.

It is worth mentioning that the examinations performed and the actions taken to reinforce the structure made it possible to ensure trouble-free operation of the Shelter to date.

Since 1998, follow-up activities examining the condition of building structures and their stabilisation are conducted in compliance with the Shelter Implementation Plan (SIP). Within the SIP framework, these activities were carried out in a more systemic and extensive manner, underpinned by the

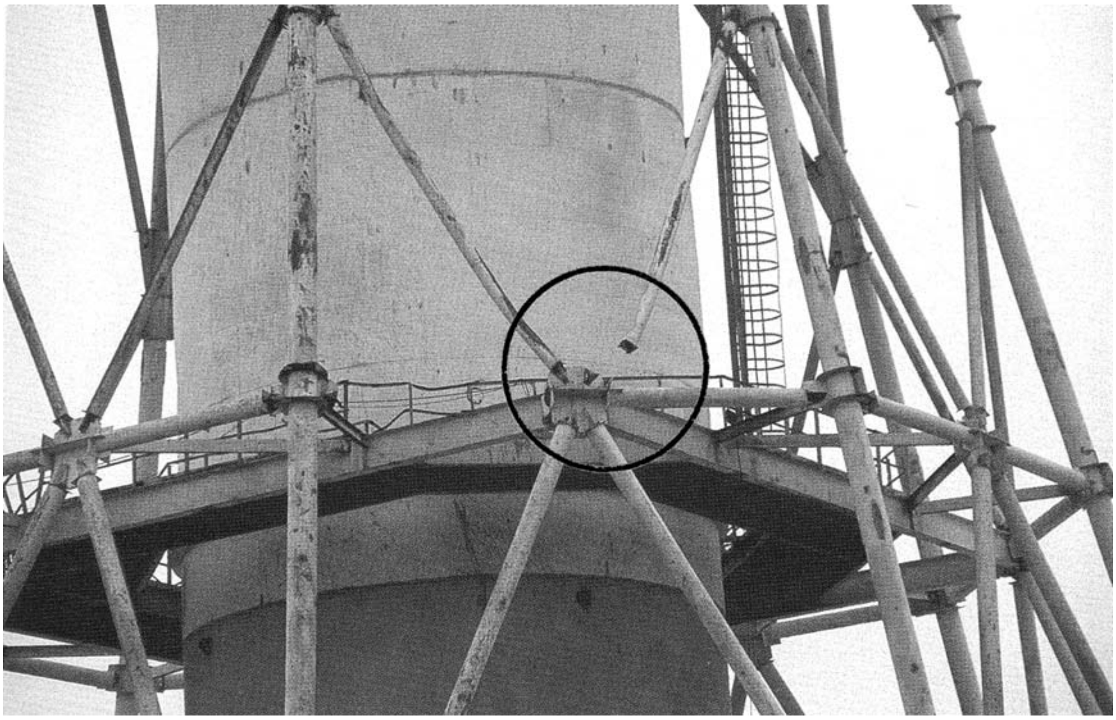


Fig. 9.7.1. Defects in the supporting frame of the vent stack VS-2

(1) classification of all previous information on the condition of structures, (2) new data from in-site examinations, and (3) development of computer models for assessing reliability of structures affecting Shelter safety.

9.8. Strategy of converting the Shelter to an environmentally safe system and the Shelter Implementation Plan

The Shelter Conversion Strategy was developed to identify the basic principles, objectives and strategic lines of activities focused on converting the Shelter to an environmentally safe system, in compliance with the Resolution of the Cabinet of Ministers of Ukraine № 1561 as of December 28, 1996. Taking into account the results of implementation of phase 1 of the SIP, this Strategy was revised and approved by the Interdepartmental Commission on an Integrated Solution of the ChNPP Problem № 2 as of March 12, 2001.

The Strategy has identified the following key directions and phases of the Shelter conversion:

Phase 1 – stabilising the condition of the existing shelter; and increasing the robustness and durability of structures and systems that ensure stabilisation and monitoring of Shelter safety indicators.

Phase 2 – construction of additional protective barriers, primarily a confinement, that would ensure adequate conditions for engineering activities in Phase 3 and the safety of personnel, population and environment; preparatory engineering-technical activities to develop the technology for removing FCM from the Shelter in Phase 3; and developing an infrastructure for Shelter radioactive waste management;

Phase 3 – removing FCM and long-lived Shelter radioactive waste, their conditioning and follow-up storage and burial in radioactive wastes depots according to existing standards; and decommissioning the Shelter.

The Shelter fails to comply with requirements for depots for long-living radioactive wastes. Creating safe engineering barriers for permanent isolation (conservation) of FCM inside the Shelter involves a consideration of dramatic changes in natural systems and unforeseen consequences, in particular, due to the geological conditions of the territory on which the Shelter is situated. Therefore, conversion of the Shelter to an environmentally safe system must provide for removing FCM and high-level wastes (HLW) from the object, converting them to a safe condition, interim monitored storage and burial in deep depots (in stable geological formations).

The timescale of removing FCM from the Shelter should be linked to the program of decommissioning the Chornobyl NPP and the Integrated Program of Shelter radioactive wastes Management.

These programs should provide for accumulating funds, implementing technologies and equipment for removing FCM and HLW, manufacturing containers and re-equipping or constructing premises intended for storing FCM and HLW prior to their removal. Removing FCM and HLW is scheduled to start in roughly 30–50 years, and it should be completed by the time the confinement service life expires.

Shelter Implementation Plan. Objectives and tasks

The objective of the Shelter Implementation Plan (SIP) is implementing immediate actions to convert the existing Shelter to an environmentally safe system. SIP activities shall be financed by the Chornobyl Shelter Fund (CSF) and the State Budget of Ukraine.

The initial budget and the SIP schedule were developed in 1997 in the form of the TACIS Report «Shelter Implementation Plan», and were a basis for concluding an agreement between the G-7 countries and Ukraine on the necessity of executing the workscope specified in the Report with the support of the international community. The Report presents a preliminary implementation schedule (commencement on 01.01.1997 and overall term of 8 years and 8 months) and the budget – USD 758 mln.

The decision on implementation of the SIP was made by the G-7 in Denver in June 1997.

The key procedures for implementation of the SIP are as follows:

- Stabilisation and preparatory activities.
- Safety and auxiliary systems.
- Construction of a new safe confinement.

The entire range of SIP activities comprises 22 tasks involving personnel protection, radiological safety and environmental safety. The basic SIP workscope includes development, construction and commissioning of objects, systems and equipment.

To manage and implement the project SIP provides *three key programme phases*:

- Confirming decisions on stabilising (P1);
- Decisions on the strategy of an optimal containing confinement (P10);
- Decisions on the strategy of removing FCM, which will identify the optimal method and time of removing FCM with a rationale of analysing costs and implementation feasibility (P8).

The phase of pre-project studies within the framework of the SIP was completed in 2002, and a transition to the development phase and performing the actual workscope in line with the SIP took place.

9.9. Stabilisation of building constructions

The aim of stabilising the building structures is to reduce the probability of potential accidents due to destruction of building structures that perform the function of containing radioactive substances and ionising radiation within the limits of the existing Shelter.

This goal shall be achieved by developing and implementation of a range of actions that would ensure acceptable reliability indicators of building structures that are critical for Shelter safety.

During 2002–2003, the CBS Consortium comprising Ukrainian organisations, in particular, the Kyiv Institute «Energoproekt», R&D Institute for Building Structures, and the Institute for Problems in Safety of Nuclear Power Plants, developed and approved, with Ukrainian regulatory bodies, an execution plan that provides for executing stabilisation measures for such constructions and assemblies.

Since late 2004, this plan is being implemented by construction organisations of Ukraine and Russia who set up the «Stabilisation» Consortium. Before this, work commenced to build infrastructure objects that are instrumental for effecting stabilisation.

Among the range of stabilisation efforts, the most challenging one is stabilising the western fragment of the Shelter.

The concept of stabilising this fragment consists of building two spatial metal towers to the west of the countermeasure, which shall be constructed on solid reinforced concrete foundations and interconnected with spatial modular frames at three elevations (Fig. 9.9.1).

Such a solution will relieve the load on the damaged skeleton and wall of the western fragment and transmit it to the newly constructed tower structures. In addition, a system of special supports located at three elevations will ensure that the new structures will bear the horizontal loads from the western fragment in the «East-West» direction in case of a seismic event. /Hence, conditions are created to secure the existing position of the wall along axis 50 and of the abutting carcass, and to prevent their further displacement in the western direction, otherwise they could collapse./

Performing the planned scope of construction work in stabilising the building structures in the prevailing radiation-hazardous conditions of the Shelter is a complex engineering task. Firstly, it concerns the problem of ensuring safety of personnel assigned to this work as well as maintaining the required and sufficient level of radiation and environmental safety of the Shelter itself. To solve this problem, documents were drawn up, they substantiate the safety of implementation of stabilisation measures.

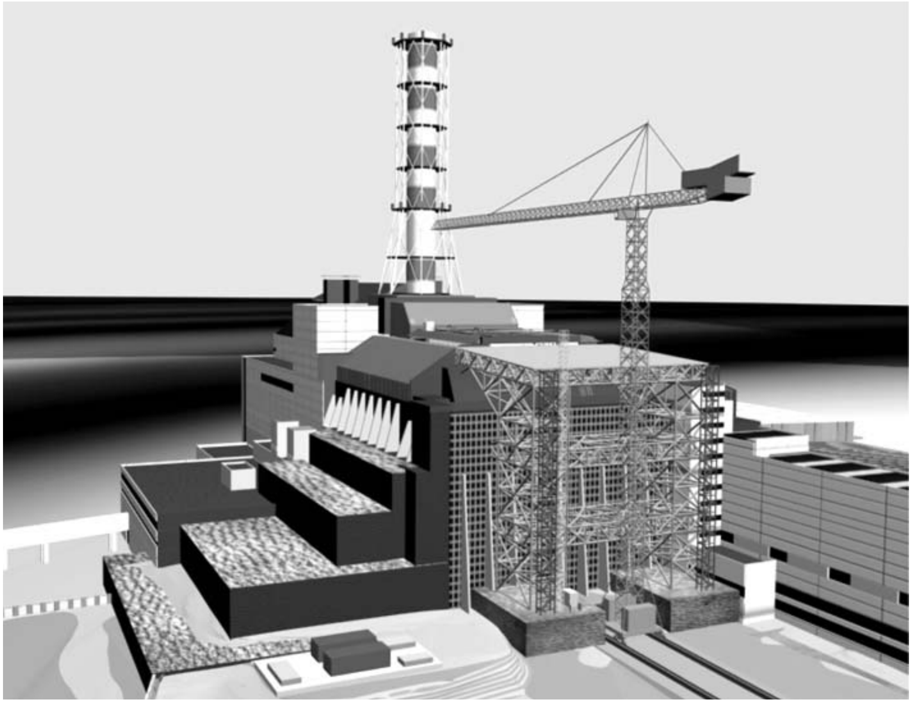


Fig. 9.9.1. Stabilising the western fragment of the Shelter. Diagram of reinforcement metal structures

A range of organisational, radiation-sanitary and engineering actions was developed and substantiated to ensure radiation safety of personnel. In executing stabilisation, the formation of roughly 350 t of low-activity solid radioactive waste (SRW) is expected. SRW will be buried in the subsurface «Buriakivka» repository located in the exclusion zone. Should HLW be identified, it will be transferred to interim storage in the disposal facility at the industrial site of the Chornobyl NPP.

A review of executed and planned stabilising activities has indicated that an additional environmental impact will occur due to the release of radioactive substances to the atmosphere and their subsequent redistribution in environmental components. Environmental impact assessment has shown that, under normal work of performing conditions, the additional introduced amount of radioactive substances will make up less than one per cent of the existing total contamination of the exclusion zone. Analysis of impacts related to potential accidents, which could occur during stabilisation activities, has shown that the maximum additional soil contamination will be observed at a distance of 1 km, and will not exceed 130 kBq/m^2 or 2% of the existing contamination level. Beyond the exclusion zone boundary, the additional contamination due to an accident will be about 4% of the existing level. The individual effective dose from potential exposure of the population beyond the exclusion zone will not exceed 1mSv, which is lower than the governments' permissible limit for taking urgent countermeasures.

Stabilisation efforts are considered justified after having taken into account both the additional contamination of the surrounding area that may occur from an accident during stabilisation activities. The probability of such an accident is several orders lower than the probability of Shelter collapse if it is not reinforced.

The construction work in stabilising the Shelter is scheduled to be completed by late 2006. The collective exposure dose of personnel is expected to be about 40 man-Sv.

9.10. Development of a New Safe Confinement

9.10.1. Objective of creations and functions

Creation of a New Safe Confinement (NSC) is the key phase in preparing for converting the Shelter to an environmentally safe system.

According to the provisions of the Law of Ukraine «On General Principles of Further Operation and Decommissioning of the Chornobyl NPP and Converting Ruined Unit 4 of this NPP to an Environmentally Safe System», construction the NSC should achieve the following objectives:

– Ensure protection of personnel, population and the environment from the impact of nuclear and radiation hazardous sources related to existence of the Shelter;

– Creating conditions for performing work in converting the Shelter to an environmentally safe system, including removal of nuclear fuel and FCM wastes; disassembly/reinforcement of unstable Shelter structures; and management of radioactive wastes.

These objectives shall be achieved by ensuring that properties of the NSC structure and its systems and elements will allow them to perform certain functions.

One of the key functions is containment. Protection of man and the environment is achieved, primarily by preventing the spreading of radioactive substances and ionising radiation beyond the NSC limits.

This function shall be performed under the normal operation conditions, derangement of normal exploitation, in emergencies and during accidents, and shall be ensured by the following:

– Integrity of protective structures of the NSC during a prolonged operation period of no less than 100 years;

– Prevention of collapse of unstable structures of the Shelter by disassembling or reinforcing them for a period specified by conditions of safe NSC operation;

– Limitation ingress of atmospheric precipitation in the structure;

– Protection of the hydrogeological environment from contamination with radioactive substances inside the NSC; and

– Limitation of spread of radioactive substances inside the NSC.

Other NSC functions are those of technological support and physical protection. The function of technological support is implemented by allocation and functioning of systems and components, as well as by providing adequate conditions required for the following:

– normal NSC operation;

– disassembly/reinforcement of unstable Shelter structures;

– management of radioactive waste;

– future removal of fuel-containing materials (FCM).

The function of physical protection consists of protection of nuclear and radioactive materials inside the Shelter.

However, this concept was systematically reviewed in details starting from 1998 when the SIP was implemented.

An International Consortium «Chornobyl», conducted an in-depth review of all previous engineering solutions, formulated the conceptual project criteria and requirements to the NSC, and offered a strategy of its development. The consortium comprised the Washington Group International, Inc (USA), BNFL Engineering Ltd (Great Britain) and Ukrainian organisations: Kyiv Institute «Energoproekt» (KIEP), R&D Institute for Building Structures (RDIBK) and the Institute for Problems in Safety of the NPP (IPBNPP).

Subsequently, these options were reviewed by independent Ukrainian experts and the International Consultancy Group, preference was given to the project called «ARCH».

In 2003, an International Consortium comprising Bechtel International Systems (the USA), Electricite' de France (France) and Battelle Memorial Institute (the USA), with participation of KIEP, RDIBK and IPBNPP, developed a conceptual project of the NSC, which key engineering solutions and safety justifications are given below.

9.10.2. NSC engineering solution

With the aim of its development and functions to be performed, the conceptual project has identified the key objects of the NSC:

– basic structure in the form of a protective structural shell;

– engineering building located on the western side of the NSC; and

– additional structures and buildings (sewage pumping station, check points for personnel, automobile transport, etc).

The protection shell shall be designed as a metal arch-type structure with end walls. The arch structure will cover the main part of the Shelter, except small areas of the deaerator stack and the turbine room, which will protrude outside through the western end wall.

The physical dimensions of the shell are as follows: length – 257.44 m, width – 150 m, and height – 108.39 m. The general view of the NSC is shown in Fig. 9.10.1.

The design life period of the NSC (no less than 100 years) shall be ensured by the following:

– Design-accounted extreme loads and influences in compliance with existing regulatory documents;

– Usage of materials with increased corrosion resistance with account of radiation factors;

– Identifying an optimal structure operation regime; and

– Design solutions that will ensure maintainability of separate structure elements.

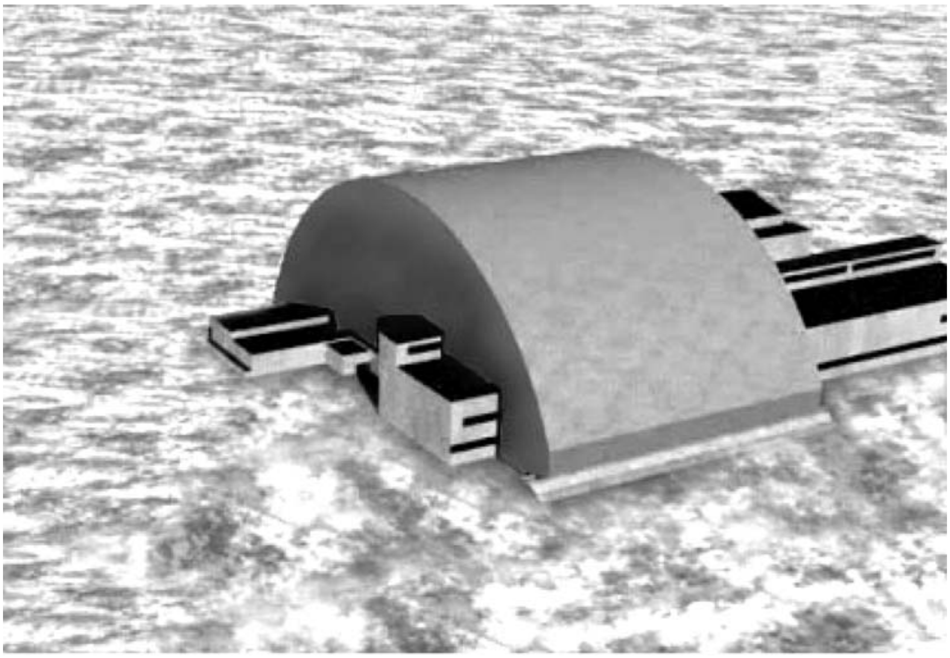


Fig. 9.10.1. NSC in design position

9.10.3. NSC systems

The NSC shall provide for the following key systems that will ensure its operation:
– crane equipment with a set of technical means for disassembling unstable structures;
– ventilation;
– dust suppression by means of a mobile unit;
– deactivation;
– water supply and sewage;
– heat supply and air conditioning;
– integrated control system;
– electric power supply;
– communication and closed-circuit TV;
– fire safety systems;
– physical protection; and
– management of solid and liquid RW.

The nuclear safety monitoring system and the FCM condition monitoring system were not developed in the conceptual project. These issues will be resolved within the framework of other projects.

The issue of physical protection during construction work, tied to the existing ChNPP and the Shelter physical protection systems, shall be reviewed at the following design stages.

9.10.4. Management of radioactive wastes

Construction and further operation of the NSC are closely linked to radioactive wastes, including FCM management. This activity has its specific features at each stage: NSC construction, disassembly of unstable Shelter structures, and future removal of the bulk of FCM and other radioactive wastes.

Engineering solutions on radioactive wastes management during NSC construction, which were suggested in the conceptual project, are based on the following prerequisites:

– Maximum usage of the existing radioactive wastes management system at the ChNPP and in the exclusion zone;

– Account of scheduled actions on improvement of the existing system, which will be effected within the framework of an integrated program for radioactive waste management at the ChNPP;

– Monitoring and inventory of nuclear materials will be performed using the existing ChNPP system;

– FCM management is the prerogative of the ChNPP, and the NSC subcontractor manages all other radioactive waste;

– Radioactive wastes shall be removed only from the construction work areas. For all other radioactive wastes, including that localised in the man made layer on the territory adjacent to the

Shelter, there shall be options for their immediate removal at the next stage of converting the Shelter to an environmentally safe system.

During construction, the bulk of radioactive wastes will be formed during disassembly or dismantling of different objects found in the construction zone, as well as during excavation work at the sites of foundations of the new NSC structures.

The total amount of radioactive wastes during NSC construction is predicted to be roughly 110 000 m^3. The bulk of radioactive wastes will fall into the category of low-activity wastes, and a significantly lesser amount (about 3000 m^3) will be intermediate-activity wastes. It is expected that the amount of high-activity radioactive wastes (HRW) will be roughly 120 m^3.

The general scheme of radioactive wastes' management consists of two sorting levels:

– Primary sorting in sites of wastes formation to identify FCM and separate remaining wastes by kinds of materials (metal, concrete, and others) and physical size (large and small-size);

– Secondary sorting in a specially equipped area to separate wastes into that to be buried, and that which can be used for repeated filling of pits where foundations are constructed.

The ChNPP's responsibility shall be organising storage of HRW in existing storage facilities at the plant industrial site.

Radioactive wastes will be formed as a result of disassembling unstable structures of the Shelter. The total amount of such wastes may reach roughly 5,000 m^3. To manage such radioactive wastes, the conceptual project provides for a technology comprising fragmentation, sorting, deactivation, sealing in containers, and interim storage inside the NSC.

The conceptual project did not consider the issue of future management of the bulk of FCM and other radioactive wastes, which will be formed at the next stage of converting the Shelter to an environmentally safe system. It is assumed that availability of main hoisting equipment and large spare industrial space after unstable Shelter structures have been disassembled will create adequate conditions for this activity. The validity of this statement shall require justification at the stage of NSC contractor design.

9.10.5. Providing of nuclear safety

Maintaining nuclear safety when erecting and operating the NSC involves creating and/or maintaining conditions focused on preventing a self-sustained chain reaction (SCR). An SCR can occur when nuclear-hazardous FCM compositions in the Shelter, as well as those that can be formed in the event of non-controlled displacement of FCM, are flooded with water.

During NSC construction and disassembly of unstable structures the nuclear safety condition can be potentially affected by the following factors:

– Creating additional pathways and increasing water inflow to nuclear-hazardous FCM aggregations;

– Disturbing the function of monitoring the FCM condition and maintaining FCM in the subcritical state;

– Uncontrolled displacement of FCM (due to collapse of Shelter structures) involving formation of new nuclear-hazardous compositions.

To eliminate the risk of occurrence of these adverse factors, the conceptual project provides for specific organisational and engineering actions. In general, while construction of the NSC taking into account projected measures, nuclear safety will maintain at a level not lower than that at the current Shelter operation stage. During disassembly work (after the NSC has been commissioned) the nuclear safety level will be significantly enhanced.

9.10.6. Providing of radiation safety

Actions on providing radiation safety were developed in the conceptual project taking into account that NSC construction and operation will be carried out as an activity with open sources of ionising radiation.

The scheduled basic organisational, radiation-sanitary and engineering radiation protection measures at the stage of confinement construction differ slightly from similar measures taken during stabilisation of the Shelter building structures.

The collective effective dose received by the personnel while construction of the NSC, which was preliminarily assessed in the conceptual project with account of implementing the measures suggested, will be up to 250 mSv. This assessment will require rectification at the contractual design stage.

After the NSC has been constructed and commissioned, conditions will be created for enhancing the radiation protection level. In particular, the majority of technological operations of disassembling unstable Shelter structures are expected to be performed using remote-controlled equipment. Effective methods of stationary and mobile screening will be implemented. Functioning of the following NSC

systems will ensure a minimal radiation impact on the personnel: ventilation, dust suppression, deactivation and others.

Besides developing radiation protection measures for conditions of normal execution of scheduled work, when personnel exposure is considered as an on-site condition, the conceptual project also reviewed the option of potential irradiation of personnel and the population in case of a possible critical event (accident). The conceptual project suggests organisational and engineering measures for reducing the probability of occurrence of critical events as well as elimination of the possible radiation consequences.

9.10.7. Assessment of an environmental impacts

The conceptual project has performed an environmental substantiation of the necessity of construction of the NSC by comparative analysis of radiation environmental impacts due to collapse of the Shelter for two different cases: no confinement and availability of a protective confinement.

Those most radioecologically sensitive environmental components were identified, such as soil, water and the atmosphere. Analysis has shown that, in the case of collapse of the Shelter without a confinement, additional soil surface contamination on the exclusion zone boundary will be within 30 to 100% of the current levels. Similar contamination due to collapse of the Shelter inside the NSC will be lower by an order, and shall not exceed 10%.

Taking into account simulations of the impact on surface and ground water, the conceptual project has concluded that the environmental risk of construction of the NSC is significantly lower than the risk of collapse of the Shelter if the NSC is not constructed.

9.10.8. Unsolved problems

The conceptual project as a whole demonstrated the possibility of achieving the objectives of construction of the NSC. The Cabinet of Ministers of Ukraine, in its Resolution № 443-p as of July 5, 2004 has approved the conceptual project of the confinement. At the same time, the Resolution emphasises the necessity of taking into account the recommendations of the Central Service of «Ukrinvest-ekspertyza» when development of the NSC construction project.

The main unsolved problems at the stage of conceptual design are as follows:

– Ambiguity of certain project criteria and requirements to the NSC construction and systems;

– Absence of engineering solutions on FCM management at the next stage of converting the Shelter to an environmentally safe system, which should comprise collection, conditioning and supervising storage of the FCM bulk;

– Inadequate interfacing of the existing Shelter and the ChNPP systems with new NSC systems, especially with regard to a different terms of their service;

– No analysis of robustness and durability of the Shelter building structures that will be integrated into the system of NSC protective structures; and

– No prognosis on changes in NSC radiation parameters at all stages of its functioning (dose rate, contamination of structures' surfaces, and others).

The current status of activities in creating the NSC are the commencement of preparatory work at the future construction site, as well as putting out a tender for identifying a Subcontractor for designing and building the confinement.

Design activities are scheduled to commence in 2006. Construction of the NSC is scheduled to be completed no earlier than 2010.

9.11. Status of implementation of the SIP program at the Shelter

In early 2005, SIP entered its final stage. All key infrastructure facilities in the ChNPP site and programs (radiation protection, labour safety, medical and biophysical monitoring, personnel training, and emergency response) have been completed. The facilities and programs specified will ensure adequate protection of personnel during the current construction work, the scope of which shall increase significantly in the current year. Part of the infrastructure of the Small Construction Base has been commissioned, and is being employed by the stabilisation subcontractor. Commissioning the full scope has been scheduled for early November.

Completing of all contract activities is scheduled for late 2006. After these activities have been completed, one of the key risks – the Shelter collapse – will be eliminated. The key engineering solutions on stabilisation have been considered in section 9.9.

In October 2003, a contract was signed with the Ansaldo Company (Italy) to develop a computer-aided integrated monitoring system (nuclear, radiation and seismic safety, and monitoring the condition of building structures). Certain technical problems have arisen in the course of implementation the contract. The Customer and the Subcontractor have approved a revised project workscope and

schedule to resolve these problems. For today, the engineering design has been completed and approved with regulatory agencies. With account of the technical revisions approved, contract completion has been scheduled for February 2007.

The Alsthom consortium has developed a contractor design for the access monitoring and physical protection system. The project has passed appraisal, and construction work has commenced. Its completion is scheduled for February 2007.

A conceptual project for the fireproofing system has been developed and approved. A pre-tender meeting has been held and a design tender has been announced. The bidders are drawing up their tender proposals.

In May 2004, a contract was signed to develop an integrated Shelter database. The contracting parties are a consortium comprising IBS (Russia) and the Chornobyl Centre for Nuclear Safety Problems, Radioactive Wastes and Radioecology (Ukraine). The IOSDB system project has been developed, and the first version of the engineering design has been presented. IOSDB has been scheduled for commissioning in March 2006.

The emergency dust suppression system (Task 11) was excluded after the analysis had shown that high doses of ionising radiation during its implementation and operation will cancel any benefits. At the same time, to reduce aerosol dust release during operation and/or in event of potential collapse of the Shelter, the current dust suppression system has been upgraded and extended by employing new compounds with an increased content of dry residue. This allows create a durable film coating that prevents dust. The local dust suppression system is expected to be commissioned in the first half of 2006 according to the results of the «Safety Appraisal».

To prevent uncontrolled flow of radio-contaminated water from the Shelter rooms at the lower elevations to the rooms in Unit 3, according to Program Decision P6, a contract was concluded in March 2004 to develop a system for discharge of water from room 001/3 Shelter to the tank BTV DSRV in Unit 3. After the water will be discharged to monitored storage conditions, it will be analysed and characterised to identify options of mandatory follow-up actions. Presently, after the regulatory agencies had reviewed the «Project criteria for the water discharge system», the contract was suspended due to the requirement of the State Agency for Nuclear Governance (SANG) that the water can be discharged only after the Shelter water treatment system and a system for managing radioactive wastes, that will be formed by such treatment, have been commissioned. During joint negotiations with the SANG of Ukraine on issues concerning Shelter water management, a resolution was approved that it is necessary to develop a conceptual engineering solution on radio-contaminated water management at the ChNPP site.

The solution being developed shall demonstrate the entire process of Shelter LRW management while implementation of stabilisation measures and other SIP projects, including:

- Current and future sources of LRW occurrence;
- Promising plants for primary purification of LRW from organic substances, surface-active substances and transuranium elements;
- interim LRW storage facilities;
- facilities (bays) for solidification and packaging of primary purification products;
- sites for interim storage of solid wastes;
- follow-up water treatment after primary purification in the current ChNPP facilities or in those designed within the framework of different projects; and
- final burial of LRW treatment products.

This conceptual solution has to be developed by late 2005. After this, a decision will be made on financing required LRW management facilities.

Within the framework of performing preparatory activities for NSC construction:

1. An EBRD «do not object» decision has been received to hold a tender with one bidder to disassemble the pioneer wall berm. On 19.07.2005, a contract was signed with the «UKRTRANSBUD» corporation on delivering engineering services (development). Presently, project and engineering documentation (POS, PPR) is being drawn up and approved with the Customer. Contract implementation is scheduled for December 2006.

2. Tender documentation is being completed for developing the site for NSC construction (cleaning, grading and excavation work for laying NSC foundations).

Key schedule phases:

- Tender completion and signing the contract – March 2006.
- Developing project documentation – June 2006.
- Commencement of construction work – July 2006.
- Completing all activities – June 2007.

As regards Task 14, it has been admitted that, conducting full-scale FCM profiling, with provisions

for sampling and creating hot chambers, will involve high dose rates and extensive labour input and, hence, based on ALARA principles, this is not advisable. Decision P7 has fixed the necessity of developing a program for monitoring FCM behaviour with time prior to, and during, removal of FCM. Taking into account that removing FCM requires a sufficiently long period of time, the Program for monitoring the FCM condition should allow for monitoring the FCM condition, and provide for an option of taking required action to constrain an adverse course of events. The long-term behaviour of FCM, which was investigated by experts of the RSC «The Kurchatov Institute» and IPS NPP NASU, has defined the requirements to the program of monitoring FCM behaviour.

On the basis of the document «Strategy of removing FCM and RW management. Follow-up action plan» it is planned to develop and implement within the SIP a program for monitoring FCM behaviour, to install an FCM behaviour monitoring system, as well as to develop preventive measures that are recommended to eliminate the consequences of adverse changes in FCM condition whose practical implementation is not covered by the SIP.

The previous strategy of FCM management, which was specified by Decision P7, proposes to postpone decommissioning until a final storage facility has been built, i.e. for an indefinite period of time, and, in the meantime, to continuously monitor the FCM condition. To develop the Strategy of FCM removal, it was found inexpedient to develop the previously suggested prototype of the FCM removal technology with account of the cost and schedule of its implementation because this activity requires significant capital and dose outlay. Therefore, the International Coordination Group of experts did not recommend continuing activities along these lines. Hence, in building the NSC, no account will taken of initial data for realising the key objective of SIP Phase 2 – preparation for FCM removal.

Conclusions

In Ukraine, and at an international level, unparalleled efforts have been taken to develop an integrated approach to resolve the problem of converting the Shelter to an environmentally safe system. The climax of all these efforts was the adoption of the Shelter Implementation Plan (SIP). The key objective of all conversion activities was: «... protecting personnel, the population and environment from the hazardous impact of nuclear and radioactive materials by their removal, isolation, and burial». The purpose of the confinement, as the final step before actually starting to convert the Shelter to an environmentally safe system, was defined in the Law of Ukraine as of April 26, 2001 «On Introducing Revisions to Certain Laws of Ukraine due to Decommissioning the Chornobyl NPP». The Law states that the «Confinement is a protective structure including a range of process equipment for removing materials containing nuclear fuel from the ruined ChNPP Unit 4; management of radioactive wastes, and other systems, which is intended for performing activities to convert this power unit to an environmentally safe system, and ensure safety of personnel, the population, and the environment».

Implementation of SIP projects is not only long behind schedule, but has also critically departed from the prime objective. For instance, the technical requirements to developing a new safe confinement specify that «the following shall be provided:

- Confinement *properties that are marginally required to isolate it from the environment*; and
- Availability inside the new confinement of *marginally-required* technological space and equipment for primary management of radioactive materials and *wastes*».

Hence, inadequate technical capabilities designated for the future confinement; and refusal to develop the strategy, technology and prototype for FCM removal is a direct violation of both the Law of Ukraine and the SIP.

Twenty years have passed since the accident at Unit 4 and 8 years since SIP activities commenced. Unfortunately, from all the activities aimed on enhancing safety and converting the Shelter, only dust suppression system upgrading has actually been completed, and building structures stabilisation work is underway, i. e. the SIP schedule has been delayed. The underlying reason for the delay is the ack of coordination between regulatory, certification and administrative procedures; ineffective management group performance; and absence of Designer and Scientific Supervisor.

To expedite the activities to reasonable limits, the following is required:

- To revive the activities of the Ukraine-EBRD Joint Committee with the aim of addressing emergent problems rapidly and checking implementation of SIP activities;
- To assign a General Designer and Scientific Supervisor. The decision on setting up these job positions has been made at the state level;
- To bring remuneration of the Project Management Group staff in accordance with the SIP implementation status;
- To initiate activities in developing FCM management process procedures.

10. CHNPP: MAIN ASPECTS OF DECOMMISSIONING

More than 5 years ago, on December 15, 2000 the last running power-generating Unit 3 of the ChNPP was closed in accordance with the «Memorandum on Understanding between the Government of Ukraine and the Governments of G7 Countries and Commission of the European Union on decommissioning of the Chornobyl NPP».

The first two power units of the Chornobyl NPP were closed:

- 1st power unit – on 30.11.1996
- 2nd power unit – on 11.10.1991

After the final closure of the power unit, Chornobyl NPP stopped being a power generating plant and became the first Ukrainian NPP stepping on the path of decommissioning. To nuclear plants and facilities for radioactive wastes and nuclear fuel management situated on the Chornobyl NPP site, which are to be decommissioned belong:

- 1st, 2nd and 3rd power units;
- the first spent nuclear fuel storage facility SNFSF-1, operated by «wet» storage technology;
- temporary storage facilities of liquid and solid radioactive wastes.

Other facilities of the power plant are also to be decommissioned: additional, electrical, hydraulic units, the cooling pond.

There is the fourth power unit destroyed in the non-project accident (the Shelter), which has a nuclear hazardous status and is an interim facility of non-organized radioactive wastes at the Chornobyl NPP site. The measures taken at the Shelter are qualified as converting it to an environmentally safe system.

By the results of primary measures taken in the period to 2010 it is envisaged:

- decommissioning of the 1st, 2nd and 3rd power units;
- development of radioactive waste management system at the Chornobyl NPP;
- completion of building and putting into operation a confinement over the Shelter.

10.1. Perspectives of solving the problem

10.1.1. Preparation for and decommissioning of the ChNPP

Decommissioning of the Chornobyl NPP is supposed to occur stage-by-stage by the following strategy chosen on the conceptual level:

1) discontinuance of operation: completion phase of operation of power units resulting in nuclear fuel discharge and its relocation to the spent nuclear fuel storage facility for long-term storage – SNFSF-2;

2) final closure and preservation of reactor units;

3) removal of reactor facilities (for the period, within which the natural reduction of the radioactive radiation level to admissible levels should occur);

4) dismantling of reactor facilities.

This variant of the strategy of decommissioning of the Chornobyl NPP meets the requirements of national norms and regulations and international standards.

At the stage of discontinuance of the Chornobyl NPP operation, the following measures are taken:

1) maintenance of power units No. 1, 2, 3 in the safe conditions;

2) development of infrastructure for spent nuclear fuel and radioactive wastes management at the Chornobyl NPP site:

- spent nuclear fuel storage facility No. 2;
- liquid radioactive wastes treatment plant;
- industrial complex for solid radioactive wastes management;

3) preparation for nuclear fuel discharge from power units (including measures for safe management of defective spent nuclear fuel);

4) drafting and approval of the documents required for licensing before the first stage of decommissioning of power units and for detailed scheduling of work:

- a program of decommissioning of the ChNPP power units 1, 2, 3;
- programs and projects of implementation of the stage of final closure of the first line and the Chornobyl NPP power Unit 3;
- projects of decommissioning the cooling pond;
- projects of upgrading of the infrastructure facilities (electric power networks, water supply, heating, fire extinguishing, telecommunications etc.);

• a program (project) of other programs (projects), aimed at reducing financial expenses for decommissioning;

5) discharge of potentially hazardous substances (inflammable and chemically hazardous materials, lubricants etc.) from systems, equipment and piping of power units, which were decommissioned and are not supposed to be used again;

6) final closure of separate systems and elements of power units;

7) organization and technical measures for control, operation, maintenance, repair of systems, which are supposed to function later and provision of safety control;

8) discharge of nuclear fuel from power units and spent nuclear fuel storage facility SNFSF-1;

9) set up of sites for fragmentation of large-size equipment and deactivation decontamination plants, decontamination of elements of the systems, equipment, piping and premises of power units;

10) inspection of premises, equipment and piping, and calculation to predict specification and volumes of radioactive wastes which will be produced in the future during decommissioning power units;

11) discharge of liquid radioactive wastes accumulated during the operation and partial discharge of solid radioactive wastes from power units;

12) partial dismantling of the equipment out of the reactor.

After the final closure of the plant, complex of measures on preparation for decommissioning of the ChNPP were taken. Technical documentation for the stage of operation discontinuance, programs of discontinuance of operation of power units 1, 2, 3, Concept, National Decommissioning Program, Integrated program of radioactive wastes' management were drafted.

After the Chornobyl NPP closure, the main regulatory and legal problems of work financed from the Ukrainian state budget were solved.

Among the most important «physical» measures on preparation for decommissioning taken for 5 years, the following are worth mentioning:

– Complex Engineering and Radiation Inspection (CERI) of all three power units;

– scientific research to determine conditions of equipment of reactor plants and conditions of building constructions of Unit 3;

– removal 168 conduits (out of 355 registered in inspection bodies) and 583 equipment units (out of registered 1470 units) out of the registry;

– oil discharge from the equipment of the powerhouse hall at all three units and the oil system of main circulation pumps of power Units 1, 2, 3;

– reconstruction and modernization of the equipment in 28 systems remaining in operation at next stages of decommissioning of the ChNPP.

However, before spent nuclear fuel is discharged from power units, the work on decommissioning of main systems and equipment of reactor plants cannot be performed.

After spent nuclear fuel is discharged from power units and SNFSF-1, no nuclear unit will remain at the ChNPP site and the plant can proceed decommissioning work.

At the first stage of decommissioning – the stage of final closure and preservation of reactor units, the following main measures should be taken:

1) dismantling of systems and elements of units out of the reactor which do not effect safety and are not required at follow-up stages;

2) consolidation of barriers preventing follow-up of radioactive substances to the environment;

3) safe preservation of parts of the units which are not dismantled;

4) provision of conditions for interim controlled storage of radioactive substances at units;

5) collection and conditioning of radioactive wastes, produced during the above operation, and transformation of the wastes to the specialized enterprises.

At the stage of conditioning of reactor units such main measures will be taken:

1) operation of systems and elements ensuring safe storage of radioactive substances, which are contained in preserved units;

2) periodic inspection of preserved unit conditions.

At the stage of dismantling of reactor units, systems and elements, which are to be controlled as ionizing radiation sources, will be dismantled, removed and located on the territory of the units in radioactive wastes' storage facilities.

However, to fulfill all these tasks in scheduled terms, first of all, the infrastructure for spent nuclear fuel and radioactive wastes management must be developed at the Chornobyl NPP site.

According to the Complex Program of decommissioning of the Chornobyl NPP approved by the Resolution of the Cabinet of Ministries of Ukraine No. 1747 of November 29, 2000, facilities related to decommissioning of the Chornobyl NPP are built at the industrial site of the Chornobyl NPP by inter-

national technical assistance programs. These are three big projects, two of which are administered by EBRD (implemented at the cost of the Nuclear Safety Account of EBRD):

- spent nuclear fuel storage facility – SNFSF-2,
- liquid radioactive wastes treatment plant – LRWTP, and a project realized by TACIS program:
- industrial complex for solid RW management – ICSRWM.

Lag from initial terms of realization of all projects is a few years: from 3 years in ICSRWM, up to 5 years in LRWTP, 6 years in SIP and 8 years in SNFSF-2. Taking into account changes of volumes and terms of work implementation under the supplementary contracts, the lag from agreed schedules is from 1 year (ICSRWM) to 5 years (SNFSF-2).

The analysis of implementation of international projects required to decommission of the ChNPP and convert the object «Shelter» to an environmentally safe system, revealed a number defects, both of objective due to the unique character and content of work, being performed at the Chornobyl NPP site, and subjective, due to, in particular, failings of management of international projects.

Construction of liquid radioactive wastes treatment plant (LRWTP)

LRWTP is a complex enterprise providing for discharge of liquid RW from storage reservoirs, reception, preparation, solidification, packing and interim storage (up to 280 and 200-liter barrels) of conditioned LRW.

To locate LRWTP (agreed with the Ministry of Environmental Safety and approved by the Resolution of the Ministry for Energy of Ukraine No. 14 of 15.01.1999) a site within the guarded perimeter of the ChNPP, next to the liquid wastes storage facility (LWSF) of the first line was chosen. The plant was connected to LWSF storage reservoirs with a process piping system laid in the existing closed overpass.

Plant capacity by emitted LRW is 2500 m^3/year. The projected term of LRWTP operation is no less than 20 years.

The final product (solid liquid wastes as cement compound) is packed in 200-liter barrels. The location of long-term controlled storage of conditioned RW will be LOT-3 of the Industrial complex for solid radioactive wastes management. Barrels with final product will be transported in steel-and-concrete.

LRWTP project was approved by the Resolution of the Cabinet of Ministries of Ukraine No. 105p «On approval of the project «Chornobyl NPP. Liquid radioactive wastes treatment plant» of March 22, 2001.

The liquid radioactive wastes treatment plant is constructed «on turnkey basis» within the framework of the contract No. ChNPP C-1/2/036 dated 16.09.99 between the National Atomic Power Company «Energoatom» and the consortium of BELGATOM\SGN\FINMECANNICA Sp D'AZI A ANSALDO NUCLEARE.

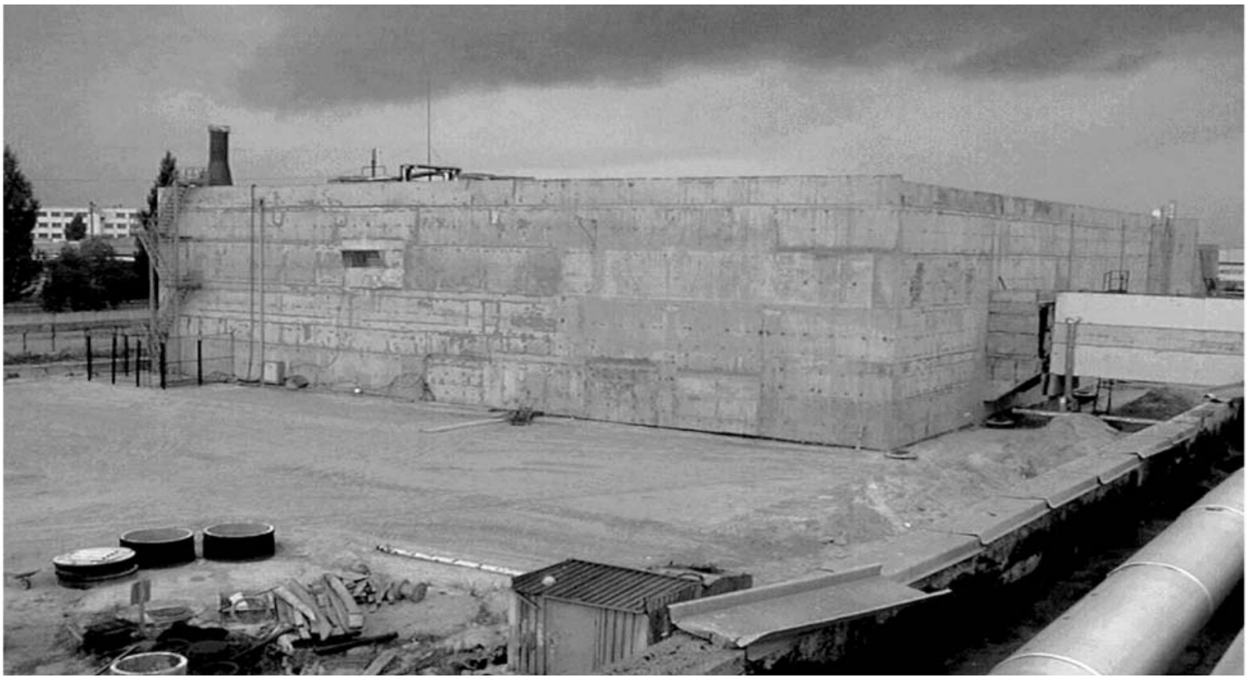


Fig. 10.1.1. Appearance of LRWTP

Fig. 10.1.2. Liquid wastes treatment unit of LRWTP

The initial contract value was €17,400,000, but after making a number of supplements the contract value amounted to €25,700,005.

The contractual work is financed by the European bank of reconstruction and development from the «Nuclear Safety Account» according to the Agreement on Grant No. 006. Until now €21,148,204 was transferred to the Contractor's account.

Terms of work completion: initial – 31.12.2001, under the additional agreement No. 6 – 31.05.2005. In August 2005 Supplement No. 7 to LRWTP construction Contract was adopted, where new key dates of the project realization and additional financing for its completion were determined. Under the Supplement, the contract value is more than €33 mln. Under the Supplement, the beginning of decommissioning the plant (first active barrel) is scheduled on 14.06.2006, project completion on 21.08.2007.

For today, design, construction and mounting work is close to completion (97% complete). The rest of work includes mainly testing the equipment, setting up and commissioning.

Putting into operation is supposed to be implemented in two phases:

– phase 1 – putting the plant into operation on 25.04.2006 with connection of only one discharge system (for 5000 m^3 reservoirs (evaporated concentrate) to it, as well as proceeding with mounting other two removal systems;

– phase 2 – connection of two more discharge systems for 1000 m^3 and 5000 m^3 reservoirs (pearlite, resins) to the plant and on 20.03.2007 – putting the whole unit into operation.

The guiding role in project implementation will differ: phase 1 – the guiding role of Belgatom, phase 2 – the guiding role of the ChNPP with technical support from Belgatom.

After signing Additional agreement No. 7, the project can be acknowledged the most satisfactory among all the international projects being implemented at the ChNPP site.

Construction of the industrial complex for solid radioactive wastes management (ICSRWM)

ICSRWM is intended for discharging solid RW from the ChNPP SRWSF, treatment, packing and interim storage thereof, and consists of three facilities:

– Lot 1 – Unit for Solid RW extraction from solid RW storage facility (SRWSF) of ChNPP.

– Lot 2 – solid RW processing plant (located at Chornobyl industrial site).

– Lot 3 – Specially equipped near-surface solid radioactive wastes storage facility (located in the Exclusion Zone on the territory of «Vector» complex) for burial of RW conditioned at LRWTP and Lot 2.

Under the additional agreement, construction 84 (liquid and solid wastes storage facility-LSWSF) is modernized, where an intermediate storage facility for highly active and long-lived RW (HAW and LLW) is planned to be located for interim storage of RW produced during the preparatory work at NSC.

In 2001 within the framework of TACIS program contract No. 1L10/99 for construction of industrial complex for solid radioactive wastes management (hereinafter – ICSRWM) was signed with the German company RWE NUKEM Gmb (Contractor). Construction and mounting at Lot 1 and Lot 2 is carried out by private small research and implementation innovation enterprise «STRUM». Lot 3 is built by «Ukrtransbud» Corporation.

The initial contract value was €33,300,000, but after making a number of supplements, the contract value amounted to €47,722,000, including EC contribution of 44 000 000 €, Ukrainian contribution – 3 422 000 €.

Terms of accomplishment of work: initial – 01.03.2004, under the additional agreement No. 3 – for Lots 1 and 2 – 25.07.2006, for Lot 3 – 16.05.2006, for LSWSF – 22.10.2005.

Unfortunately, the terms were again foiled by the Contractor. In the summer 2005, the Contractor requested from the European Commission to prolong terms of implementation of project of ICSRWM: for Lots 1 and 2 completion term is 25.07.2007 (prolongation for 11 months), for Lot 3 completion term is 01.11.2006 (prolongation for 5.5 months), for HLW and LW storage facilities in Construction 84 (LSWSF) – unchanged.

However, in early autumn the Contractor confirmed the prolongation of terms for Lots 1 and 2 for 11 months, for Lot 3 prolongation for 4 months. For the first time the Contractor admitted the slippage for HLW and LW storage facilities in Construction 84 (LSWSF) – prolongation for 3 months. By the end 2005 data, the HLW and LW storage facilities in Construction 84 is scheduled to be put to operation in April 2006.

Failure to fulfill the new terms proposed by the Contractor will definitely result in stoppage of preparatory work at NSC construction site of the Shelter.

Issues of unsatisfactory ICSRWM project implementation and necessity of additional financing of completion of ICSRWM were discussed at the meetings in the ME with the representatives of the European Commission late 2005. The joint (EC-ME) approaches for improving ICSRWM project implementation were worked out.

Among technical problems of ICSRWM the following can be specified:

– Insufficiently grounded effectiveness of the sorting system of Lot 2 to determine the content of α-radiators in solid RW. This prejudices the correctness of the characteristics of the final product - containers with RW, which will be buried in the near-surface storage facility in (Lot 3).

– The situation arose when the storage facility at Lot 3 is already under construction, the analysis of its safety, remains unsatisfactory, criteria of reception of RW for burial therein have not been determined yet. Without determining these criteria putting the RW treatment objects – LRWTP and Lot 2 – into operation is threatened, while a situation may arise when RW in them conditioned cannot be buried in the storage facility constructed specially for it (Lot 3) because of inconformity of RW characteristics with the criteria of reception to the storage facility.

10.1.2. Conversion of the object «Shelter» to an environmentally safe system

Object «Shelter» has a status of a nuclear hazardous object and an interim storage facility of non-organized radioactive wastes. However, it does not meet the requirements for the long-lived and highly radioactive wastes storage facilities (LW and HLW). Creation of reliable enough technical barriers for permanent isolation (preservation) of fuel-containing materials (FCM) inside the object is related with environmental hazardousness of the Shelter in its present state. Therefore, transformation of the Shelter should provide for discharge of FCM and HLW from the object, turning thereof to safe system, intermediate controlled storage and burial in deep storage facilities (in stable geologic formations), unless an alternative way of securing safety of storage of FCM in the Shelter is proposed before FCM discharge (estimated 30–50 years).

Object «Shelter» is converted to an environmentally safe system in three basic phases. At the first phase, technically intensive safety in the near perspective should be reached through minimization of current risks of the existing object «Shelter». The second phase is transitional. The third phase provides for converting FCM to completely controlled conditions either by complete discharge from the Shelter or completely controlled storage of the remaining FCM within the object.

Within the framework the Shelter is converted to an environmentally safe system through such stages:

1) Maintenance the Shelter in safe conditions;

2) Drafting and approval of normative and project documentation on converting the Shelter into environmentally safe system;

3) Development of necessary infrastructure for activity aimed at stabilisation of the Shelter and construction of a new confinement;

4) Stabilization of the existing object, increase of operational safety and service life of constructions and systems providing control of safety indicators of the Shelter;

5) Creation of additional preventive barriers, first of all, a confinement, providing necessary conditions for technical activity at the stage of converting the Shelter into an environmentally safe system and safety of personnel, population and environment;

6) Dismantling (early and postponed) unstable constructions of the Shelter;

7) Development of technologies of discharge of fuel-containing materials from the Shelter;

8) Development of infrastructure for radioactive wastes management of the Shelter;

9) Provision of storage facilities for burial (in particular, in geologic formations) of fuel-containing materials and long-lived radioactive wastes of the Shelter;

10) Discharge of fuel-containing materials and long-lived radioactive wastes from the Shelter (or transfer to controlled conditions), conditioning thereof with further storage and burial in the proper storage facilities.

11) Dismantling constructions of the Shelter and confinement elements.

The consequence of executing the above steps and content of work should be correlated with the results of fulfillment of the Shelter implementation plan.

Shelter implementation plan (SIP) is realized according to the Framework agreement between Ukraine and EBRD on activities of the Chornobyl Shelter Fund.

The plan provides for fulfillment of total 22 tasks and the project management task. Initially, the confinement construction was to be completed in 2004; and dismantling and project were to be completed in 2007.

Problem issues

The main problem of completion of work in the object «Shelter» by Shelter implementation plan (SIP) is providing the Chornobyl Shelter Fund (CSF) with money required to complete the project.

The following table illustrates financing conditions of the project.

Description	Value
Initial evaluation of SIP (TACIS report of 1997)	~ $758 million
General estimate evaluation of SIP (May 2005)	~ $1091 million
Amount of used funds (as of 01.09.2005)	~ $376 million
Additional funds for NSC	~ $260 million
General amount required to complete SIP	~ $1350 million
Amount of raised funds (up to 2005)	~ $645 million
Accumulated interests (up to 2005)	~ $45 million
Total raised funds by the beginning of 2005	~ $690 million
New claimed amount (May 2005)	~ $230 million
General amount of claimed funds	~ $920 million
Funds deficit evaluated by PMC SIP (May 2005)	~ $170 million
Funds deficit with the regard for NSC	~ $200–300 million
Funds deficit with the regard for RW	~ $300–400 million

As the table data show, the corrected value of SIP is 1,091 million USD against the previous evaluation of 758 million USD. The total amount of the funds claimed by donor countries to fulfill SIP is about 920 million USD, funds deficit totals 170 million USD. Besides, the value of construction of a new safe confinement (NSC) exceeds significantly the amount of funds planned by the Project management group. With regard for the costs of NSC, the funds deficit may amount to 200–300 million USD.

The second important problem is the one of radioactive wastes (RW) management. At present, in EBRD there is package of functional specifications for the first-line facilities of the integrated scheme of RW management. The budget of projects, which should be fulfilled first of all and failed to fulfill, which can have negative effect on further realization of SIP, amounts to about 100 million USD (the amount is not included to the above budget of 1,091 million USD). The issue of financing this program was discussed at the last Assemblies of CSF Donors, but, unfortunately, until now the decision has not been taken.

Thus, the total funds deficit required to complete SIP can amount to 300–400 million USD. The support of the G8 and EU countries should be enlisted so that the governments of the donor countries agree for the stage-by-stage provision of additional funds to complete work by the SIP project.

The problem, which is worth mentioning is the lack of coordination of strategies of further steps from the complex of work related to fuel-containing materials.

The position of ME is such that the system will be safe only after fuel-containing materials and RW are discharged from under a new shell. Therefore to solve the future tasks of converting the Shelter to an environmentally safe system, the international community should be engaged now in solving the problem. The development of the program of implementation of Phase 3 should be resumed at task group level, which would allow to solve completely the problem of converting the Shelter into an environmentally safe system and show the ability to elimination jointly the severest nuclear and radiation accidents consequences.

Among the current problem issues, the problem of management of radioactively contaminated water of the Shelter should be noted. A more general scheme of treatment of radioactively contaminated water at the ChNPP site should be developed. Solution of the problem is proposed within the framework of creation of the integrated RW management scheme.

10.2. Development management scheme of infrastructure for long-term safe storage of spent nuclear fuel of the ChNPP

10.2.1. General characteristics of spent nuclear fuel of the ChNPP

As of end of 2005 the total number of spent fuel assemblies (SFA) at the Chornobyl NPP was 21 284 pieces, 68 not-spent FA and 3 unirradiated fuel elements (FE) with the general uranium mixture weight of 2393.071 t.

In the fresh fuel storage facility building there are 68 not-spent FA and 3 unirradiated FE.

In active zones of reactors of power units 1 and 3 there are 2 375 SFA, in conditioning ponds of units 1, 2, 3 there are 3 306 5 SFA. Power units have total 5 681 5 SFA. In conditioning ponds of spent nuclear fuel storage facility (SNFSF-1) 15 603 SFA are stored.

Nuclear fuel is to be discharged from the ChNPP power units for long-term safe storage in a new spent nuclear fuel storage facility SNFSF-2 of the ChNPP.

10.2.2. State of construction of new spent nuclear fuel storage facility SNFSF-2

SNFSF-2 was to take all spent nuclear fuel, except for defective fuel, for long-term (100 year) storage.

It was provided that each fuel assembly would be divided into half, each half of FA (one beam of fuel elements – FE) would be placed to a so called hermetic cartridge, 196 cartridges (98 FA) would be placed to a hermetic dry shielded case, and 4 cases would be placed in a concrete storage module. They are shown in the figure below.

Thus, meeting the requirement of the regulatory authority for two additional safety barriers for spent nuclear fuel (SNF) storage was planned.

Contract ChNPP/C-2/2/033 «Intermediate spent nuclear fuel storage facility» (SNFSF-2 of ChNPP) was signed on July 7, 1999 between the National Atomic Power Company «Energoatom» (Customer) and the consortium consisting of representatives of: Framatome (leader), Campenon Bernard-SGE and Bouygues Travaux Publics (Contractor).

The initial value of the contract was €52 467 000 + $18 510 600, the initial term of fulfillment was from 14.06.99 to 15.03.03. The project was financed at the expense of the International Technical Assistance from the EBRD Nuclear Safety Account.

Seven additional agreements were signed. As of end 2005 the total value of the project amounted to €95 720 005 (in equivalent). Under the last additional agreement the contract completion was scheduled for 31.08.2005.

The storage facility project designed by the Contractor passed the state examination and was approved by the Resolution of the Cabinet of Ministries of Ukraine of July 11, 2001 No. 269-p. However, in April 2003 the ChNPP suspended project execution due to its defects, which make impossible licensing of the facility SNFSF-2 and its further safe operation. Among the basic defects of the project are: absence or inconsistency with the norms of the normative documentation and technical specification on management spent fuel assemblies (SFA). In reply to Customer's announcement about suspending project execution, the Contractor created an independent expert group consisting of representatives of companies of «AREVA» group to analyze the project and develop correcting project solutions. At the end

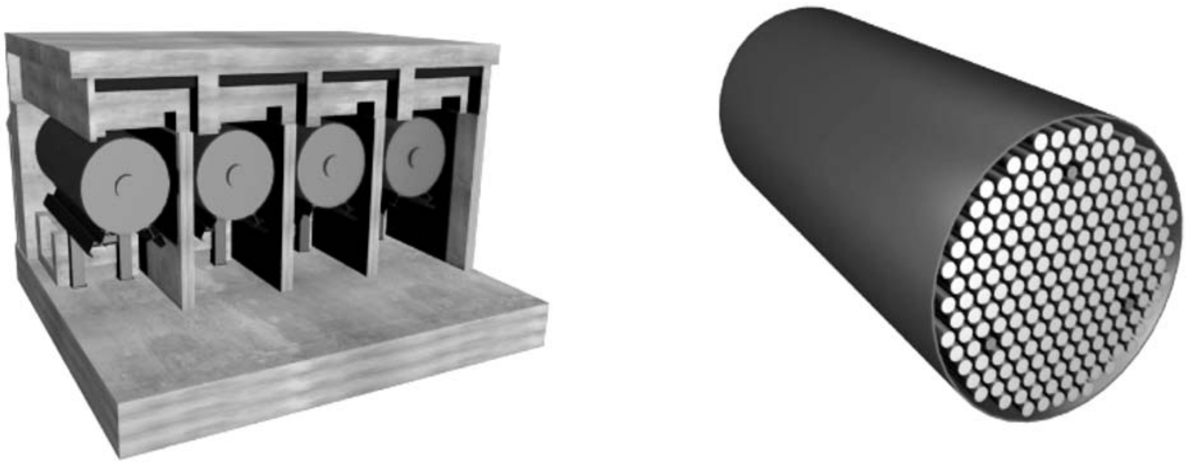


Fig. 10.1.3. Concrete storage module and dry shielded case with cartridges of spent nuclear fuel

of 2003 the group presented final conceptual changes of project SNFSF-2 and coordination of Additional Agreement No. 8 got started, which was scheduled for signing in April 2004. However, in May 2004 the Contractor detected a new problem - possible presence of water under the FE shell.

It should be noted that according to the conclusion of an independent expert B.Pello who made audit under the contract with the European Bank of Reconstruction and Development (EBRD), the Contractor from the very beginning should have supposed presence of water under the FE shell in non-hermetic FA, which can appear during the long-term «wet» storage. The solutions proposed by the Contractor (non-hermetic porous insert to the cartridge) do not meet the requirements of the regulatory authority for of two safety barriers for SNF storage.

In November 2004, the Assembly of Donors considered the issue of the project of SNFSF-2, where the Customer's and the Contractor's positions on solving the problem of presence of water in non-hermetic SFA were discussed. By the results of the negotiations a memorandum about staged realization of the project was signed:

– completing SNFSF-2 for reception of hermetic SNF (about 95% of all fuel),

– grounding of the concept and technologies of non-hermetic SFA storage.

At the Assembly of Donors in May 2005 the presentation coordinated by the Customer and the Contractor was made, based on the following approach:

– usage of the two-barrier system of SFA storage (hermetic cartridges with beams of SFA in a hermetic case);

– only SFA of Group I (hermetic SFA), which will be stored in hermetic cartridges, without usage porous inserts, will be sent for storage at SNFSF-2.

– the Customer is responsible for 100% additional characterization of SFA (dividing fuel assemblies to SFA of Groups I and II);

– For SFA of Group II another conceptual technical solution using a ventilated construction was proposed.

The Assembly demanded that the parties to the contract concentrate on final determination of grounding of safe management SFA of Group I and determine conditions of Additional Agreement No. 8 so that it envisages management only SFA of Group I.

At the meeting of the Assembly of Donors in July 2005 in London Contractor's representative made a report about the results of the work done and coordinated decisions between the Customer and the Contractor concerning the technical aspect of the problem were reached. According to the decisions, the volume of work at SNFSF should include only 95% spent fuel assemblies; a 5% non-hermetic fuel was removed from work volumes at SNFSF-2. Contractor's representative reported on financial consequences of proposed technical solutions (about 75 mln. euro) and terms of completion of the construction (52.5 months after resuming work).

By the results of the Assembly of Donors on July, 20 2005 the following decisions were taken:

– Independent audit of SNFSF-2 project is required to as certain technical reasons of changing content of work, starting from 1999 and related cost increase.

– Parallel to audit some work from project SNFSF-2 (on grounding of safety) should be continued.

It should be noted that due to the delay of putting SNFSF-2 into operation Ukraine incurs losses, both financial and political:

– Each year additionally about €15 mln. budget funds are spent to maintain in the operational status systems, equipment for nuclear fuel management, and salary of the licensed personnel of the ChNPP. Thus, for 6 years of delay of SNFSF-2 completion it amounts to about €90 mln. withdrawn from the Ukrainian budget.

– Delay of SNFSF-2 project not only results in significant increase of expenses of the Ukrainian budget for maintenance of the Chornobyl NPP, but increases safety risks related to the resource exhaust of systems and equipment, related to SNF storage in the existing constructions (project resource is exhausted: for constructions and equipment of power unit 1 – in 2007, power unit 2 – in 2008, existing SNFSF – in 2016).

– 5% non-hermetic fuel assemblies, excepted from the content of work at SNFSF-2, the decision on management which has not been taken yet, will result on extra financial costs worth €60–80 mln.

– Failure to solve problems with SNFSF-2 can result a delay of work at the new safe confinement (NSC), since all nuclear fuel should be removed from power Unit 3 before dismantling of ventilation pipe VP-2 and pulling Arch of NSC.

10.2.3. Steps on management of spent nuclear fuel of the ChNPP for the period till 2010

Project of discharging nuclear fuel from power units is the main factor determining the duration of the stage of decommissioning out of operation. The duration of decommissioning effects directly the term of operation of active safety systems and maintenance of power units in safe condition.

According to «the Chornobyl NPP Decommissioning Concept», nuclear fuel was subject to discharge from power units of the ChNPP to the spent nuclear fuel storage facility (SNFSF-2) for long-term safe storage after putting SNFSF-2 into operation in the middle of 2005. At present, with regard for:

– indefinite terms of putting SNFSF-2 into operation;

– impossibility of pulling new safe confinement to design position without dismantling ventilation pipe of the 2nd line of the ChNPP;

– project terms of operation of the reactor power unit No. 1 ends in September 2007, power unit No. 2 – in December 2008;

– costs of maintaining power units of the ChNPP in safe conditions constantly grow,

– decision on discharge of SNF to the existing SNFSF-1 for interim storage was taken.

However, this is far from being a simple task, while only about 75% all available spent nuclear fuel can be loaded to SNFSF-1 in the design mode. To solve this task the nuclear unit – SNFSF-1 – should be modified to enable compact storage of fuel. A similar task was solved successfully at Leningrad NPP, and the ME counts on assistance of Russian colleagues in solving the task.

A conceptual decision on modification of nuclear unit SNFSF-1 has been worked out, technical solution for mounting is being developed.

It should be mentioned that the MES and the Chornobyl NPP require complex solution of the problem of spent nuclear fuel of the ChNPP, which would include solving the problem of non-hermetic and defective fuel, take into account resource of the nuclear units of the ChNPP and terms of completion by SNFSF-2 project. It consists of parallel fulfillment of the following three main tasks:

1) Discharge of spent fuel to the existing interim storage SNFSF-1 of the «wet» type mentioned above.

2) Further cooperation with the Contractor of SNFSF-2 project (Framatom): performing parallel audit of drafting documentation for modernization of SNFSF-2 project and, in case of positive conclusions of audit and successful coordination of the project, documentation with regulatory authorities of Ukraine, resuming work by the project and completion of the construction of SNFSF-2 in the shortest possible terms. The negotiations held by the ChNPP with «Framatom» allow to resume work by the project in the near future and to complete construction of SNFSF-2 in the shortest terms.

3) Solution of the problem of non-hermetic fuel management using the Russian technology of SFA storage in the metal container. Besides, the same containers can be used to discharge fuel from SNFSF-1 in 2008–2010 before putting SNFSF-2 into operation.

The main factor for determining the order of SFA discharge from power units is the end of the project resource of power Unit 1 and necessity of complete SNF discharge from the power Unit 3 to create conditions for work, scheduled within the SIP framework (removal of ventilation pipe of the 2nd line, pulling the new safe confinement).

Population radiation dose during the preparatory, technological and transport operations with nuclear fuel, taking into account long-term retention, discharge of nuclear fuel, maintenance, repair of equipment, based on the experience of operation, will amount to about 1960 mSv.

Population radiation dose with compact mode of SNF storage at SNFSF-1, based on experience of operation, will amount to about 940 mSv.

In 2006–2007 feasibility study should be performed to choose the optimum decision on defective SFA, management and in 2008–2009, a project of modification of power unit for defective fuel storage was developed. Within the framework of the project of modification of power unit, defective nuclear fuel from the ChNPP site should be additionally inspected and corresponding recommendations should be developed.

According to the previous calculations, discharge of spent nuclear fuel from the ChNPP power units is scheduled to be completed by 2009, and defective nuclear fuel - in the middle of 2010.

Discharge of nuclear fuel from SNFSF-1 is planned after construction of SNFSF-2, which is expected to be put into operation in 2010. By this time the transport technological part of SNFSF-1 should be reconstructed to the extent sufficient to for safe removal of nuclear fuel.

However, all the practical steps on decommissioning of the ChNPP scheduled by the ME can be carried out only in case of proper financing of the work in the extent stipulated by the National Program of decommissioning of the ChNPP. Unfortunately, in draft budget-2006 drawn up by the Ministry of Finances, again only funds for maintaining the existing conditions of the ChNPP are envisaged. If discharge of nuclear fuel from power units is not started now, in two years much more funds will be required to prolong the operation term of reactor units. Inadequate financing of the ChNPP in 2006 will result in ineffective spending budget funds in much larger extent in 2007 already. Thus, instead of decommissioning, Ukraine will have to spend money to prolong the service life of units of the plant, which had been out of operation for 5 years.

11. RADIOACTIVE WASTES' MANAGEMENT

After the Chornobyl NPP accident in Ukraine the huge amounts of radioactive waste (RW) were formed, which considerably exceed RW amounts, which were accumulated due to NPP operation and other kinds of activity.

The aim of this chapter is to analyse the state of the main problems, which are connected with safe management of radioactive waste, which appeared due to the accident at the Unit 4 of Chornobyl NPP, in the context of necessity of development of the National system of radioactive wastes' management. For this, the following was considered:

– main principles of the state policy and directions of activities in the field of RW management;
– amounts and characteristics of RW of Chornobyl origin;
– amounts and characteristics of RW, which were accumulated in Ukraine due to electric power production at NPPs and other kinds of activity;
– current practice of RW management;
– factors of negative influence of the absence in Ukraine of the long-term strategy of RW management on economy, national safety, social & psychological state of the society, environment;
– factors, which confine development of the National system of radioactive waste management.
– main measures, which are the necessary ones for settling this problem.

11.1. Chornobyl component in the total system of RW management

11.1.1. The main principles of the state policy and the main directions of the activity in the field of RW management [1]

Main principles of the state policy in field of RW management are determined by the Law of Ukraine «On radioactive wastes' management» [2] and the state program of RW management, which is affirmed by the Resolution of the Cabinet of Ministers of Ukraine of December 25, 2002 No. 2015. [3] They are, first of all:

– priority of protection of life and health of the staff and population, protection of the environment from influence of radioactive waste according to the state radiation safety norms;
– ensuring RW reliable isolation;
– establishing state regulation of RW management;
– separation of the functions of state regulation and control in field of RW management;
– separation of the functions of the bodies of the state control in field of using nuclear power and in the field of RW management;
– responsibility for safety of RW management before their transfer to the specialized enterprises is laid on generators of RW;
– RW temporary storage at the generators' sites with subsequent transfer to the specialized RW management enterprises;
– long-living RW must be disposed only in the deep geological repository, short-living RW can be disposed in the surface repositories;
– making decisions, concerning location of the new RW repositories with participation of citizens, civil associations, and also the local authorities;
– prohibition of import of RW to Ukraine for their storage or disposal;
– international cooperation in field of RW management.

According to the principles of the state policy, the following main directions of activity are determined:

– centralization of facilities for RW treatment and storage;
– transformation of damaged Unit 4 of the Chornobyl NPP into environmently safe system;
– development and functioning of the state system of RW record keeping;
– development of the deep geologic repository for disposal of long-living and high-level RW;
– development of new and implementation of the advanced technologies of RW management;
– scientific, technical and information support of the activities in field of RW management;
– development of normative & legal basis in field of RW management;
– expansion of international cooperation in field of RW management.

11.1.2. RW of Chornobyl origin

Due to the Chornobyl catastrophe, considerable amount of radioactive materials including RW is concentrated in the Exclusion Zone and zone of absolute resettlement.

The main places of RW location in the Exclusion Zone are the following:

– the Object Shelter (OS) or according to [4] the temporary storage for unorganized RW;

– SDRW, or sites for RW disposal («Buryakivka», «Pidlisny», «The 3-rd turn of ChNPP»);

– STLRW, or sites for temporary localization of RW;

– natural and artificial objects of both OS and ChNPP industrial sites and adjacent territory.

In 2003, total amount of RW in the Exclusion Zone (without the Object Shelter) was about 2.8 million m^3. From them, over 2.0 million m^3 RW with total activity of about $7.4 \cdot 10^{15}$ Bq [5] are in SDRW and STLRW. The total activity of radioactive substances in the natural objects of the Exclusion Zone (in the surface layer of soil, bottom precipitates of water reservoirs, vegetation, etc.) was over $8.5 \cdot 10^{15}$ Bq [5]. The total amount of radioactively contaminated materials concentrated in the Exclusion Zone was equal to 11 million m^3 [1]. The above-mentioned waste consist mainly of short-living low- and middle level RW.

RW of the Chornobyl origin vary greatly by their radionuclide composition, the levels of specific activity and substance composition. In contrast to other technological types of RW, the Chornobyl origin waste are characterized by the presence of wide spectrum of radionuclides (including those having considerable half-lives). The most Chornobyl RW are kept under conditions, which do not meet the requirements of the modern radiation safety norms. So, at the majority of RW repositories in the Exclusion Zone (except for SDRW «Buryakivka» and «Pidlisny») the facts of radionuclides release from the repositories (for example, contamination of ground water with radionuclides) are observed. This is a result of absence of the proper system of engineering barriers, periodical flooding of STLRW and biogenic release of radionuclides.

RW of the Object Shelter

According to [1, 6], from 400000 to 1740000 m^3 of RW are located in the Object Shelter and at its site. At the beginning of 2005, their total activity was about $4.1 \cdot 10^{17}$ Bq (it is recalculated on the basis of the data of [7, 8]).

Over 10% of the total amount of the OS RW is high level waste (HLW), great amount of which are concrete, metal structures and equipment, materials of backfill of the reactor. Over 2800 t of HLW are fuel-content materials (FCM), including lava-like FCM, fragments of the reactor active zone, reactor graphite and fuel dust.

At the OS constant accumulation of atmospheric water, condensation and technological origin takes place. Due to interaction of water with radioactive materials, liquid RW (LRW) arose. Annually, up to 900 m^3 of LRW are pumped from the accessible SO rooms, and transported to the system for treatment and storage of liquid RW at the Chornobyl NPP [9].

In process of the OS operation including implementation of the measures on OS transformation into environmently safe system (OS stabilization stage) considerable amounts of solid RW arose, which now are disposed in SDRW «Buryakivka». In 2002, these amounts were over 7700 m^3 [9].

The areas of RW disposal

SDRW «Pidlisny» is built for RW with the exposure dose rate (EDR) of up to 50 R/h, but, according to the decision of the Government commission, RW with ER of up to 250 R/h were located there. The total amount of RW is $1.1 \cdot 10^4$ m^3, according to the data of 1990, accepted estimation of total activity is $2.6 \cdot 10^{15}$ Bq [10]. The results of SDRW external investigations, which were conducted for the last years with taking into account RW in this facility, given in 1991, by VSRIPET ($2.6 \cdot 10^{18}$ Bq), give the grounds to suppose that the estimation of RW activity is considerably understated [11]. All the RW in SDRW «Pidlisny» are practically long-living ones, and they are liable to the disposal in the stable geological formations.

Presence of many cracks in concrete foundation and walls of the structure calls for the necessity of investigation of condition of its structures. The main goal of the investigation should be estimation of SDRW safety and development of the design for its stabilization for the whole period up to the construction of deep geological repository.

SDRW «The 3-rd turn of the ChNPP» was built for RW with EDR of up to 1 R/h, but the waste with much higher EDR were located in it. According to the data of investigation of 1995 SDRW contains $2.6 \cdot 10^3$ m^3 of low and intermediate level RW including the long-living ones with total activity of $4.7 \cdot 10^{14}$ Bq [11]. Atmosphere and ground waters have free access to the depository owing to the absence of isolation. SDRW «The 3-rd turn of the ChNPP» requires investigation aimed at development of the project of its stabilization and in prospective – liquidation of this SDRW.

SDRW «Buryakivka» was created in 1987 for disposal of RW with EDR of up to 1 R/h. By the decision of the Government commission it was allowed to place wastes with EDR of up to 5 R/h in it.

Now operation of SDRW continues. According to the calculations, it contains $7.0 \cdot 10^5$ m^3 of RW with total activity of about $2.45 \cdot 10^{15}$ Bq. Available free volume of SDRW will be filled in the nearest future; in this connection, its reconstruction has been designed.

Areas of RW temporary storage location

The sites for RW temporary location (STLRW) are the territories, which are adjacent to the ChNPP from the south, west and southwest, where in 1986–1988 decontamination of the area was conducted with localization of decontamination of wastes on-site in the simple trenches or clamps, with no engineering barriers. It is considered that about 1000 trenches and clamps are concentrated in nine STLRW on the total area of about 10 km^2. More than half area of STLRW was not investigated in fact. STLRW waste include: contaminated soil, equipment, metal, concrete, building materials, remains of houses, rubbish, etc.

According to the existing estimations [11], about 1.3·106 m^3 of waste with total activity of $1.7 \cdot 10^{15}$ Bq are localized in STLRW. Generally, these are low-level waste and waste, which activity is below the exemption level. Practically all the waste contain long-living radionuclides, some parts of waste are classified as long-existing ones. All the STLRW are situated at the territory with a high level of ground water; about 100 trenches with waste are flooded constantly or periodically, and radionuclides freely come to ground water because of the absence of protective barriers.

RW, which are concentrated in the natural and artificial objects of the OS and the ChNPP industrial sites and adjacent territory

According to the existing estimations (see Chapter 9) about 15 thousand m^3 of RW remained in an active layer of soil of the local zone of the OS after completing the work on decontamination of the territory. According to the data of drilling activity and gamma-ray logging investigations, RW are concentrated mainly in the layer of disposed soil with thickness of 10–30 cm (in some places – considerably more).

Low- and intermediate level wastes include contaminated and mixed pre-accident soils, contaminated concrete blocks and plates, metal structures, fill-up soils (crushed stone, sand, etc.), construction waste.

In total, 500 thousand m^3 of RW of low and intermediate level waste are on the ChNPP industrial site. They are contaminated soils, metal, concrete, equipment, various materials, etc.

Considerable amount of radioactive materials is concentrated in the cooling pond of the ChNPP. Its bottom sediments contain over $0.2 \cdot 10^{15}$ Bq. The certain part of the cooling pond sediments belongs to RW by the content of radionuclides.

11.1.3. Distribution of radioactive wastes by the possibility of their disposal

The possibilities and approaches to disposal of RW of Chornobyl origin should be considered in the context of the entire problem of RW management in Ukraine.

According to the requirements of Ukrainian legislation, short-living radioactive wastes can be disposed in surface repositories, and the long-living ones «are liable to disposal only in solid state in stable geological formations with their obligatory transformation into explosion-, fire-, nuclear safe form, that guarantees localization of the wastes within the bounds of mining lease of bowels» [2].

Tables 11.1.1 and 11.1.2 give generalizing estimations of amounts and activity of RW and SNF, accumulated in Ukraine, and those, which will arise during operation and decommissioning of the existing reactors. They also estimate the amount of long-living RW and their share from the total amount.

Table 11.1.1

Generalizing estimation of RW amounts in Ukraine

RW source	RW total amount, thousands m^3	Long-living RW amount, thousands m^3 (per cents from RW total amount)
Vitrified HLW	0.1 (estimated by the data [12])	0.1 (100%)
RW from the NPP operation	230 [13]	3.3* (1%)
RW from NPP decommissioning	150 [6]	15 (10%)
Reactor of INI of NAS of Ukraine	(7т) [1]	?
UkrSA «Radon»	5.3 [1]	?
The Shelter object	400...1740	44* (3...8%)

Continuation table 11.1.1

RW source	RW total amount, thousands m^3	Long-living RW amount, thousands m^3 (per cents from RW total amount)
The SO industrial site	15	?
The ChNPP industrial site	500	?
STLRW and SDRW	2000	12.5* (0.6%)
Total	3300...4600	75 (2...3%)

* By estimations [14]

Table 11.1.2

Generalizing estimation of Ukraine SNF amount and activity [12]

SNF source	Uranium total weight, t	Estimation of the total activity, Bq
VVER-1000	8200	3.4×10^{20}
RBMK-1000	2400	4.8×10^{19}
SNF total	10 600	3.9×10^{20}

Analysis of data, given in Table 11.1.1 shows that, in Ukraine, from 3.3 to 4.6 million m^3 radioactive wastes are liable to disposal. Among them, from 2.9 to 4.2 million m^3 have the Chornobyl origin and are located within the Exclusion Zone. So, their part is about 90% by amount and about 10–15% by activity from the total amount and activity of RW in Ukraine.

The majority of wastes (to 97–98%) can be disposed in the surface repositories and only about 75000 m^3 RW are of the long-living ones, so they must be disposed in the deep geological repository. If, in future, spent nuclear fuel is determined as radioactive waste, it also will have to be isolated in the deep geological repository.

11.1.4. Current practice of RW management in Ukraine

RW management in the Exclusion Zone

RW management in the process of the ChNPP decommission

The objects, listed below, are being under construction for the period of current preparation stage for management of RW, accumulated at the ChNPP and which arising is expected at NPP decommissioning [9]. They include:

– the interim storage for spent nuclear fuel (ISNF-2);

– the liquid RW treatment plant (LRWTP);

– the industrial complex for solid RW treatment (ICSRT), components of which are: the plant for retrieval of solid RW from the NPP storages (Lot 1); the plant for treatment of solid RW (Lot 2); the interim storage for long-term storage of low and intermediate level long-living and high level waste (Lot 2); the surface repository for disposal of low and intermediate level short-living waste (Lot 3).

RW management in the process of transformation of the Shelter Object

On the Object Shelter site, preparation work is conducted for construction of the new safe confinement (NSC), which is envisaged for protection of fuel containing materials (FCM) from external effects, reduction of radionuclides releases and discharges into the environment, minimization of the consequences of possible damage of the existing Object Shelter, and also for future retrieval of FCM.

According to the affirmed «Strategy for the OS transformation into ecologically safe system» [15], FCM, HLW and other long-living wastes must be retrieved from the OS and disposed of in deep geological repository. The first stage of this strategy – stabilization of the OS structures, and the second stage – construction of NSC and preparation for FCM retrieval, are carried out within the project «Shelter Implementation Plan».

It is envisaged that, in the nearest future, the amounts of liquid RW to be collected inside the OS and treat will increase. Considerable amount of solid RW will arise during the OS stabilization, NSC and infrastructure objects construction activities. Improvement of the existing system of RW management is envisaged by the Integrated program for RW management at the ChNPP [9].

RW management is performed by the State Specialized Company «Technocentre» (SSC «Technocentre»), consisting of the separate department (SD) «Complex». «Complex» performs RW collection and transportation in the Exclusion Zone, operation of SDRW «Buryakivka», monitoring of laid up SDRW «Pidlisny» and SDRW «ChNPP3-rd turn» and monitoring of STLRW. Disposal of short-living low- and intermediate level RW is performed in the repositories of trench type at SDRW «Buryakivka», constructed in 1986. The repositories of SDRW «Buryakivka» do not comply completely with the modern requirements for surface repositories of RW. That is why, in 1997, SSC «Technocentre» began construction of the Vector Complex, which accordingly to [3] will be a basis for construction of the Centre for Treatment and Disposal of Low and Intermediate Level waste. This Centre will carry out the following activities:

– conditioning and disposal of low- and intermediate level RW of Chornobyl origin;

– disposal of low and intermediate level RW, which arose due to operation of the Object Shelter, and in perspective of those, which will arise at transformation this object into ecologically safe system;

– disposal of low and intermediate level RW, which arose due to NPP operation, and in perspective of those, which will arise at NPP decommissioning;

– disposal of RW, accumulated at the industrial enterprises, in medical and scientific, research and other institutions and now are kept at the storage sites of the state inter-regional specialized enterprises UkrSA «Radon».

RW management at NPPs and the special centres of UkrSA «Radon»

The at-reactor storages for low, intermediate and high level solid RW (SRW), storages for liquid RW (LRW), facilities for SRW sorting, facilities for SRW and oils incineration, facilities for SRW pressing, facilities for LRW deep evaporation, facilities for equipment decontamination were constructed at the industrial sites of each NPP.

The spent nuclear fuel from VVER-440 and VVER-1000 reactors of NPP of Ukraine after storage in the cooling ponds, which are at every unit of NPP, is transported to Russia for reprocessing. The only exception is Zaporizhzhya NPP, on the industrial site of which the interim storage is constructed for «dry» container storage SNF of VVER-1000. SNF of reactors RMBK-1000 is kept in the cooling ponds and in the basin storage ISNF-1 at the ChNPP site. Near ChNPP, the module facility of «dry» type (ISNF-2) for SNF storage SNF from RMBK-1000 reactors during 100 years is being constructed. In Ukraine, the activities on development of the centralized interim storage facility of SNF (CISNF) for the spent nuclear fuel of Rivne, Khmenytsky and South-Ukrainian NPP, including site selection process and development of storage technologies, have been started.

The storage facilities of trench type for SRW and of well type for spent industrial radiation sources (SIRS) and reservoirs for LRW are located on the industrial sites of UkrSA «Radon» branches. In contrast to the previous years when RW were disposed here, now UkrSA «Radon» accepts RW only for storage.

11.1.5. Current problems, which accompany the activity on RW management

For the years of independence in Ukraine, certain work on the development of the national system of radioactive waste management was conducted. The main Laws, which regulate the activity of natural and artificial persons and the bodies of public administration, are accepted. All this allows improvement of life quality of Ukraine people.

However, many of the problems remain unsolved. They equally accompany the activities connected with management as of radioactive wastes of Chornobyl origin, as of nuclear power waste. Among the problems, which should be solved for essential improvement of state of affairs in field of RW management, one can mark out the national, normative & legal, interdepartmental and technical ones.

National problems

The national problems include absence of special fund for RW management and the problem of legal regulation of the sources for fund filling. Due to the absence of the stable financing, any of the previous programs for RW management was not realized completely. As a result of instability and insufficiency of financing in Ukraine, the national system for RW safe management, which should be balanced taking into account the interests and mutual obligations of radioactive waste generators and organizations, responsible for their storage and disposal, has not been created yet.

One should consider as the national problem, first of all, the unsolved problem concerning transformation of the Object Shelter into environmentally safe system. According to [16], the Object Shelter

dismantling in 50 years after NSC construction does not seem a viable decision, as it means the necessity of long-term keeping of highly skilled staff of the ChNPP and the staff who will provide NSC safety in the state of relative inactivity.

Besides, the joint expenses on NSC and the Object Shelter operation during 100 years can excess the expenses on construction of deep geological repository. The problem of postponed decision on FCM retrieval is also the continuous process of their self-destruction. With time, it will require using much more complex technologies for FCM and RW retrieval. So, FCM retrieval immediately after the Shelter Object stabilization is more advisable than connection the beginning of their retrieval with the moment of putting into operation of RW deep geological repository. These kinds of work should be implemented in parallel. In other words, the stabilization measures and NSC construction will permit to get improvement of the Object Shelter safety level only for the certain period of time. The stable rising of its safety level can be reached only in case of implementation of the strategy of urgent preparation, retrieval and disposal of RW and FCM from the Object Shelter, which requires additional urgent decisions on the national level.

If in the nearest future in Ukraine the national system of RW management is not created and the effective RW transfer from the adjacent with NPP storages to the national ones is not started, subsequent NPP functioning will be substantially complicated. According to the estimations made during the work [13] in 2010, capacities of the NPP storages will be exhausted. Besides, according to [17] after 2010 vitrified high level waste will begin to come from Russia to Ukraine. To create national system for RW management and its flexibility assurance it is also necessary to make the state decision concerning reprocessing or direct disposal of spent nuclear fuel.

Safe management of the said RW should be a component of the total system of RW management, which will cover also RW arising in course of decommissioning of other units of ChNPP and those located at the territory of the Exclusion Zone. This system of RW management should be provided by the corresponding infrastructure and its capacity for RW conditioning, storage and disposal. Such infrastructure has not existed in Ukraine yet. The part of the Exclusion Zone (so-called Industrial zone) where the ChNPP is located and the main objects, which are intended for RW management, are being constructed, can become the technological basis for such infrastructure realization.

In view of the above said realization of the Vector Complex consisting in the first and second turns, and also the Central Interim Storage of SNF of NPP of Ukraine in the Exclusion Zone gets the national meaning. In future it will allow to guarantee radiation safety of Ukraine and to create the National Centre for Treatment, Storage and Disposal of all kinds of RW.

It is necessary by all means to carry out inventory of all radioactive materials with drawing up corresponding lists and cadastres for creation of the national system for RW management and design of the National Centre for Treatment, Storage and Disposal.

We should separately emphasize the necessity of creation of the national system of involving the international technical assistance and its effective using.

The national tasks are essential improvement of the state of scientific support of activities concerning RW management: For the last years, this support was almost not financed. It is also necessary to improve the state of training skilled specialists and the level of information & education measures with the aim of constant elimination of the consequences of Chornobyl catastrophe. In future these problems will be able to become decisive for practical activity and development of using nuclear power in Ukraine.

Normative & legal problems

Normative & legal field of Ukraine incompletely satisfies the needs of practical activities in the field of RW management. It concerns harmonization of Ukrainian classification of RW with the requirements of the international standards, development of normative requirements to conditioning, transportation, storage and disposal RW of different kinds, and also the normative requirements to the corresponding repositories.

Management of long-living RW is not only a technological problem, but also a normative & legal one. The way of solving this problem is development and introduction of more perfect RW classification than the one, which is determined in BSRU-2005, which can become a reliable basis for the modern strategy of RW management in Ukraine. The possibility of using new approaches to RW classification on basis of criteria of long-term safety, developed in IAEA, gives the hope for economically weighed solving the problems of management of radioactive waste of the catastrophe origin and radioactive waste of uranium-mining industry at the territory of Ukraine.

As for RW disposal in the deep geological repository, the normative requirements concerning development of waste acceptance criteria, safety provision at all stages of the repository life cycle, criteria of site selection and the decision-making procedure in such process are absent.

In the Exclusion Zone, a large amount of radioactively contaminated materials (hereinafter - RCM), which cannot be referred to any category of RW are concentrated. First of all RCM include soils, which not only fulfill the functions of the natural barrier against radionuclides release, but also are suitable for obtaining useful production. Practically all kinds of activities in the Exclusion Zone are connected with RCM management. At that, secondary waste are created. Part of them can be referred to RW. At the same time, RCM status is not legally determined. It creates obstacles for obtaining useful production by means of using radioactively contaminated natural objects (soils, forests, water reservoirs, etc.).

Interdepartmental problems

Interdepartmental problems equally negatively influence management of both RW of Chornobyl origin, and RW of nuclear cycle.

They are partially solved. In particular, the first steps have already done concerning liquidation of the fact when there are two state control authorities in the field of RW management (Ministry of Emergencies of Ukraine and Ministry of Fuel and Energy of Ukraine) in the Exclusion Zone. Till recently, such distribution of responsibilities has led to two sources of financing, two strategic aims of activities and two approaches to the problems of future status of the Exclusion Zone. However, relatively simple decision on the transfer of SSC «ChNPP» and the Object Shelter to the field of responsibility of Ministry of Emergencies of Ukraine requires implementation of subsequent measures on coordination of Ministry of Emergencies of Ukraine and Ministry of Fuel and Energy of Ukraine concerning management of RW of power engineering field of Ukraine.

Technical problems

Unfortunately, the problem of RW management in the former USSR was considered as the secondary one. With getting independence, Ukraine inherited not only problems connected with the necessity of mitigation of the consequences of Chornobyl catastrophe and management of RW of Chornobyl origin, but also the problems of management of RW of power engineering field. Due to it, the NPPs, which are now operated in Ukraine, were not covered by the total system of RW management. In fact, RW management in the former USSR was limited by creation of the special temporary storages, adjacent to NPP, for liquid and solid RW. The production run equipment for conditioning of RW of NPP in Ukraine has not been manufactured yet. In Ukraine, the stock of containers, which covers the needs of the available types and categories of RW transportation, storage and disposal, is practically absent [13].

Technical problems of management of RW of Chornobyl origin, located in STLRW and SDRW, apart from non-completion of their inventory, also include absence of approved methods and technical means for investigation of RW storages.

In spite that investigated temporary RW storages in the Exclusion Zone don't create noticeable radiation risk for population at the moment [16], it is necessary to carry out the forecast of the most dangerous RW storages (especially of those, which are flooded) long-term influence on the population and environment. Taking into account that the water level in the cooling pond of the ChNPP is artificially kept until NPP decommissioning, and the large-scale excavation at the ChNPP industrial site hasn't begun yet, such forecast should be done as soon as possible in accordance to the international standards and recommendations. Concerning the less investigated storages, it is necessary to determine their characteristics (RW amounts and activity, nuclides content, RW storage conditions) for estimating their safety, to determine radionuclides migration dynamics and, probably, to develop the measures for minimization of their negative influence. The necessity and queue of RW retrieval from the site of their current location and re-disposal should be determined only on the basis of the results of conducting the above said estimations.

It is also necessary to develop the guides on the RW management quality control, reports on the safety analysis and estimations of the influence on environment for decision making concerning the subsequent RW storages matching to the requirements of radiation safety and for optimization of the expenses on conducting the activities on RW storage or re-disposal from the sites of their current location.

The above-mentioned reports should consist of organization measures, estimations of risks and proposals concerning prevention of the accidental situations at construction and operation of new objects for RW management. On this account, the methods of risk estimation, emergency plans and the projects of the counter-measures require revision and official affirmation. Let us also note that, for taking the administrative decisions, introduction of the integrated system for monitoring RW repositories, environmental conditions state on the territories of RW repositories location and, in particular, total hydrologic and hydrogeologic condition of the Exclusion Zone is important. This is necessary for estimation of risks connected with radionuclides migration from the landscapes of the Exclusion Zone, industrial sites of the ChNPP and Object Shelter, and also from SDRW and STLRW.

The important technical problems, connected with keeping the integrity of the engineering barriers, of RW surface repositories which exist or are under construction in the Exclusion Zone, can arise in future as a result of ignoring or absence of complex scientific recommendations for site selections. In particular, the site for construction of the Vector Complex is chosen at the area of the wide development of relief depression forms, which are dynamically developing. The evolution of these structures in time can lead to cracks in foundations and base-plates of repository modules, and also to unpredictable fast radionuclide contamination of ground water [18]. The detail estimation of the said risks is not done so far.

Besides the problems, connected with demonstration of reliability of NSC unique construction, qualitative and practical implementation of the project, it should refer the necessity of development of the strategy of the Object Shelter transformation into the environmently safe system and the equipment for FCM retrieval, their sorting, conditioning and packing, and also the necessity of development of transport means and repositories for RW isolation, to the problems, which accompany the activity on transformation of the Object Shelter into the environmently safe system. The problems of management of radioactive waste, created due to conducting preparatory excavation for construction of NSC foundations, also require solving.

The state of physical protection of objects for RW management in the Exclusion Zone requires its matching to the requirements of the existing legislation. The guarding of all the territory of the zone on its perimeter incompletely prevents illicit spreading of RW beyond the bounds of the Zone. It is necessary to create own system of physical protection at every object, intended for RW management.

The absence of requirements and equipment for wastes characterization also belongs to the inherited technical problems of management of RW of power origin. The data concerning radiation, isotopic, chemical and mechanical properties of waste are extremely necessary both for completing RW inventory and for development of technical requirements for technologies of RW treatment, conditioning, transportation and storage and also for design the corresponding objects.

Management of vitrified high level wastes from reprocessing SNF of Ukrainian NPPs in Russia should also be referred to the problems of RW of power origin.

It is also necessary to develop the projects of NPP units decommissioning due to expiration of their service life with determination of amounts, properties and schedule of RW arising, for solving the problem of management of RW of the power engineering field and creation of the State system of RW management.

Absence of the certified container stock and the means for their transportation, as well as of containers for RW storage and disposal in Ukraine is the common technical problem in field of RW management.

Besides the above said problems in Ukraine, as it has been underlined above, the very critical problem of organization of adequate scientific & technique support of all activities, connected with RW management, exists. It concerns the work planning, the development of ecologically safe technologies for waste treatment and conditioning, estimation of radiological risks and consequences of different elements of RW management, site selection for repositories, etc.

11.1.6. Influence of the existing state of RW management on Ukrainian society

The modern state of affairs in Ukraine in field of radioactive waste management is characterized by dominating of branch approach concerning the technical policy. But financing of the measures on nuclear and radiation safety of RW management is done by residual principle. It leads to impossibility of systematic implementation of the long-term national program of RW management because of availability of several managers of means that have different priorities.

At the same time, keeping the existing state without changes will inevitably lead to the pessimistic scenarios of events for our country. The said problems will continue accumulating. It increases probability of various emergency situations and can cause negative reaction and imposing corresponding sanctions to Ukraine by EU and international organizatios.

Keeping the existing state of affairs without changes and absence of the national strategy of RW management considerably negatively influences the national safety. This influence is determined by the following factors:

1) dependence of Ukrainian NPP's operation on successful development of Russian program of RW management;

2) threat to the stable development of nuclear power engineering due to exhausting of capacities of at-reactor storages for RW and SNF;

3) substantial threat of terrorism at the time of SNF transportation and HLW and long-living RW storage in the vulnerable surface facilities;

4) economical burden for future generations, which will be obliged to pay operating costs on RW storage, created by their predecessors;

The unsolved problem of radioactive waste isolation does not reduce social & psychological stress in Ukrainian society, connected with distrust of population to safety of nuclear power engineering and incompleteness of elimination of the consequences of the ChNPP catastrophe.

11.2. RW management strategy

11.2.1. The main principles concerning the national strategy of RW management

Analysis of the information, given in the previous section, shows that, for development of national strategy of RW management, it is necessary:

– to make a number of political and administrative decisions concerning creation of the special fund of RW management, determination and formation of the mechanism of such fund filling and the strategy of spent nuclear fuel management;

– to develop and affirm the national purpose program of radioactive waste management;

– to develop and affirm the national program of disposal of high level and long-living RW, as separate part of the national program;

– within the measures of the national purpose program of radioactive waste management, to provide development and improvement of the normative basis of RW management; the projects of NPP decommissioning; technical & economical assessment of the activities on re-disposal, localization and reliable monitoring of STLRW and SDRW in the Exclusion Zone and storages of UkrSA «Radon»; designing of facilities for storage and disposal of all kinds of radioactive wastes, which exist in Ukraine; the designing concerning development of infrastructure for RW management; technologies for RW treatment and conditioning; the container stock for transportation, storage and disposal of all kinds of RW, and means for transportation of RW containers.

The mentioned national purpose program of RW management should be balanced with taking into account of interests and mutual obligations of manufacturers of radioactive wastes and organizations, which are responsible for radioactive wastes storage and disposal.

The territory of the Chornobyl Exclusion Zone is optimal for solving the problems connected with the development of the national system of RW management (taking into account a number of social, transport problems and conditions of radiation safety assurance and necessity of minimization of alienation of land for creation of infrastructure for RW storage and disposal). It is determined by the following:

– over 90% of amount of radioactive waste in Ukraine are located in the Exclusion Zone, that is caused by the consequences of the Chornobyl accident, ChNPP operation and decommissioning;

– the work on creation of infrastructure for RW storage and disposal is concentrated in the Exclusion Zone;

– the Exclusion Zone is a territory, which is the most contaminated by radionuclides due to the ChNPP accident, its population has been evacuated, so social issues concerning RW disposal and the allocation of objects intended for RW management will be reduced to minimum here;

– as the main part of RW, liable to disposal, are concentrated in the Exclusion Zone, transportation expenses and the problems of safety of RW transportation to disposal facilities in near and middle prospective will be minimum too;

– previous investigations conducted within the Exclusion Zone and the adjacent territories indicate the availability of prospective areas for repositories construction (including geological one) for storage and disposal of RW of all kinds.

The main tasks concerning creation of the national system of RW management in Ukraine are the following:

– completing inventory of RW of power engineering, industry, scientific and medical institutions of Ukraine and UkrSA «Radon» facilities and RW and RCM ones in the Exclusion Zone;

– development of reports on safety analysis and estimation of the influence of RW depositories in the Exclusion Zone on the environment as the basis for making decisions concerning their conservation or re-disposal;

– conducting the work on site selection for location of repositories for storage and disposal of short-living RW and the work on site selection for location of deep geological repository for isolation of high level and long-living RW;

– development of feasibility study for creation of the national system for RW management in Ukraine taking into account the problems of power reactors and other nuclear and radiation hazardous objects;

– development of the schedule of creation of infrastructure for RW management in Ukraine including facilities for RW retrieval from RW storages in the Exclusion Zone and at-reactor RW storages, facilities for RW conditioning with the aim of their subsequent storage and disposal, the container stock and means for RW transportation and the container stock for RW storage and disposal;

– development of the general plan of location of the objects for RW management in the Exclusion Zone;

– development of the schedule of supply of RW of Ukrainian origin for treatment, conditioning, storage and disposal taking into account the nuclear power engineering needs;

– optimization of operation of the existing objects intended for RW management;

– design and construction of facilities for storage and disposal of all kinds of RW;

providing realization and functioning of the National Centre for RW Treatment, Storage and Disposal in the Exclusion Zone as the basis for improvement of radiation safety of Ukrainian people and the stable development of nuclear power engineering and technologies.

11.2.2. The ways of solving the problem of high level and long-living RW isolation

The state of the problem of disposal of existing in Ukraine long-living RW in the stable geological formations is the following. Due to scientific & research work [19], Chornobyl region (the Exclusion Zone and the zone of absolute resettlement and some adjacent territories) is practically determined as such where the specialized work on site selection for long-living RW disposal should be concentrated.

The choice of potentially suitable areas should be based on the results of complex studying of geological structure and hydrogeological conditions of the territory by using various geophysical, remote and indicator methods, direct geological and hydrogeological investigations with carrying out required drilling operations and experimental work, and using complex of borehole geological & geophysical investigations.

Now the following alternative options of RW geological repositories are conceptually examined.

1. ***Construction of single shaft-type deep geological repository*** intended for placement of RW, accumulated to the moment of its putting into operation (about year 2040) and accumulated during the period until closure of the repository. According to this option, all kinds of high level and long-living RW will be withdrawn into such deep geological repository [3, 9]. The repository should be complex and multimodule by its structure [20].

2. ***Construction of two geological repositories of different types: borehole type and shaft-type.*** It means distribution in time of all amounts of RW by two flows, which must be withdrawn into the stable geological formations. SNF, FCM and vitrified HLW could be located in the repository of borehole type, which can be constructed considerably faster: by 2025. The shaft-type repository can be put into operation later, when the main work on decommissioning and preparation to the disposal of long-living RW from the Object Shelter and storages of the Exclusion Zone is completed. The high level and long-living RW, which arise at operation and decommissioning of NPP reactors, will be also withdrawn to the shaft-type repository.

According to the calculations [21], disposal of SNF and vitrified HLW in the repository of borehole type is twice cheaper, and the total value of the investigations, necessary for grounding the possibility of creation of such repository, is about 4–5 times less in comparison with the repository of shaft type.

Besides, reduction of RW amounts for isolation in the geological repositories of both types can be achieved, if the possibility of disposal of the part of long-living RW in the surface repositories at the territory of the central part of the Exclusion Zone is grounded.

This variant will be suitable, first of all, if total amounts of SNF and RW, which in fact are liable to disposal in the shaft-type repository, will be sufficient for justification of expenses for this repository realization.

So, the choice of optimum concept for long-living RW isolation in the stable geological formations requires urgent comprehensive technical and economical analysis with consideration of alternative decisions, particularly those, concerning the Object Shelter. However, irrespective of subsequent development of RW withdrawal conception, and, in particular, of determination of the amount and the type of geological depositories, conducting direct geological investigations on studying subsurface structure of the region with appropriate drilling activities using the complex of borehole geological & geophysical methods, is quite necessary.

11.2.3. The main measures concerning disposal of RW of Chornobyl origin

In view of the thematic orientation of this document, main attention will be paid below to determination of measures concerning the problem of management of RW, concentrated in the Exclusion Zone. It does not mean that these measures are planned separately from the common needs of develop-

ment of the national system of RW management. On the contrary, they must become the integrated part of this system. Expediency of creation of main objects concerning RW storage and disposal just in the Exclusion Zone has been grounded above. So, the primary task is formation of technical requirements to the infrastructure for RW management, which will be created in the Exclusion Zone, by the departments and organizations, which are RW owners.

The main approach concerning solving the problem of radioactive waste storage and disposal is based on the following:

– storage of all kinds of RW and disposal of short-living RW are planned to be carried out at the Vector Complex, for which the National Centre for RW Treatment, Storage and Disposal should be created on the industrial site of the Vector Complex;

– surface repository of the trench type should be used for disposal of RW of very low activity;

– deep geological repository for RW should be developed for disposal of high level and long-living RW.

All technical measures concerning radioactive wastes management in the Exclusion Zone are considered separately for RW, which were created as a result of the following [22]:

– the Chornobyl accident (and those to be created in course of mitigation of its consequences);

– the ChNPP (and those to be created in the process of its decommissioning);

technical maintenance of the Object Shelter (and those to be created during transformation into environmentally safe system).

By terms of the work implementation, all the measures are divided into primary, short-term and long-term ones.

Primary measures

The duration of primary measures implementation is about 5 years. The content and amounts of the work for this period are determined by the Complex Program for Radioactive Waste Management for 2002–2005 and for the Period to 2010, which is affirmed by Resolution of the Cabinet of Ministers of Ukraine from December 25, 2002 No. 2015 [3].

Primary measures include construction of the following objects in the Exclusion Zone:

– Vector Complex;

– facility liquid RW treatment;

– facility for removal and treatment of solid RW;

– repository for disposal of RW, to be retrieved from the ChNPP storages (at industrial site of the Vector Complex);

– new safe confinement for the Object Shelter.

Besides, one should consider the essential expansion of the scale of exploration activities aimed at site selection for geological repository (of shaft and borehole types) as primary measure.

The final result of primary measures realization will be achieved, if the following objects intended for RW management are put into operation:

– the first and the second turns of the Vector Complex;

– facilities for liquid and solid RW treatment at the industrial site of the ChNPP;

– the second turn of SDRW «Buryakivka».

The perspective areas for detailed exploration aimed at site selection for deep geological repository should be determined.

Short-term measures

The duration of implementation of short-term measures concerning RW and RCM management in the Exclusion Zone is about 20 years. The aim of the short-term measures is transformation of RW and RCM into ecologically safe condition. It is realized by means of the following:

– re-disposal or localization of the most hazardous STLRW and SDRW;

– preparation to retrieval of high level wastes from the Object Shelter;

– beginning of retrieval of high level waste from SDRW and their placement in special facilities at the Vector Complex;

– conditioning and storage of RW at the Vector Complex;

– carrying out detailed exploration activities on searching the most prospective sites for location of deep geological repository;

– design and construction of underground research facility for confirmation of site selection for the deep geological repository and experimental verification of the technologies of high level and long-living RW isolation;

– completion of the work on prospecting and confirmation of the site and conducting the work on

construction of the deep geological repository (in case of making decision on creation of the deep geological repository in the deep boreholes).

It is envisaged during implementation of short-term measures to create and ensure operation of Vector Complex as a part of:

– technological complex for all kinds of RW treatment;

– repositories for short-living RW disposal;

– storages for long-living RW storage;

– storages for FCM storage;

– storages for vitrified high level waste.

It is necessary during short-term measures realization to determine the amounts and sources of financing, the customer for conducting exploration, scientific and research activities concerning siting of deep geological repository, to select site, to develop the technical and economical assessment of investments, to complete design activities and start construction of the deep geological repository.

The final results of short-term measures must be the following:

– assurance of STLRW and SDRW transformation into ecologically safe condition;

– transformation of the Object Shelter into the surface repository for short-living RW disposal;

– completing radioactive equipment conservation as the intermediate stage of the ChNPP decommissioning;

– completion of exploration activities aimed at site confirmation, and start of the deep geological repository construction.

Long-term measures

The duration of the long-term measures is about 50–70 years.

The strategic goal of the long-term measures is concentration of the main work concerning SNF, RW and RCM management in that part of the Zone, which will become so-called «industrial» zone, which is not liable to rehabilitation.

The main activities, related to elimination of the consequences of Chornobyl accident are carried out at the territory of «industrial» zone. This is a territory where objects intended for RW management are located, and where the work on prevention of spreading of radionuclides from the most hazardous places of their concentration to the natural objects is carried out. Here, the following activities are carried out:

– RW treatment, storage and disposal;

– ChNPP decommissioning;

– transformation of the Object Shelter into environmently safe system;

– designing, construction, licensing and putting into operation of the deep geological repository of shaft type and the deep geological repository of borehole type.

The final results of long-term measures must be the following:

– completion of the stage «final closure» and «conservation» during the ChNPP decommissioning;

– putting into operation deep geological repository in the Exclusion Zone.

In total, the Vector Complex and deep geological repository will permit to create the National Centre for treatment, storage and disposal of all the types of RW.

Conclusions

Summing up the aforesaid, one can make the following main conclusions:

1. The considerable amounts of radioactive waste are accumulated in Ukraine. They arose due to the ChNPP accident, operation of nuclear power plants and research nuclear reactors and at the use of the industrial radiation sources in the industry, medical and scientific institutions. RW amounts will increase due to operation of nuclear power cycle facilities and at NPP decommissioning. The total amount of RW, which is liable to disposal, can be equal to 3.3–4.6 million m^3. Among them, about 75000 m^3 must be disposed in the deep geological repository. To 90% of amounts of all radioactive waste are concentrated in the Exclusion Zone.

2. In Ukraine the national system of RW management, which should be balanced taking into account the interests and mutual obligations of manufacturers of radioactive waste and organizations, responsible for their storage and disposal, is absent. Such situation creates the threat for the national safety, stable development of economy and is an obstacle for integration into European structures.

3. For implementation of the national system of RW management in total and solving the problem of RW final disposal, it is necessary to carry out such primary activities:

– to establish the National fund for radioactive waste management;

– to develop the strategy of radioactive waste and spent nuclear fuel management;

– to accept the long-term national purpose program of radioactive waste management and, as its component, the national program for high level and long-living RW disposal.

4. The long-term national purpose program of RW management will allow to achieve high level of nuclear and radiation safety owing to creation of the unified RW management system, introduction of unified technical policy concerning radioactive wastes management and their physical protection, reduction of risks of radioactive wastes ingress into non-controlled using.

5. Creation of the unified system and introduction of unified technical policy concerning radioactive waste management will provide a number of economical, social and ecological results, namely:

– stimulation of the stable development of nuclear power engineering and reduction of the economical burden on future generations (economical results);

– rising the level of the national safety (reduction of radiation consequences of natural and man-caused accidents, acts of terrorism, military operations); reduction of social & psychological stress in the society and providing social development of the regions where RW repositories will be created (social results);

– guaranteed isolation of radioactive waste for prevention of radiation hazardous influence on biosphere for thousands years; transformation of the Object Shelter into an environmentally safe system; completeness of the ChNPP accident consequences elimination; rising radiation safety of NPP units (ecological results).

12. GOVERNMENT MANAGEMENT IN THE SPHERE OF THE ChNPP ACCIDENT OVERCOMING AND LEGAL SUPPORT

12.1. Government management in the sphere of the ChNPP accident overcoming

The scale of the Chornobyl NPP nuclear reactor accident did not fall within the framework of the Soviet Union regulatory documents because such accidents had never been considered possible. In reality, a wide range of the Chornobyl-origin radioactive isotopes became globally spread, and this posed absolutely new challenges to the Soviet legislative and executive bodies. Those challenges included localizing and minimizing Chornobyl catastrophe consequences. The problems that emerged as a consequence of the ChNPP accident as well as the recovering management measures on the state level were implemented on the basis of resolutions taken by the Central Committee (CC) of the Communist Party of the Soviet Union (CPSU), USSR Council of Ministers, decrees of the corresponding Ministries and departments, different State Commissions' decisions. All those measures were either totally classified, or partially classified or restricted, narrowed the frames of their implementation. In the Ukrainian SSR, the CC of Ukrainian CP and the Cabinet of Ministers took their own resolutions. They were published in 1990 in the collection of resolutions published for the Ukrainian Verkhovna Rada (VR) deputies [1].

To provide population with radioactive protection from the very first days of the accident, the USSR Ministry of Health started to introduce frames for radioactive contamination levels of environmental objects, the human body, buildings, roads, individual radioactive exposure doses, permissible levels of radioactive elements content in food products, agricultural materials, etc. Those rules helped to implement organizational and management measures that ensured the optimal level of human protection from the ChNPP radioactive releases. In 1987, a new edition of Radiation Safety Norms (RSN-76/87) and Principle Sanitary Norms (PSN-72/87) [2] were enacted in the USSR with consideration of verified data on ionizing exposure of the human body, and with regard to the additional experience in ensuring radiation monitoring and implementation of preventive measures. Special guidelines framed medical assistance for the population in the areas of NPP location and at radioactive accidents [3–6].

Radiation Safety Norms (RSN-76/87) contained an absolutely new set of norms for each category of irradiated people, with a breakdown into three classes: main exposure limits, permissible limits and control limits. Maximum limit of annual admissible doze considers the main exposure limits for category «A» (staff), while an annual dose limit (DL) pertains to category «B».

According to RSN-76/87, the radioactive exposure of the limited part of the population should be controlled through measuring of radioactive emissions, dose rate in the locality and levels of environmental radioactive contamination (air, water, food, etc.) with subsequent dose calculations. When people of category «B» get exposed to the radiation, the individual effective dose should not exceed 0.5 rem (0.005 Sv)/year.

In 1996, practically all the documents and materials related to the ChNPP accident became accessible to the public and were published in a special collection [7]. It contains materials regarding the conditions of the NPP construction and running, system of government control over accident recovery operations and its consequences as well as reference to the adopted regulatory documents as regards the accident recovery operations (508 documents from 1967 till 1996). This can serve as a proof that problems connected with the ChNPP accident became the focus of attention for the former USSR, and also Ukraine, Belarus, Russia State authorities from the very first days of the accident.

In this resolution dated 25.04.90 [8], the USSR Supreme Council admitted that, by aggregate consequences, the ChNPP accident was the biggest disaster of present times, a national calamity that influenced millions of people residing on huge territories.

The CPSU XXVIIIth Congress [9] made a political assessment of the ChNPP catastrophe and its recovery operations. The Congress recognized that the recovery measures had not been satisfactory and sufficient. In Ukraine, the Declaration to the XXVIIIth Congress of the Ukrainian CP «On the ChNPP Accident Recovery Operations and Population Protection from its impact», dated July 1990, and the Ukrainian Verkhovna Rada Decree dated August 1, 1990 [10] made a general assessment of the ChNPP accident recovery operations. Those documents became a starting point to transfer to a new quality approaches in implementation of recovery operations.

In 1990, the Ukrainian Verkhovna Rada (VR) at its sessions two times considered the environmental situation and urgent measures to protect population from the ChNPP accident consequences. The VR Commission was set up to solve ChNPP problems. 1990 was announced the year of rehabilitation of children who resided in the area affected due to the accident [11]. To provide scientific support

in solving the issue of population radioactive protection and increasing participation in international cooperation in this sphere, it was decided to set up a National Commission for Ukrainian population protection and a State Committee of Ukrainian SSR for resolving the ChNPP accident issues. The national territory was announced as a zone of environmental disaster. The Head of the State Commission of Emergencies received the authority of the 1st Deputy to the Chairman of the Ukrainian Cabinet of Ministers. It was also decided to set up special departments in the Ukrainian Government, in different Ministries, in Zhytomyrska, Kyivska, Rivnenska, Chernihivska, Volynska, Cherkaska, Vinnitska regions administrations, and, if necessary, in other regions, which would be responsible for arranging the ChNPP accident recovery operations as well as operations to overcome natural disasters and other emergency situations consequences [10].

Following the proposals of the Ukrainian Verkhovna Rada Deputies and general public regarding perpetuation of the tragic events connected with the ChNPP accident and to prevent nuclear accidents in the future, on March 29, 1990, the Presidium of the Ukrainian SSR Verkhovna Rada in its Decree № 8985-XII announced the day of April 26 to be «The Day of Chornobyl Tragedy».

Beginning from 1990, the decisions taken at the government level regarding the assessment of implemented measures to recover from the ChNPP accident and proposals to prevent them in the future started to get enacted. The «State Union-Republic Program for immediate Actions in 1990–1992 to recover from the ChNPP accident consequences» [8] was approved. It reflected the measures to be implemented specifically in Ukraine.

Resolution № 115, dated May 21, 1990, issued by the Ukrainian Cabinet of Ministers and Ukrainian Trade Unions Council instructed Kyivska, Zhytomirska, Rivnenska and Chernihivska Oblasts' executive committees to ensure resettlement of citizens from the territories that had been exposed to radioactive contamination following the ChNPP accident.

Before 1991, the Program of tasks had been implemented on the all-union level. After the USSR separation, the accident recovery operations were implemented by each republic independently, which created many problems.

In general, the State Union-Republic program and adopted decrees stipulated a number of wide-scale state measures directed on ensuring on environmental safety, health protection and improvement as well as social and legal protection of the ChNPP catastrophe victims.

Ukrainian government and local authorities implemented measures to minimize the ChNPP radioactive exposure impact on human health. Over the period 1987–1990, the Ukrainian government adopted 116 resolutions and decrees to recover from the ChNPP catastrophe consequences. The State Program «Urgent Measures to recover from the ChNPP accident consequences in Ukraine during 1990–1992» was developed and implemented. Despite those measures, the situation on contaminated areas remained very adverse. The problems attributed to lack of detailed inspection of the contaminated area and evaluation of the radiation condition, absence of proper and objective information for the public regarding the radioactive condition, as well as unjustified delays in developing the national concept of people residence in areas affected from radioactive contamination became extremely acute. Till today, the status of the 30-km exclusion zone and other contaminated territories has not been identified, and reliable social protection for accident victims has not been ensured. The decisions regarding provision of clean food and dosimeters to the population of the contaminated areas, health improvement and medical care of people, construction of households and social assets, and solving other urgent tasks were not implemented.

While making decisions, the local executive authorities were guided by provisional norms of radionuclides contamination that had been approved by the USSR Ministry of Health in May 1986.

Pollution density was considered to be the main criteria of provisional norms for radionuclides contamination, which were approved by the USSR Ministry of Health in May 1986.

On 25.04.90, the USSR Supreme Council issued an order to the USSR Cabinet of Ministers to develop a scientifically grounded concept of safe residence in the contaminated sites. The 35-rem concept recommended by the USSR Ministry of Health was not adopted by the supreme legislative bodies – Supreme Soviets of USSR, RSSR, BSSR, and Ukrainian SSR.

At that time, discussions regarding selection of one of two concepts: the 35-rem or the 7-rem, were very heated between the scientists.

The USSR Supreme Council issued Resolution № 1452-1 dated April 25, 1990, where attention was paid to the fact that «...the measures taken to recover from the accident consequences have not been sufficient. In radiation contaminated areas, there is a very tense socio-political situation, stipulated by the contradictions in recommendations issued by scientists and specialists in radioactive safety, by delays in implementing the required measures and, as a result, some people lost their confidence in the central and local authorities.» Therefore, it was decided not to accept the maximum dose of 35-rem pro-

posed by the USSR Academy of Sciences and approved by the USSR Cabinet of Ministers in September 1989. The USSR Cabinet of Ministers was ordered to finish in 1990 the formation of scientifically grounded criteria for safe residence of people with consideration of the non-threshold (human) concept and other modern developments.

Therefore, supporters of the 7-rem concept won.

At the end of 1990, the Supreme Council Commission in the issues of the ChNPP accident, the USSR government, the National Academy of Sciences, NGO «Soyuz Chornobyl» moved the draft Concept of Residence in areas with elevated levels of radiation contamination due to the ChNPP accident and draft laws «On the legal regime of the area affected from radioactive contamination due to the ChNPP accident» and «On the status and social protection of citizens who suffered from the ChNPP catastrophe».

While developing the draft Concept of Residence in areas with an elevated level of radioactive contamination due to the ChNPP accident, the materials of the Scientific Report of the NASU Council that studied the productive forces in Ukraine were taken as a basis [12] to be submitted to the Ukrainian Cabinet of Ministers. The report suggested the Concept of Radiation Safety where criteria and norms of human residence and life support were identified and substantiated. On the basis of the radio-geo-chemical indicators for the contaminated areas by the level of radioactive threat to the population and economic performance, the following zones were differentiated in the report:

1. Relatively safe zones for living – are those areas where the contamination density reaches: Caesium-134, 137 – up to 1 Ci/km^2, Strontium-90 – up to 0.1 Ci/km^2, Plutonium-239, 240 – up to 0,005 Ci/km^2;

2. Relatively unsafe zone for living – are those areas where the contamination density reaches: Caesium-134, 137 – 1–3 Ci/km^2, Strontium-90 – 0.1–0.2 Ci/km^2, Plutonium-239, 240 – 0.005–0.01 Ci/km^2;

3. Unsafe zone for living – are those areas where the contamination density reaches: Caesium-134, 137 – 3–5 Ci/km^2, Strontium-90 – 0.2–0.5 Ci/km^2, Plutonium-239, 240 – 0.01–0.03 Ci/km^2;

4. Absolutely unsafe zone for living – are those areas where the contamination density reaches: Caesium-134, 137 – more than 5 Ci/km^2, Strontium-90 more than 1 Ci/km^2, Plutonium-239, 240 – more than 0.03 Ci/km^2.

With regard to the major social importance of the draft laws, the Commission in the issues of the ChNPP accident decided to initiate a nation-wide discussion. The draft-laws were published in the central newspapers. Thousands of Ukrainians, different ministries, departments and organizations sent their comments to the Commission. Proposals and conclusions as well as the governmental decisions in the period 1986 – 90 regarding the ChNPP accident, were attentively studied by the Commission, the draft-laws were elaborated and on February 5, 1991 they were moved for the consideration of the VR Session, first reading. On February 27–28, 1991, they were adopted by an overwhelming majority of deputies.

The Concept, being a basic document for decision-making, was agreed with the majority of Ukrainians, the Ukrainian Cabinet of Ministers and the Academy of Sciences.

The purpose of the adopted Concept is «to reduce the ChNPP adverse impact on human health» and «the basic principle of the Concept is that for the critical group of the population (children born in 1986), the amount of additional effective radioactive exposure dose due to the ChNPP accident should not exceed 1.0 mSv (0.1 rem)/year and 70.0 mSv (7-rem) during a lifetime in excess of the dose received by the population before the accident depending on specific natural conditions» [13].

The Concept specifies that «to perform resettlement of the population, the provisional criteria of soil contamination with radionuclides will be used till the individual effective exposure equivalent dose is determined».

The Concept and the following Laws stipulated that the whole territory, contaminated with accident emissions should be divided into zones.

Social protection of the catastrophe victims is ensured by the Ukrainian law «On the status and social protection of citizens who suffered from the ChNPP catastrophe», adopted on 29.02.1991 [14].

The law differentiates between two groups of population who suffered from the ChNPP accident. The first group included the ChNPP recovery operation workers (ROW). To the 2nd group belong those, who suffered from the catastrophe, i. e., citizens, including children, who were influenced by radioactive exposure after the ChNPP accident. To determine benefits and compensations, all the victims were divided into 4 categories.

The adopted laws «On the legal regime in the area that suffered from radioactive contamination due to the ChNPP accident» [15] and «On the status and social protection of citizens who suffered from the ChNPP catastrophe» helped to provide legal definition of contaminated zones depending on the

level of probable adverse impact on human health, determine criteria for first-priority resettlement, arrange control over safe living, and organize proper living conditions in the contaminated areas. Each victim of the ChNPP accident received guaranteed benefits and compensations from the state depending on the determined category [16].

To raise the status of the state authorities which deals with the ChNPP issues, Ministry in the issues of population protection from the ChNPP accident consequences was set up by law № 1030б-XII, dated May 13, 1991 «On the list of ministers and other central bodies of Ukrainian SSR state management», which was proposed by the Commission in the ChNPP accident affairs.

The stated facts provide all the grounds to consider that the state function in recovering from the ChNPP accident consequences was among the most important ones.

The state function becomes really important after it gets fixed in the Constitution. In contrast to other former USSR republics, the Ukrainian Constitution reflects the state function in recovering from the ChNPP consequences in its Constitution: «...recovering from the ChNPP consequences – the catastrophe of a global scale, preservation of the Ukrainian people gene pool – are the duty of the state (Article 16).

After «Chornobyl» laws were adopted, the issues of financial support for the whole Chornobyl program came on the agenda. The Verkhovna Rada Resolution № 2006-XII, dated 20.12.1991 «On the draft of the Ukrainian National Budget for the 1st quarter of 1992» set up a special Fund for recovering from the ChNPP consequences and for providing social support to the population. Contributions from enterprises and business entities regardless of their ownership were to be made to the Fund in the amount of 19 % of waybill with referring the allocated amounts to the products' (services, works) cost price. The Verkhovna Rada resolution «On the procedure of enacting the Ukrainian Law № 2147- XII, dated 21.02.92 «On the taxation of revenues of enterprises and organizations» decreased the allocations to the Chornobyl fund to 12%.

The Ukrainian law «On forming the Fund to implement measures in recovering from the ChNPP catastrophe consequences and population social protection» (1997) decreased the contributions rate to 10% with referring the allocated amounts to the gross production costs and turnover of the payer [17].

Ukrainian President's decree № 857/98, dated 07.08.1998 «On some changes in taxation», stopped levying the duty on the Chornobyl Fund. The decree pointed out that financing of costs attributed to recovering from the ChNPP accident consequences and associated with social protection of the population would be executed at the expense of the State Budget entailing increase of budget allocations at the expense of the taxation basis increase.

The Ukrainian law № 1445-III, dated 10.02.2000, set the procedure for forming, paying and allocating Fund finances to support measures in recovering from the ChNPP accident consequences. The law pointed out that all the expenses attributed to the measures in recovering from the ChNPP catastrophe consequences were to be covered by the Fund finances as well as by other sources specified in Ukrainian laws. The Fund was created within the Ukrainian State Budget. The fund amounts were accumulated at the special account of the Ukrainian State Budget. The Ukrainian Ministry of Emergencies and in issues of population protection from the ChNPP accident consequences [18] was appointed as the manager of the Fund money.

It was the way of creation of a legislative foundation to implement national policy in comprehensive protection of the ChNPP accident victims.

The experience gained while implementation of the Ukrainian law «On the status and social protection of citizens affected from the ChNPP accident» testifies that the strategic tasks in social protection of the Chornobyl accident victims were set correctly. ROW who personally performed recovery operations at the ChNPP, as well as the most vulnerable population cohorts – children and disabled, residents of settlements that are located in the radiation-contaminated areas – were taken under protection.

More specifically, this law identifies the main provisions in implementation of the ChNPP accident victims' constitutional right to guaranteed life and health protection. A unified procedure of determining the status of the victims was also determined. After the laws were approved, work was initiated to develop and enact by-laws to implement the requirements and provisions determined by the law, especially the procedure of determining the status of victims and arranging their reliable social protection. However, we have to point out that the majority of the stipulated measures have never been implemented and have not met expectations.

In 1991–2004, the Verkhovna Rada made a number of amendments to the current Ukrainian Law «On the status and social protection of citizens who suffered from the ChNPP accident», the majority of which pertains to specifying the law norms and delivery of social guarantees to the victims. For example, when making a revision to the law on June 6, 1996, a new procedure to determine the categories of victims was introduced. Besides, the list with benefits and compensations to the children, disability of whom was attributed to the ChNPP accident, was extended [19].

In total, since 1990, the regulatory base in the ChNPP accident area has incorporated more than 800 documents, which provide for regulating different aspects of the ChNPP accident victims. Amendments to the Law «On the status and social protection of citizens who suffered from the ChNPP catastrophe» were moved for approval 27 times, and the law «On the legal regime of the area that suffered from radioactive contamination due to the ChNPP accident» was moved 9 times.

The Verkhovna Rada pays much attention to the study of theoretic and practical issues in legal regulation of the ChNPP victims' social protection. Review of the legislation as regards social protection and practices of its enactment, carried out annually by the Verkhovna Rada within the framework of parliamentary hearings, or the so-called «Government days», helps identify main problems of its improvement and proposes the ways of its enhancement.

First of all identify problems in Recommendations of the parliamentary hearings participants «15th anniversary of the ChNPP accident. Experience of recovering», approved by the Verkhovna Rada decree № 2404-III, dated 26.04.2001, state that it is necessary to develop and move for the VR approval a National program on elimination of the ChNPP accident consequences in the period 2001–2005 and till the year 2010. A special provision should be reserved for accomplishing the resettlement of citizens from the compulsory resettlement zone (those who agreed to resettle) with provision of housing to the citizens who independently resettle from the contaminated areas, and to the citizens who are referred to as category 1 and 2 victims [20].

It was also proposed to elaborate the issue of indexing disability pensions paid with regard to disability or disease due to the ChNPP accident, and pensions due to the death of a family provider because of the ChNPP accident; to consider the possibilities of increasing pensions by age to the former ROW and victims of the ChNPP accident; to reconsider the Cabinet of Ministers resolution № 987, dated June 20, 2000 «On approving the procedure for utilizing the Fund's finances when implementation measures on recovering from the ChNPP accident consequences and social protection of the population» as regards payment of compensations and benefits, stipulated by the Ukrainian law «On the status and social protection of citizens who suffered from the ChNPP catastrophe», to working pensioners in places where they receive their pensions; prepare and forward proposals to the VR as regards indexation of compensations for property lost during evacuation, resettlement or independent movement, paid to the citizens before the Ukrainian hrivna was introduced.

Five years ago, the issue of developing and approving a National program for social and economic rehabilitation of settlements for the period till 2010 was raised for the first time. The Program has not been approved yet.

Having assessed the work of the Ukrainian government in implementation of the «Chornobyl legislation», the Ukrainian VR found that it has been insufficient or unsatisfactory. The VR also stressed that the above-named legislation had to be enacted.

During Parliamentary hearings on the eve of the Chornobyl accident's 17th anniversary, special attention was paid to the growing importance of comprehensive scientific research that is to become the foundation for management decisions. It was stressed that identification of risks for human health attributed to radioactive exposure due to the ChNPP accident, integral indices of exposure hazards used to calculate those risks; studying radioactive exposure impact on the environment; development of new strategies in solving the problems of radio nuclides spread in water, air, and soil; and studying probable consequences for different population groups exposed to the radiation risk due to their lifestyle remained to be very acute. Attention was paid to the problem of setting radioactive exposure doses, to the necessity of continuing assessment of the Chornobyl accident consequences to implement an adequate policy regarding the contaminated areas, and to implement comprehensive measures in economic, social and medical-psychological rehabilitation of the population [21].

Failure to implement those recommendations today impedes the process of taking grounded decisions regarding revision of boundaries for radiation-contaminated zones.

«Vision of the future» [22] made a comprehensive analysis of state control in the sphere of recovering from the Chornobyl accident consequences and legal support.

First of all, the necessity to look for new ways of recovering from the Chornobyl accident consequences and to protect the victims of the Chornobyl catastrophe – transfer to a new phase of recovering from the ChNPP accident consequences, the phase of renewal and development – was stressed.

Parliamentary hearings participants issued recommendations where they stressed that the main prerequisites for transferring to a new phase – renewal and development – were full repayment of outstandings in benefits and compensations, implementation of state obligations in providing housing, resettling from contaminated areas, meeting house-construction obligations, etc. Any delay in repaying all types of outstandings to the Chornobyl victims is totally impossible any longer.

Transfer to a new phase is to be followed by revision of the status of the areas that suffered from

radioactive contamination after the ChNPP accident in accordance with the state program of rehabilitating radiation-contaminated areas. Along with this, it was stressed that change in the settlements' status should not in any way be followed by changes in the status and level of the Chornobyl accident victims' social protection.

This argument is supported by the Concept of the draft law «On amending the Ukrainian law «On the legal regime in the area that suffered from radioactive contamination due to the ChNPP accident» and «On the status and social protection of citizens who suffered from the ChNPP catastrophe».

The Concept stresses, primarily, that, in case the area status is changed, a number of measures are to be identified including actions in medical and psychological protection and rehabilitation of victims, prevention or limitation of stresses and ensuring a stable level of the population health indicators. Change in the areas status does not necessarily mean the change in the status of residents of the areas that suffered from the ChNPP accident.

Based on the current and forecasted situations we may conclude that improvement of the ChNPP accident victims' health should become the priority goal of minimizing of the ChNPP accident consequences. To achieve that goal, the methods of prevention, social and medical protection should be in preference. Support and expansion of national and international scientific programs that are aimed at solving the problems of the ChNPP accident consequences in the next 10 years, increase of the role of comprehensive scientific research and its practical usage should become the foundation of the further strategy in recovering from the ChNPP accident consequences.

Review of the ChNPP accident causes and processes in recovering its consequences obviously indicates that the new strategy should combine ecologic, social, medical and radioactive aspects of the problem. Without this, the optimal ways of prevention and elimination of consequences of that global disaster could never be developed, the vicious circle of self-reviving causes of new and old problems could never be broken, and the efficiency of expenditures that are to minimize the risks and create appropriate life quality of the exposed victims could never be enhanced.

In the state legislative acts, it is necessary to determine clearly the frameworks of legal regulation of state functions in the sphere of minimizing long-term consequences of the ChNPP accident. The system of constitutional-legal principles regarding that problem could have become an important stimulus for further improvement of state control over the system of problems attributed to the ChNPP accident and its consequences.

Accumulation of new scientific data regarding the ChNPP accident consequences, the health of victims and many other factors require further intensive work in improving the legislation to protect victims. In future, that work may be recommended for implementation along the following lines.

Social protection of the ChNPP accident victims should be understood as a system of economic, legal and other measures implemented by state authorities to compensate damages inflicted by the accident; to provide for social adaptation and rehabilitation of the victims, and their material support, and increase the level of medical and social service. Social protection should not be limited only to covering the damage inflicted by the ChNPP accident but it should have a multilevel character.

The following principles should underline the legal support in the sphere of the ChNPP victims' social protection: presumption of state responsibility for damages inflicted by the ChNPP accident; state guarantees for social protection; prevalence and personified character of the social protection; differentiation of compensations and benefits depending on the character of adverse impact and its consequences; and maximum utilization of available state resources provided for social protection.

The modern stage of the «Chornobyl legislation» development will involve the solution of a number of complex issues, among which one should mention development of unified approaches in determining criteria for damage coverage and differentiation of coverage scope; specification of victim cohorts; and identification of optimum forms for damage coverage and citizen protection.

As for today, the Ukrainian government has stipulated an increase in the Ukrainians' social protection level through focused public assistance based on determining its size according to the property status and family income.

From the legislative point of view, objective need (level of well-being) of the ChNPP accident victims should not be a precondition for rendering them social protection. The character and volume of the compensations and benefits provided should be determined by the level of adverse impact. But along with this, some of the benefits could not be considered damage coverage and should be excluded from the scope of damage coverage. We imply here labour benefits, which are rather hard to provide but they have to be provided by the employer; benefits in out-of-turn provision with highly demanded goods; out-of-competition entrance into educational establishments, etc.

As a result of the proposed program implementation regarding revision of the «Chornobyl legislation» in the future and enactment of protection measures in the «contaminated» areas, some of the areas

might loose the status of radiation-contaminated sites, meaning that the residents of those areas would also loose the right to receive compensations and benefits. In relation to this, it is considered to ensure those citizens with legally fixed guarantees of medical protection on the grounds that they have resided in the adverse impact zone.

From the VR point of view, the issue of reconsidering the boundaries of radiation-contaminated zones is one of the most important and complicated of all Chornobyl issues [22]. Firstly this is attributed to the fact that the majority of the special regulatory acts consider that, due to the ChNPP accident, large areas contaminated with radionuclides, where the life of residents requires a special form of economic performance and management have emerged. Secondly, one of the preconditions to refer citizens to the ChNPP accident victims is residence in the corresponding radiation-contaminated areas [14].

According to the laws [14 and 15], the boundaries of the radiation-contaminated areas are set and revised by the Ukrainian Cabinet of Ministers on the basis of expert evaluation performed by the Ukrainian National Commission in Radiation Protection, NASU, Ministry of Health, Minagroprom, State Committee for Hydromet, Ministry of Environmental Protection, Ministry of Emergencies in the response to the application issued by the Regional Councils of People's Deputies and to be approved by the VR. Until now, those zones have not been approved according to the legislation.

According to the Ukrainian Cabinet of Ministers Resolution No.106, dated 23.07.91, Paragraph 8, the Ministry of Emergencies and Regional Councils, in cooperation with the mentioned central executive authorities, would be making their annual proposals before December 1 of each year as to the revisions of the list of settlements considered to be the zones of radioactive contamination (Annexes No. 1, 2, and 3) [23].

But the majority of Regional state administrations propose to refrain from revising the zones boundaries. Some of them propose to develop a mechanism of reconsidering the status of the settlements that stipulate definition of the future status of those areas residents according to the social and economic conditions in which they live, and consider it necessary to retain the status of victims and guarantees of their medical support.

Ukrainian legislation stipulates that, in order to prevent radiological impact, it is essential to implement a system of medical, sanitary-hygienic and radiation protection measures, which would primarily rely on the Ukrainian Law requirements «On Ensuring Sanitary and Epidemiological Well-being of the Population» [24], and which are determined with the help of scientifically grounded evaluation of the radioactive exposure effect on a human being and principles of radioactive protection that are given in the State Hygienic Norms «Radiation Safety Norms in Ukraine» RSN-97 [25]; in the publications of the International Commission in Radioactive Protection; the UN Scientific Committee in the effects of Nuclear Radiation, the World Health Organization; the main standards of radiation safety set by the International Agency of Atomic Energy, and data of local and international experts [26].

All those documents envisage that radioactive protection measures have to be adequate to meet radiation hazards in each given moment and they should depend and be implemented according to the practical needs guided by the principles of justification, non-excess and optimization, specified in the norms RSN-97. Their practicality and economic viability should be ensured with principally new system measures for conducting radiation monitoring and monitoring the health condition of the ChNPP accident victims residing in the radiation-contaminated areas, and monitoring the hygienic condition of infrastructure objects.

Therefore, ecologic improvement of areas contaminated with radio nuclides, restoration of life in those areas, support for social adaptation of the victims, provision of medical and sanitary services for the victims are the principal social priority of the state policy in recovering from the ChNPP accident consequences.

Results of dosimetry certification testify a stable trend of radiation situation improvement in areas referred to radioactive contaminated zones. If in 1991 Ukrainian territory had 826 settlements, where the annual exposure dose for the population could exceed 1mSv, in 2001 there were 389 such settlements, and in 2004 there was 202 of them [28]. Dosimetry monitoring results testify that in 1,551 settlements, referred to the zone of elevated radiation monitoring, during the latest 3 years the annual total effective radiation exposure dose for the population has not exceeded 0.5 mSv [28]. Those settlements could be removed from the radioactive contaminated zone.

On February 3, 2004, the VR adopted the Ukrainian Law «On referring some of the settlements of Volynska and Rivnenska Oblasts to the zone of guaranteed voluntary resettlement» [27]. This law pointed out 6 settlements were transferred from the zone of compulsory resettlement to the zone of guaranteed voluntary resettlement. Adoption of that law was a positive step in increasing efficiency of social-economic and economic measures in the radioactive-contaminated areas, stabilization of the economic situation in the region, development of entrepreneurial performance, support of the working enterprises, etc.

At the same time, the adopted law created a legal conflict when the named six districts should be referred to the radioactive-contaminated zones in accordance with the legislation. In relation to this, there is a necessity to approve ASAP the list of settlements referred to the zone of radioactive contamination. For this, there should be adopted a special law following the proposal from the Cabinet of Ministers. The next step would be gradual removal of the settlements from the zone of radioactive contamination in accordance with the law.

One of the most important issues in elimination of the ChNPP accident consequences is a return of contaminated areas to normal life; provision of people with work provision of cities, regions, settlements, and people with the opportunity to implement their economic potential. Therefore, economic rehabilitation of the contaminated areas becomes a very important priority in victims' social protection.

The highest priority of social and economic protection must belong to the settlements that were transferred in 2004 from the zone of compulsory resettlement to the zone of guaranteed voluntary resettlement as well as the settlements that are planned to be reconsidered as regards the category of a radioactive contaminated zone.

Due to new scientific data regarding the ChNPP accident consequences, the issues of protecting the victims' health require further improvements in the legislation. At the same time, this process is hampered by lack of coordination between different levels of state authorities to minimize the ChNPP accident consequences.

The state legal mechanism to recover from the ChNPP accident consequences is an important component of the legal systems of Ukraine and other neighbouring countries that suffered from the ChNPP accident. It should represent a combination of state authorities that consistently implement the measures in localizing and minimizing the long-term ChNPP consequences as well as a system of organizational, regulatory and other means with the help of which the state implements the function of the ChNPP accident consequences recovery.

As stated in the VR regulatory acts, as of now the structure of the state-legal mechanism to recover from the ChNPP accident consequences in Ukraine is unbalanced. On the one hand, there is a sufficiently developed but not implemented system of regulatory support. On the other hand, the central and local executive authorities do not display consistent practical performance in this sphere.

The Ukrainian Ministry of Emergencies was responsible for elimination of the ChNPP consequences, but, since 1997, the Presidential Decree № 1005/96, of 28.10.96, delegated that responsibility to the Ministry of Emergencies and in Issues of Population Protection from the ChNPP consequences, which was the major (leading) authority in the system of other central executive bodies to implement the state policy in recovering from the ChNPP consequences. It was also responsible for coordinating state power bodies that are involved in solving various issues in protecting the victims, and in arranging cooperation and discussions between the state bodies and the victims (their representatives), as well as between all the social groups when making governmental and local decisions in protecting the victims.

We have to admit that, along with increase of the Ministry's functions in recent years, attention to the Chornobyl victims' problems got unfocused. Review of the Ukrainian Ministry of Emergencies' performance indicates that, in comparison with Ministry of Chornobyl, it has not become the body of inter-branch control, and, correspondingly, has not been able to solve the issues of cooperation with other ministries, state committees and other state authorities in full scale as well as to control their performance in implementing the programs of the ChNPP accident consequences recovery.

Feeling concern about the structural changes in control bodies, the local executive authorities, self-governing bodies, NGOs, People's Deputies proposed to set up a separate State Committee in the issues of the ChNPP accident consequences recovery, which would become a key uniting state authority in the sphere of ChNPP accident consequences recovery. This drive was supported by the taken decision regarding share of responsibilities between different executive authorities in performing the Chornobyl programs [22].

The VR paid attention to lack of consistent performance of central executive authorities in creating social and economic, organizational conditions and guarantees in the sphere of ChNPP accident victims' social protection and development of the contaminated areas. Contrary to recommendations approved by the VR resolutions, the destruction of the system of state control in recovering from the ChNPP accident consequences is continuing.

The Ukrainian President Decree № 755/2004 of July 6, 2004 «On measures to improve the system of state control in the sphere of the ChNPP accident consequences recovery» created a State Committee in issues of the ChNPP accident consequences recovery as a special central executive authority on issues of protecting population and areas from the ChNPP consequences, including victims' social protection, converting the Shelter to an environmentally safesystem, and rehabilitation of areas contaminated after the ChNPP accident.

In order to further improve state control in the sphere of the ChNPP accident consequences recovery, another Presidential Decree № 681/2005 of April 20, 2005 «On the Ukrainian Ministry of Emergencies and in the issues of population protection from the ChNPP accident consequences» abolished the Ukrainian State Committee in issues of the ChNPP accident consequences recovery and its functions were again transferred to the Ministry of Emergencies.

The year 2005 became prominent not only because of the «de-jure» abolishment of the State Committee in issues of the ChNPP accident consequences recovery, but also because of the fierce struggle between Ukrainian ministries to have «the right» to take care of Chornobyl victims.

As a consequence of such «state control», we have a situation when, on the eve of the 20^{th} anniversary of the Chornobyl accident, the country has manifested its inability to comprehend deeply the consequences of that tragedy, to timely solve scientific, psychological and legal problems that adversely impact implementation of a wide-scale system of measures in recovering from the ChNPP accident consequences.

Elimination of the ChNPP accident consequences is not an interim activity. It should be designed for many-years' focused national performance that will be implemented in the course of a long historical period. In this context, stability and persistence must become typical features of state control in the sphere of ChNPP accident consequences recovery.

12.2. On the issue of evaluating of the Chornobyl legislation efficiency

Efficiency of any means or measures is determined by their ability to reach the set goal in the set time by using identified resources. This raises the issue of scientific substantiation of the set tasks that are to be accomplished to reach the goal, and ways of implementing those tasks in the specified time with usage of special resources.

Having recognized that, in 20 years time, the ChNPP accident consequences have not been recovered, we have to ask a question about the efficiency of the Chornobyl legislation as a means to recover from the catastrophe consequences. We have to admit that the majority of measures initiated to implement the Chornobyl legislation requirements, have not been consummated and have not justified expectations in achieving the planned results. There are two reasons for this phenomenon.

The first reason, which is mentioned most often as the principal one, is the lack of finance in implementation of the planned measures; and the second one is insufficient substantiation of the planned measures.

The literature does not contain information about availability of detailed cost estimates as regards implementation of Chornobyl laws at the time when such decisions were taken by the VR in February 1991, but even at that time it was clear that implementation of those laws would be a serious test for Ukraine. In its resolution № 797 of 28.02.91 «On the procedure of enacting the Ukrainian Law «On the status and social protection of citizens, who suffered from the Chornobyl catastrophe» the VR, among other things, commissioned the Cabinet of Ministers with the following task:

– to move a proposal to the USSR Cabinet of Ministers to provide full financing from the Union budget to support the system of operations and measures to recover from the ChNPP accident consequences.

In case this proposal is rejected, allocations to the union budget should be decreased to the amount required to finance a system of works and measures to recover from the ChNPP accident consequences».

Literature can provide data on Ukrainian expenditure for recovering from the ChNPP accident consequences (see Section 7.1). There are also data on the ratio between planned and actual budget payments to finance measures stipulated by the Chornobyl legislation since 1992 [29]. But data on the financial needs for all the measures stipulated by the Chornobyl legislation, and their comparison with the planned and actual expenses are available only beginning from 1996 [30 and 31], Table 12.2.1. Regardless of some differences in figures presented in the named sources, the data reviewed allows for drawing the following conclusions.

Firstly, according to current legislation, financial needs have a steadily growing trend; from 1996 till 2004, they increased by 4.4 times. There are two reasons for that: first, inflation processes and cost of living increased; second, but not less important, constant «improvement» of the Chornobyl legislation through its amending and revision that has led to increase in the number and cost of benefits and compensations along with an increase in the circle of people who have received those benefits.

Secondly, there is a stable trend in decreasing the ratio between the state planned payments and the needs in accomplishing Chornobyl legislation. In 1996–1998, the planned expenditures covered 44–57% of the needs; in 1999–2002 – 21–29%; and in 2003–2004 – only about 11% of the planned expenditures from the current legislation. A paradoxical situation has been created when the legislator has been constantly increasing the costs stipulated by the Chornobyl legislation and, at the same time,

has kept reducing part of the needs, the financing of which is stipulated by the State budget, understanding, probably, that the state is incapable to finance in full scope the needs of the Chornobyl laws and also feeling doubt that the planned therein benefits and compensations have been well substantiated. That reduction in part of needs has been done by cutting expenses for implementing Chornobyl programs by way of suspending the strength of Chornobyl legislation articles (or their parts) when adopting the Law on the Ukrainian State Budget.

Thirdly, the plans to finance Chornobyl programs have not been met in full scope since 1999 inclusive, and the actual financing amounted to 55–87% of the plan. Only since 2000 actual financing has become comparable with the plan.

Table12.2.1

State of financing measures implemented to recover from the ChNPP accident after-effects and ensure social protection of the population in 1996-2005 (mln. UAH) [29 and 31]

Year	Need accord. to the current legislation	Amount stipulated by the State budget for the given year	Percentage of the need	Actually allocated	Percentage of the budget	Outstandings at the beginning of the 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 incl. 634.6 for soc. protection
2003	126567.4	1381.16	11.0	1381.16	100.0	7 incl. 596.4 for soc. protection
2004	14872.5	1710.97	11.5			685.4

It is natural that, in such conditions, Ukraine, represented by the state authorities and NGOs, addressed to the international community for help. It received substantial assistance, but in the recent years its volume has dropped, and we have to return back to the demand of substantiating assistance requests and substantiating the Chornobyl legislation itself. The situation becomes more understandable if it is considered in retrospective.

One of the key issues that determined further directions in planning and implementing the measures that were directed to protect population from the ChNPP accident consequences, was 1991 the VR approval of the **Concept of residence in the areas of Ukraine with elevated level of radioactive contamination due to the ChNPP accident** [32]. The Concept named the *main principle of population protection* which was **a stage-wise resettlement to radiation-clean areas identified by an interim criterion of the density of soil contamination with radio nuclides (Caesium, Strontium, and Plutonium)**. The reference to **lack of comprehensive information on the radiation condition of Ukrainian territory and the doses of additional radioactive exposure that have already been accumulated since the ChNPP accident, and which can additionally be taken in during the whole period of residence in the contaminated areas** was the key argument to substantiate that principle.

The Ukrainian laws «On the legal regime in the area that suffered from radioactive contamination due to the ChNPP accident» and «On the status and social protection of citizens who suffered from the ChNPP catastrophe» used that principle and criteria of the contamination density as a foundation for zoning the area that suffered from radioactive contamination due to the ChNPP accident.

The Ukrainian Cabinet of Ministers Decree No.106 of 23.07.1991 «On organizing implementation of VR decrees «On the procedure to enact Ukrainian SSR laws «On the legal regime of the area that suffered from radioactive contamination due to the ChNPP accident» and «On the status and social protection of citizens who suffered from the ChNPP catasrophe» determined a series of measures directed to implement the provisions of the current legislation regarding population protection from adverse impacts of the ChNPP accident and of recovery operations. It also determined a list of settlements referred to the zones of radioactive contamination (in total they counted 2,293 settlements) [33].

We have to point out that «Chornobyl laws» are substantially self-contradictory. According to Article 1 of the Ukrainian law «On the legal regime of the area that suffered from radioactive contamination due to the ChNPP accident», the areas that were exposed to radioactive contamination due to

the ChNPP accident included areas where the residents can receive an annual radioactive exposure dose of about 1.0 mSv (0.1-rem) [33]. A similar provision is contained in Article 3 of the Ukrainian law «On the status and social protection of citizens who suffered from the ChNPP catastrophe», where it is stated that the prerequisite for residence and labour performance without limitations connected with the radioactivity factor, is exposure to an additional dose from radioactive isotopes in the contaminated area. The additional dose should not exceed the annual level of exposure 1.0 mSv (0.1-rem) [34]. However, Article 2 of both mentioned laws, along with the determined categories of radiation-contaminated zones, contains also a zone of enhanced radiation monitoring, which is determined as a territory with the soil contamination density exceeding the pre-accident level contaminated with Caesium isotopes from 1.0 to 5.0 Ci/km^2, or Strontium from 0.02 to 0.15 Ci/km^2, or Plutonium from 0.005 to 0.01 Ci/km^2 on the condition that the estimated effective exposure dose for a human exceeds 0.5 mSv (0.05-rem) per year in addition to the dose that a human received in the pre-accident time. Ratios of radio nuclides migration in plants as well as other factors should also be accounted here.

In other words, some articles of the laws state that the zone of enhanced radiation monitoring is not the area that from radioactive contamination and does not require any limitations by the radioactivity factor in residential and labour conditions, while other articles of the same laws introduce measures of radioactive protection in the same areas, and the population receive benefits and compensations for residing in contaminated areas, and also it faces limitation of the labour performance by the radiation factor. According to official data [31], the number of population in radiation-contaminated zones is about 2.3 mln. people, including 1.6 mln., residing in the zone of the enhanced radiation monitoring.

We also have to point out that, according to the Concept, the density of soil contamination with radionuclides is used as a temporary criteria for decision-making till the individual effective exposure dose for the population is set. In Ukraine, since 1991, dosimetry certification of settlements that suffered from radioactive contamination due to the ChNPP accident has been carried out regularly. Individual effective doses of these settlements residents' exposure (the so-called certification doses) and their dynamics are well known and are published regularly. As for today, due to environment self-cleaning as well as implemented countermeasures, the concentration of radionuclides in environmental objects has decreased by 37%, and in agricultural products by 1.5–2 and more times, which correspondingly decreased by 2–3 times the doses of residents' external and internal irradiation. This is manifested in the change of settlements subdivision by levels of certification doses shown in Table 12.2.2. For the sake of comparison, the same Table contains the reference of the settlements to the zones of radioactive contamination as stated in the Ukrainian Cabinet of Ministers Resolution No. 106, of July 23, 1991, which is still in force today, excluding 6 settlements of Volynska and Rivnenska Oblasts, which, by the law [35], were transferred from the zone of compulsory resettlement to the zone of guaranteed voluntary resettlement. From Table 12.2.2, it is evident that there are contrasting differences between the regulatory reference of the settlements to the zones of radioactive contamination and dosimetry realities of today, but now there is no approved mechanism of changing the status of the settlements belong-

Table 12.2.2

Breakdown of settlements (ones that, according to the current legislation, have been referred to zones of radioactive contamination) by the level of additional irradiation doses determined on the basis of data from dosimetry certification [36–39]

Year of certification	Average irradiation doses in settlements (mSv annually)			
	< 0,5	0,5–0,99	1,0–4,99	> 5,0
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
1991. CMU Decree № 106	–	1290 (zone 4)	835 (zone 3)	92 (zone 2)

ing to zones of radioactive contamination. The whole issue has lost any sense and has become merely a political one.

In recent years, the Ukrainian government has been trying to remove contradictions between the current legislation and Ukraine's economic potential on the one hand, and between the level of social protection of the ChNPP accident victims and the growing social-psychological tension in different social groups on the other hand. But no noticeable changes in this regard have ever occurred. More than once, the submitted amendments and additions to the Ukrainian laws pertaining to on the ChNPP accident, which were called to lift discrepancies between separate articles of the laws, to agree the current legislation with the economic potential of the country, and to create a system of comprehensive protection of victims, were turned down by the VR Committees (previously, by Standing Commissions) as those that contradicted the current Concept. It impelled to develop a new document as a necessary foundation to reconsider Ukrainian laws in relation to the ChNPP accident. Such a document was prepared and approved by the Ukrainian Government in 1997, and in 1998 it was submitted to the VR, but at the end of 1999 it was recalled by the new Government to assess its topicality and for further elaboration.

The recent version of the Concept to protect population against the ChNPP accident consequences was based on internationally acknowledged scientific radiological criteria and recommendations; on the experience and knowledge accumulated during the years of recovering from the ChNPP accident consequences by local and foreign experts from different scientific branches.

Taking into account the importance of the Concept, the VR Resolution «On parliamentary hearings on the eve of the 14^{th} anniversary of Chornobyl catastrophe» recommended NASU, the Academy of Medical Sciences, and the Academy of Agrarian Sciences to study the Concept draft. The presidiums of all the above mentioned Academies studied the Concept at their sessions and expressed their support to it as a foundation for further improvement of the current legislation.

In 2000–2001, the Ukrainian government made some additional attempts to submit the draft of a new Concept for the VR consideration, but due to opposition from VR committees the document has never reached the stage of approval. The whole process was terminated by the Cabinet of Ministers Decree dated 25.07.2002 «On approval of the draft Concept of Ukrainian Law «On amending Ukrainian laws «On the legal regime of the area that suffered from radioactive contamination due to the ChNPP accident» and «On the status and social protection of citizens who suffered from the ChNPP catastrophe»

One more aspect to pay attention to this is a substantial difference in the compensation rates for the exposure dose stipulated by the Ukrainian Chornobyl and nuclear legislations. The Ukrainian law «On protecting humans from ionizing radiation» [34] has Article 19 «Compensation for excess over the annual main radiation dose», which stipulates that compensation for the excess annual main radiation dose is provided to people that reside or temporarily stay on the Ukrainian territory and experience forced consumption of food products and water contaminated with radionuclides, or if they reside, work or study in radiation- hazardous conditions provided they totally correspond to the ChNPP accident situation.

The same article stipulates that the compensation for the excess annual main irradiation dose should be equal to 1.2 non-taxable minimum income tax for each mSv exceeding the set admissible exposure limit.

According to the Ukrainian Law «On taxation of natural persons' income» (Article22. final provisions, paragraph 22.5), in case the regulations of other laws have references to non-taxable minimum and that minimum is planned to be used, then the amount of UAH 17 is used, excluding the norms of administrative and criminal legislation in the sphere of crimes' or offences' qualification, for which the amount of non-taxable minimum is set on the level of social benefit in taxation, determined by subparagraph 6.1.1, paragraph 6.1, Article 6 of this Law, and valid for the corresponding year (with consideration of the provision of paragraph 22.4 of this Article) [40].

Therefore, according to the «nuclear legislation» compensation for each 1mSv in excess of the annual main irradiation dose is UAH 20.4 (recall that, for the population, this limit is 1mSv per year). Taking again Table 12.2.2, we may easily calculate that if the residents of areas contaminated due to the ChNPP accident receive their compensations in accordance with the law, then we would see that, by the results of dosimetry certification of settlements referred to the zones of radioactive contamination according to 2004 data, the residents of only 206 settlements would have had the right to get compensations for over irradiation (excessive dose to the main dose limit), and that the annual compensation would have been no more than UAH 81.6 per person, because the highest dose did not exceed 5 mSv, and the dose, excessive to the main limit, was not more than 4 mSv.

According to the «Chornobyl legislation», the total amount of benefits and compensations

received by the residents of settlements, referred to the radioactive-contaminated zone, considerably exceeds the amounts stipulated by the «nuclear legislation» as compensations for the excess annual main irradiation dose, which violates the principle of social justice.

Therefore, in conclusion, we have to admit that the «Chornobyl legislation», despite is high humane content, has the following shortcomings:

- It is substantially self-contradictory;
- It is oriented to self-preservation; it does not contain active internal mechanisms of adaptation to changes in radiation situations in contaminated territories;
- The amounts of the stipulated benefits and compensations are not substantiated from the point of view of radiation protection;
- The total value of implementing all the legislation provisions is disproportionate to the economic potential of Ukraine;
- Its provisions regarding compensations for doses exceeding the main exposure dose limit contradict the Ukrainian «nuclear legislation». Due to this fact, the principle of social justice is violated and the ChNPP accident consequences can never be efficiently recovered.

Conclusions

Elimination of the ChNPP accident consequences is not an interim measure but a long-term state-targeted initiative to be implemented in the course of a long historical period.

Ukraine has a legal regulatory foundation to implement the national policy in the sphere of consistent protection of the ChNPP victims, which meets modern international and national norms of radiation safety.

The work of the Ukrainian Government in implementation of the «Chornobyl legislation» in the course of the last five years has been evaluated by the Ukrainian Verkhovna Rada as insufficient or unsatisfactory. The structure of the state legal mechanism to recover from the ChNPP accident consequences is not balanced. On the one hand, there is a substantially developed and non-implemented system of legislative-regulatory support, but, on the other hand, there is no consistent performance of central and local executive authorities in this area.

When forming new grounds for state policy in the sphere of recovering from the ChNPP accident consequences and social protection of victims, the VR stresses the necessity to transfer to a new phase in recovering from the ChNPP accident consequences – the phase of renewal and development.

For today, the issue of reconsidering the boundaries of radiation-contaminated zones due to the ChNPP accident is one of the most important and complicated issues in the Chornobyl issues pool.

Environmental improvement of radioactive-contaminated territories, renewal of life on these territories, support to victims' social adaptation, and provision of medical and sanitary services to the victims should become the overriding social priority of the state policy in recovering from the ChNPP accident consequences.

13. INTERNATIONAL COOPERATION

The Chornobyl accident has demonstrated that severe nuclear accidents cause global consequences and affect vital interests of many countries. Resources, which are necessary to overcome consequences of technological accidents of such scope exceed the limits of economic and industrial potentials of a separate country and require joint efforts of the world community.

At the first stage (1986–1989), international cooperation on Chornobyl matters was carried out under the coordination of the International Atomic Energy Agency (IAEA), since Ukraine and IAEA cooperation concerning peaceful application of nuclear power had begun long before Chornobyl accident.

The detailed information on the accident, its consequences and measures taken was reported by Soviet experts at IAEA meeting in Vienna in August 1986. The following priorities of interaction between ex-USSR and IAEA were defined:

• to define the causes of accident and its scopes;

• to assess implemented measures adequacy on radiation protection of population;

• to increase a safety level of RBMK reactors and all Nuclear Power Plants with reactors of the Soviet production.

IAEA, leading institutes of France (IRSN), Germany (GRS), national laboratories of the USA (PNNL, BNNL, ANL, etc.) and other countries have been cooperating in the important direction up to now.

Events in Chornobyl urged on creation of Convention on early notification of a nuclear accident and Convention on assistance in case of a nuclear accident or radiological emergency, which were accepted by IAEA General Conference at special session in Vienna on September 26, 1986. At the same time, it took official soviet circles some more years before to abandon the policy of ignoring real reasons and scopes of accident and to appeal to professionals of world nuclear society. Thus, in spite of the fact that the Convention on assistance in case of a nuclear accident or radiological emergency entered into vigor in the USSR on January 24, 1987 [1]; only in December 1989 for the first time the USSR appealed officially to international experts coordinated by IAEA. Ex-USSR government asked to make international examination of safe residence conception in areas with radiation contamination and to assess the efficiency of appropriate measures taken in Ukraine, Russia and Belarus. Since that moment, the number of participants of international collaboration on Chornobyl have been increasing, international collaboration on Chornobyl problems gained more intensity and the cooperation procedures have been improving; the necessity of cooperation on Chornobyl accident problems has finally been understood both in Ukraine and the World community. At the beginning of the year 1990, IAEA secretariat initiated International Chornobyl project, within a framework of which study and assessment of radiation consequences of Chornobyl accident to a human being and the environment were carried out by international experts. Chornobyl project was managed by the International Consultative Committee initiated by proper organizations of UN and CEC (Commission of European Communities).

In the course of Chornobyl project, radiation state of environment (density of soil contamination, content of radionuclides in agricultural products and drinking water), and health of population (clinical, hematological and other indices) were analyzed and assessed. On the whole, correctness of the chosen criteria for decision making and measures on population protection was confirmed. The tactics of the USSR government, i.e . consideration of concrete social and economic conditions equally with radiation situation at decision making for evacuation of the people, was supported [2].

In April 1990, the permanent representation of Ukraine in UN in New York, on behalf of its government, together with plenipotentiaries of ex-USSR and Belarus appealed to UN to include the additional item, viz. «International cooperation on elimination of Chornobyl nuclear power plant accident consequences» [3], in agenda of the first current (spring) session of 1990 of the UN Economic and Social Council (ECOSOC).

The positive decision of ECOSOC on the USSR appeal favoured the multilateral international cooperation on Chornobyl. Thanks to it, in spite of large delay, the practical application of international experience and knowledge commenced to study Chornobyl accident consequences and to provide technical, medical, social assistance to population, remediation of victims and contaminated territories. It became possible for Chornobyl experience to be applied by other countries for improvement of their preparedness to extraordinary radiation accidents. The proclamation of Ukraine as an independent state resulted in consequent positive changes in the scheme of international cooperation on reducing Chornobyl accident consequences.

Activities of UN, other governmental and non-governmental organizations, including Commission of European Communities (CEC), increased. In order to formalize the research cooperation an «Agreement for International collaboration on the Consequences of the Chornobyl Accident» was

signed in June 1992 between the EC and the relevant ministries of the three Republics. The financial resources provided by CEC to Ukraine to support nuclear safety and to mitigate Chornobyl consequences increased ten times in 1992 against 1991 [3].

Influential international organizations and institutions were enlisted the cooperation, intergovernmental interaction in scientific-technological and humanitarian spheres was widened, business contacts with leading scientific centers and laboratories of the advanced nuclear states were established.

Analysis and generalization of practice of international cooperation on Chornobyl problems allows defining its main procedures:

• Interaction with the leading international organizations and funds (UN, CEC, IAEA, UNESCO, SASAKAWA Fund and others) at the state level;

• Bilateral cooperation according to intergovernmental agreements and memoranda;

• Participation in international projects according to concrete programs.

• Involving financial resources of international and national financial institutes of other countries, such as the World Bank of Reconstruction and Development, the European Bank of Reconstruction and Development, the Fund «Know-how» of the government of Great Britain as well as companies and organizations, which have experience and technologies to provide assistance on mitigation of Chornobyl accident consequences.

International organizations and countries that assisted Ukraine in solving Chornobyl problems, aimed at relieving the hundred thousands of Chornobyl accident victims and thus, fulfilling the humanitarian mission, stipulated by the good will and common to all mankind values, and hence, getting access to a unique Chornobyl contaminated area and gaining experience on largest nuclear accident consequences overcoming.

Gradually in 1990–1995, a dominating factor of international cooperation on Chornobyl was aspiration of world community for safety that defined the following main goals:

• To stop Chornobyl NPP finally;

• To convert the ruined power Unit 4 to ecologically safety system;

• To increase the safety level of NPPs of Ukraine up to world standards.

The key role in the raise of NPPs safety was played by the so-called Lisbon initiative, enunciated in May, 1992, as well as the top level Council decision in Munich in July, 1992, at which the heads of the states and governments of the Great Seven countries proposed a multilateral program of actions for safety level of nuclear power plants to the countries equipped with reactors of the soviet design.

The positive position of leaders of Great Seven countries significantly activated bilateral cooperation of Ukraine and separate countries.

The bilateral cooperation covered practically all aspects of nuclear problems: nuclear safety, radioecology, radioactive wastes, medical and social consequences and others. The main countries taking the most active part in cooperation are Great Britain, Germany, France, the USA, Canada, Japan, Sweden and others. Two documents made up international-legal basis of bilateral cooperation of Ukraine and the USA on Chornobyl problems:

• Agreement on humanitarian and technological-economic cooperation, 1992.

• Agreement on cooperation in the field of nuclear safety, 1995.

Bilateral technological cooperation with foreign countries is carried out within a number of bilateral intergovernmental agreements and/or memoranda:

– Agreement between the government of Ukraine and the government of the Federal Republic of Germany on cooperation on problems being of mutual interest in connection with the nuclear-technological safety and radiation protection of 10.06.1993;

– Agreement between Ukraine and the government of the Federal Republic of Germany on cooperation in the field of the environmental conservation of 10.06.1993;

– Framework agreement concerning grants for technical assistance between Ukraine and the International Bank of Reconstruction and Development of January 14, 1998;

– Additional agreement to framework agreement of May 29, 1996 between the government of Ukraine and the Government of the Federal Republic of Germany on consulting and technological cooperation of 30.10.1997;

– Memorandum on mutual understanding between the government of Ukraine and the government of the USA concerning technical assistance of the government of the USA on problems of reformation of electric power sector of Ukraine (resolution of Cabinet of Ministry of Ukraine (CMU) of 04.12.1999 № 2202);

– Memorandum on mutual understanding between the government of Ukraine and the government of the USA on technical assistance in the field of health protection of Ukraine (CMU resolution of 31.03.2003 № 408);

– Memorandum on mutual understanding between the government of Ukraine and the government of the USA concerning main directions and goals of assistance program of the USA international development agency in 2005–2007. (CMU resolution of 16.11.2005 № 458-p) and others.

Great Seven provided additional multilateral procedures for urgent taking of measures to raise operational and technological safety of NPP, which did not enter upon bilateral programs and called world public to take part in its financing. In 1993, EBRD directors council opened the nuclear safety Account, to which countries – donors transferred means to finance projects on higher NPP safety in the region. The most active donors are the CEC and 14 countries, Belgium, Canada, Denmark, Finland, France, Germany, Great Britain, Italy, the Netherlands, Norway, the USA, Switzerland, Sweden and Japan.

It is essential that the majority of nuclear states enlisted the works on localization of ruined power unit and its conversion into the ecologically safe system, which has been one of the most important problems connected with the elimination of Chornobyl accident consequences up till now.

The international competition announced by the government of Ukraine commenced comprehension of ways of the technological solution of the problem. In 1992–1993, many countries of Europe, the USA and others took part in the competition for the best project of constructing another «Sarcophagus» over the temporary «Shelter» object and developing technologies to extract fuel-containable masses from it, organized by the Ministry of Emergencies of Ukraine and the National Academy of Sciences of Ukraine. The participation of leading international experts, representatives of powerful engineering-technological companies, their experience and knowledge were extremely useful and promoted to work out a more efficient view on a versatile problem of the «Shelter». In 1993, on the basis of international competition results the conception of step-by-step conversion of «Shelter» into the ecologically safe system has been approved and a tender of technical and economic assessment of the first stages of the conception was announced by CEC [4].

A tender winner – consortium Alliance – presented a report on technical and economic assessment in 1995, main conclusions of which have been of great urgency up till now.

Main milestones of subsequent actions concerning Shelter were:

• Signing Minutes between the European Commission and Ukraine for specification and coordination of the plan of subsequent actions by investigation results of «Alliance» in Brussels (September, 1995);

• Acception of Memorandum on mutual understanding between the government of Ukraine and governments of Great Seven countries and the CEC concerning Chornobyl NPP stoppage (December, 1995).

According to the Memorandum, as continuation of «Alliance» work within TACIS project «Chornobyl power Unit 4. Short-term and long-term measures» the so-called Recommended course of actions was proposed. Thus, real and valuable steps to strengthen activities of international cooperation on Chornobyl problems were undertaken in the middle of the '90s, that initiated the decision of Ukraine to stop Chornobyl NPP in 2000, and the Memorandum signed in connection with it.

At last, in 1997, to continue above-mentioned TACIS project upon cooperation of CEC, the USA, Ukraine and a group of international experts, detailed plan was elaborated according to the Recommended course – the so-called SIP (Shelter Implementation Plan).

SIP financing is carried out by payments of countries-donors to the specially set up International Chornobyl Fund under administrative management of EBRD. Directions and SIP project course are given in a part of the National report «Object Shelter» (chapter 9).

The joint international research between the European Commission and the contaminated states – Ukraine, Belarus and Russia was the important contribution to solving complicated Chornobyl problems. Leading scientists of about 200 scientific institutions on the both sides took part in experimental and research projects. For 4 years (1992–1996) were carried out 16 projects devoted to: creation of the Atlas of radioactive contamination of Europe; research of regularities of radionuclides resuspension to the environment and their migration to natural landscapes and food chains; study and assessment of ways of forming and reconstructing of absorbed doses to human; diagnostics of medical radiation-induced effects, methods of their early diagnostics and treatment; support of decisions making [5]. Creation of scientific-coordination Council to control and correct programs contributed to successful cooperation. B. Prister and V. Kholosha, Deputy Ministers of Emergency, V. Barjakhtar, vicepresident of NASU, were the Members of the Council.

The research results of the majority of the projects were implemented in research institutions, and were used for planning and undertaking of the countermeasures on contaminated territories. Main achievements were presented in many home and foreign top level publications, they became the property of world science in the field of radiation protection of population and the radiation medicine.

Institutions of CIS (the Commonwealth of Independent States) obtained the modern scientific equipment, the cooperation contributed to improving the methodical level of scientific research in Ukraine, Belarus and Russia. The results of all projects were discussed at the International Conference in Minsk in 1996 and published [6].

Of particular attention is a problem of influence of radiation components exposure to a human health. The most actual item of the problem is radiation-induced cancer of thyroid gland – its diagnostics and treatment. Among 16 International projects two were devoted to this problem, viz. «Molecular, cellular, biological characterization of childhood thyroid cancer» and «Development of optimal treatment and preventive measures for radiation induced childhood thyroid cancer». International cooperation on study of medical consequences of Chornobyl NPP accident to health of population of Ukraine has been conducting up till today.

In 1992–1994, the Institute for Endocrinology and metabolism of AMS of Ukraine, under the aegis of the World Health Organization (WHO), carried out a pilot project «Thyroid gland» in the frame of the international program on medical consequences of Chornobyl accident «IPHECA». Since 1996 up till today within the cooperation between governments of Ukraine and the United States of America the Ukrainian-American project «Scientific Program of cancer and other diseases of thyroid gland research in Ukraine after Chornobyl NPP accident» has been conducting.

The important stage of international cooperation was a number of projects within programs «IncoCopernicus» and «Radioactive decay safety». The Scientific Center of Radiation Medicine of Academy of Medical Sciences of Ukraine took part in the joint project «STRESS-95» devoted to assessment of different ways of forming radiation exposure for population on the contaminated territories.

In 1997–1999, under the aegis of the European Union the institute for Endocrinology and metabolism of AMS of Ukraine carried out two scientific Projects within the program «IncoCopernicus»:

- Role of lymphoid infiltration in developing post Chornobyl thyroid tumours: morphological, immuno-histochemical and molecular-biological research;
- Research of thyroid cancer and other thyroid pathology in CIS countries, affected by Chornobyl catastrophe.

In 1989–1999, the Institute for Endocrinology, under the aegis of WHO, implemented the scientific project «Studies of thyroid gland pathology and iodine excretion with urine among ukranian children born before and after the Chornobyl accident, for assessment of ecological factors influence on origin of thyroid gland diseases».

Since 1998, up to the present, the joint project of the World Health Organization, the European Union, the National Institute of Cancer of the USA, Fund «Sasakawa» (Japan), «Chornobyl tissue bank» of the Commonwealth of Independent States – International scientific resources» has been conducting.

Medical aspects of radiation accidents continue to arouse interest of the international public. In 1992–2000, under the aegis of the European Union the scientific project «Investigation of spreading of subclinic and clinic insulin independent diabetes mellitus and autoimmunal thyroidit of children and adolescents, living around Chornobyl NPP» was carried out. In 2000–2002, a joint project «Chornobyl, all European investigation: morphology, oncogenes, DNA damage due to radiation cancerogenesis» was carried out together with Cambridge University (Great Britain).

In 2000–2003, Institute for Endocrinology together with the National research center of ecology and health (Germany) carried out projects: «Irradiation of thyroid gland of Byelorussian and Ukrainian children after Chornobyl accident and risk of thyroid cancer development» and «Range of application of compiled data to define risk factors in epidemiological research».

An important step in the international cooperation was the French-German initiative (FGI) «Chornobyl: Results and Their Implication for Man and Environment», the goal of which was in compilation, unification and agreement of a wide range of scientific data on accident consequences and the efficiency of countermeasures. With the commencement of the large-scale program, governments of France and Germany contributed to the International Chornobyl center, which the government of Ukraine had called upon to set up in 1995. The Institute for Radiation Protection (IRSN, France) and the Institute for Reactor Safety (GRS, Germany) organized FGI program. Chornobyl Center for problems on nuclear safety, radioactive wastes and radioecology was set up in 1996 in the town of Slavutich, which also executed functions of the administrative body of the International Chornobyl Center, coordinated scientific Centers, laboratories and Institutes of Russia, Ukraine, Belarus taken part in FGI program. FGI had 3 subprojects. A subproject «Safety of the Chornobyl Shelter», a subproject «Study of Radioecological consequences of the accident», a subproject «Study of health effects».

FGI program completed with creation of integrated databases for all main aspects of assessment and minimization of consequences of accident. It is very important that materials accumulated in

Belarus, Ukraine and Russia were verified, discussed in detail and agreed upon with all executors and scientists of leading scientific institutions in the field of radiation and nuclear safety of Germany and France. Basic results were summarized at the conference in the city of Kyiv on October 5–6, 2004, in which representatives of the IAEA, the EBRD and other international organizations took part. Data on assessment and elimination of Chornobyl accident consequences became the property of both CIS scientists and the international public.

For years of the existence, under the aegis of the International Chornobyl Center with financial support of government of the USA, Great Britain, France, Germany, and Japan, about 100 research projects in the sphere of nuclear unit safety analysis, stoppage of Chornobyl NPP units, physical protection of ionizing irradiation sources, investigation of the state of the object «Shelter», etc. were completed.

In 1998, the intergovernmental agreement between Ukraine and the USA was concluded, according to which the International Radioecological Laboratory (IRL) forming as a part of Chornobyl Center was created. Activities of IRL contribute to the international studies of radiation action on vegetation and the animal world of Chornobyl zone.

The broad international scientific cooperation on problems of medical consequences of Chornobyl accident carries out the Scientific Center of Radiation Medicine of AMS of Ukraine (SCRM of AMS), which has been a regional center of WHO collaboration for Medical Preparedness and Assistance Network (REMPAN) since 1998. International scientific research is carried out within a framework of programs of WHO, IAEA, CEC, cooperation with scientific-research institutions of the USA, Japan, Germany, Italy, France and other countries.

The largest and important investigation programs executed with the participation of SCRM of AMS of Ukraine were «Effects of prenatal irradiation of brain as the result of Chornobyl accident» and WHO program IPHECA (International Program on Health Effects of Chornobyl Accident). Execution term was 1992–1997. The program included projects «Haematology» and «Epidemiological register», «Prenatal brain damage, thyroid gland».

Since October 2000, up to the present, according to the Intergovernmental agreement between Ukraine and the USA on cooperation in the field of elimination of Chornobyl accident consequences (2000) the program «Scientific minutes on study of leukemia and other hematological diseases among participants of elimination of Chornobyl accident consequences in Ukraine». As a result of the research a cohort of ROW (recovery operation workers) at Chornobyl NPP of 1986–1987, viz.– 110 645 males residing in 6 regions of Ukraine, was formed to define cases of leukemia, myelodisplastic syndrome (MDS) and myelomatosis (MM).

Since 2001, jointly with the NATO Scientific Committee on threats to the society, SCRM of AMS has been executing the International research project «Investigation of risks of Chornobyl accident consequences», the results of which became a basis for the would-be international scientific conferences «Chornobyl, medical consequences and lessons for future» (2001, 2003 and 2004).

One of the most efficient forms of the international collaboration and combination of efforts of the scientific public to achieve the common goals is International conferences. The International Conference «15 years after Chornobyl accident. Overcoming Experience» was held in Kyiv in April 2001 [7, 8].

The main goal of the conference was:

• to define common vision of scientists and experts of the most contaminated countries and the international scientific society in regard to Chornobyl accident consequences in ecological, medical and social and other spheres in 15 years;

• to agree upon conclusions and recommendations to be applied by bodies and persons responsible for decisions making both at the national and international levels to implement the subsequent measures in regard to overcoming of accident consequences;

• to reach the common comprehension of the current situation, which occurred because of the accident, and that of the necessary countermeasures to be taken in future.

A common point of view of the conference participants is that accident essentially has changed life of millions of people who reside on the most contaminated territory, first of all, in Belarus, Russia and Ukraine. The events associated with the accident (evacuation, reduction of agricultural and industrial production, applied countermeasures, discrepant estimates of probable consequences of the accident) have dramatically changed a way of life of these people. Lack of special knowledge of radiology didn't allow the population to assess the truthfulness of the information, which mass media, radio and television had given. That's why the subjective perception of possible accident consequences considerably exceeded the real state of affairs. Through worsening the economic state, the USSR disintegration, everything taken together, converted the accident really to the catastrophe for millions of people, transformed them to a category of Chornobyl accident victims.

Guided by the common comprehension of reasons and consequences of accident and efficiency of response, the conference determined the main lessons of Chornobyl accident, which follow from the analysis of consequences and actions of the contaminated states in the post accidental period.

Done by the efforts of many countries (Belarus, Russia, Ukraine, Countries of the European Union, the USA, Japan and others) and international organizations (UN, WHO, IAEA), the practice of the international scientific cooperation allowed to obtain important scientific results in the field of nuclear and radiation safety, radioecology and radiation medicine, which are of important practical value. At the same time, insufficient financing of national scientific research and their imperfect agreement do not contribute to the creation of scientifically grounded complex strategy of research. At national (Belarus, Russia and Ukraine) and international levels there is necessity to develop and deepen programs of scientific research with regard to long-term problems.

To contribute to developing of the direction of the international cooperation The Cabinet of Ministry of Ukraine by its resolution of February 15, 2002, set up the integral system of enlisting, application and monitoring of the international technical aid. The functions of the coordinator of activities connected with enlisting of the international technical aid and its providing in accordance with significant trends of the social-economic development of Ukraine, were entrusted to the Ministry of Economics of Ukraine.

The important step was Chornobyl Forum set up in 2003 under the aegis of UN with the participation of WHO, IAEA, the European Commission, EBDR and other international organizations and governments of the contaminated countries aiming at making up conclusions of knowledge and contributing to better comprehension and improving measures to overcome accident consequences. At the session of Chornobyl forum in April 2005, Forum participants from Belarus, Russian Federation and Ukraine made a request for governments of the three countries to work out recommendations on special programs of Health Protection and environment remediation, defining demands for subsequent research, and social-economic policy. In September 2005, in Vienna the final meeting of the Forum was held, which considered and approved papers-reports of two groups of scientific experts – «Health» prepared upon WHO coordination and «The Environment» prepared by leading experts of the world science upon IAEA coordination.

The final document was prepared by Forum Secretariat on the basis of recommendations presented in technical papers of Forum. Besides, the UNDP proposed recommendations on economic and social policy based on the research conducted by the United Nations Organization in 2002: «Humanitarian consequences of the Chornobyl accident: remediation strategy», and the document of the All-World Bank «Belarus: Look at Chornobyl» (2002). Forum recommendations were distributed among participants and accepted on the basis of consensus.

Forum acknowledged that accident of 1986, was the heaviest nuclear disaster in the history of the world atomic industry. Due to release of a great number of radionuclides it has become the largest radiation accident. However, for years as levels of irradiation decreased, and accumulation of humanitarian consequences increased, the heavy social-economic depression of contaminated regions of Belarus, Russia and Ukraine and serious psychological problems of accident elimination participants and their population have gradually topped took the first place.

Scientists concluded that radiation would cause about 4000 deaths among those who absorbed higher radiation doses. Another critical group of victims have become children and adolescents, whose thyroid gland absorbed large radiation doses due to taking milk with the higher content of the radioactive iodine. In 1992–2003, about 4000 cases of thyroid cancer were registered, the most of which (99%) were successfully operated.

One of the main conclusions of Forum is that measures taken by past governments to overcome consequences of Chornobyl accident were timely and adequate. At the same time, modern research and observations point out the necessity to change trends of the efforts. Forum considers that the priority must be the social and economic regeneration of the contaminated regions of Belarus, Russia and Ukraine, elimination of the psychological load in their population and recovery operators.

There can be no doubt, that the International scientific conference in the city of Kyiv, which is planned on April 24–26, 2006, will become a new step on the way to reduce consequences of accident, to increase the level of nuclear and radiation safety and will contribute to the subsequent development of the international cooperation on Chornobyl matters.

14. NUCLEAR POWER ENGINEERING. CHORNOBYL EXPERIENCE

14.1. The influence of Chornobyl accident on the development of the global nuclear power engineering

There are few technologies in the history of civilization that influenced so dramatically social, political and economic life of human society as nuclear power. Especially in such short period of time. Since the moment of its origin on June 27, 1954, nuclear power has had its week and strong points. Even on the territory of Ukraine, nuclear power shown not only its doubtless consumer benefits, but also the dramatic losses it can cause. Analysis of the causes and circumstances of the Chornobyl NPP accident led to the formation of ideas of the «safety culture», used for the first time by the International Consultative Group on Nuclear Safety (ICGNS) that was established by the director general of the International Atomic Energy Agency (IAEA). The notion «safety culture» is defined as «a set of characteristics, peculiarities of organizations activity and behaviour of individuals, which determines that NPP safety problems, as those, which have the highest priority, are paid the attention determined by their value».

The main thing, which makes us repeatedly come back to the events that took place twenty years' ago, is the necessity to understand the basic causes of the accident, how the accident influenced world nuclear power and to ensure that everything is done not to repeat the tragedy.

The Chornobyl accident impacted on the development of nuclear power not only in Ukraine, but in the whole world. Minimization and overcoming of the consequences of the Chornobyl catastrophe is a complex task that required considerable intellectual, material and financial resources, and consolidation of efforts both at the national and international levels.

In some countries political speculation around the problems of nuclear power began, moratoria on the further development of nuclear power were accepted and cancelled. It caused considerable disruption of work on increasing the safety and modernization of nuclear power. A number of countries (Sweden, Italy, Austria, Australia, Germany) even decided to stop their nuclear power programmes in future. In fact, these decisions were realized only in Austria and Italy. In Sweden and Germany closed only those NPPs that had exceeded their design life. Immediately after the Chornobyl accident a number of countries refused or hold up construction of new NPPs (Poland, Bulgaria, Slovakia, Ukraine). However, it is worth to be mentioned that a common sense prevailed, and following detailed analysis of what happened, the design and development of the measures of prevention future large catastrophes in nuclear power has began.

Following the accident experts in countries operating NPPs were required to estimate the influence of human factors upon nuclear power safety. Following extensive investigations of human behaviour in various situations, operator training was improved including the development of technologies designed to deliver the training. Considerable attention was paid to identifying operator activities in extreme situations, under so-called out-of-project accidents (i. e. those for which the technical means of their protection were not or could not be envisaged by the project). The greatest attention was paid by all countries operating NPPs to increasing the independence and technical potential of nuclear regulation bodies, improvement of nuclear legislation and normative regulation of nuclear safety.

It is obvious that the Chornobyl accident provided serious lessons not only to Ukraine, but to the whole world. However, it is important to mention that in most countries a large amount of work on estimating the safety of nuclear power units and identifying ways in which they could be modernized had been undertaken before the Chornobyl NPP's accident. The accident at the «Three Mile Island» NPP in America in 1979, in which there were no radioactive releases beyond the limits of the site, led to a critical analysis of the state of nuclear power, including consideration of improving safety measures and increasing operational efficiencies. The Three Mile Island accident also provided a powerful stimulus to developing scientific investigations on nuclear safety, introducing methods of probabilistic estimation of safety, improving nuclear regulation, improving levels of staff skills and introducing various simulator facilities for training and maintenance of their skills. Unfortunately, experience of the overcoming of the consequences of the «Three Mile Island» NPP's accident was not taken into account by the USSR countries.

The most important consequence of «Three Mile Island», and particularly the Chornobyl accident was to increase the efficiency and competitiveness of power generation using nuclear power. This was prompted by a number of factors. Firstly, the investigations of safety and subsequent modernization of operating units removed many concerns and considerably improved NPP safety. Secondly, significant resources were made available which allowed the output many operational nuclear reactors to be increased. Thirdly, restrictions placed on the development of nuclear power (including the construction of new reactors) made operators implement considerable efforts to improve operational and maintenance modes, including optimizing the usage of nuclear fuel. Consequently, the proportion of electricity gener-

ated using nuclear power in the world has remained constant at about 16% over the last 20 years, despite few new NPPs being built. This increase in the efficiency of electricity production by NPPs over the last 20 years was equivalent to the commissioning of 33 nuclear reactors of 1000 MW each. At NPPs in the USA the average installed capacity utilization factor, increased from 70% in the 1980s to nearly 91%.

The investigations conducted after the Three Mile Island and Chornobyl accidents and accumulated experience of operating NPPs, also allowed prolonging the service life of nuclear reactors to be considered. In the USA the service life of 20 reactors was increased from 40 to 60 years. In Russia the service life of 5 reactors have been increased. Applications for prolonging the service life of reactors are applied pragmatically for all operating units. Consequently, nuclear reactors in many countries could potentially become profitable.

It is obvious that the Chornobyl accident increased world attention to the safety of NPP from RBMK and other reactors of Soviet design. Further discussions at meetings of Great Seven countries (G-7) in 1991 and 1992, international technical assistance programs connected with quantifying and increasing the safety of Soviet-designed reactors began. These nuclear safety projects were funded between 1990 to 1998 by the European Commission, OECD/NEA, European Bank of Reconstruction and Development (EBRD) and the Off-budget program of IAEA. The aim of the Off-budget program was to help countries operating reactors of Soviet design, to conduct fundamental analyses of NPP safety and identify potential design and operational flaws.

The IAEA played the fundamental role in identifying where technical assistance was required and promoted the efficient exchange of information between different countries. The program was unique in that it provided regular information exchange between all participating countries and allowed detailed dialogue on NPP safety between experts of West and East European countries to occur. The results and recommendations of this program are widely used as the technical basis for developing measures for raising NPP safety and to determine priorities in national, bilateral and other international programs on nuclear power safety.

Significant assistance was provided by the international community for analyzing and improving the safety of Ukrainian NPPs. Numerous studies funded by international organizations and bilaterally, estimated the level of reactor safety and recommended specific measures for improving it. This assistance allowed Ukraine to train expert groups in the use of modern tools for safety analysis, to implement measures to increase reactor safety and to improve the training of operational staff. This technical assistance has totaled over US $500 million and have enabled Ukrainian NPPs to achieve international standards of reactor safety. Other programs are ongoing with the aim of increasing the efficiency of electricity generation and improving operational safety.

Ukraine has considerably increased and strengthened links with foreign partners in the field of nuclear power. In May 1997, SAEC «Energoatom» became a member of the World Association of Nuclear Operators (WANO). The basic premise of WANO, which was created after the Chornobyl accident, was to unite world-wide attempts to raise the safety and reliability of NPPs. WANO is unique because it is an international professional organization, for which political barriers, frontiers and other interests do not exist; its main aim is to develop nuclear power safety and efficiency. Cooperation within WANO is organized via programs within regional centres in Moscow, Paris, Atlanta and Tokyo.

WANO voluntarily exchanges information on events occurring at NPPs, and also undertakes results comparisons, partner checks and exchanges of experience. The inviolable main principles of WANO are the independence of its members, voluntary participation in WANO programs, equal partnership, mutual aid and non-disclosure of the exchanged information. The realization of WANO programs and the wide exchange of information by NPP experts have allowed tasks associated with nuclear safety and efficiency of electricity generation to be solved globally.

Inspection of NPP safety levels and operation quality by WANO missions is also important. They give an opportunity to compare the safety conditions of different reactors , to investigate modern tendencies and approaches on settling safety problems in time. WANO partner inspections were conducted at the South-Ukrainian NPP in 2003 and the Rivne NPP in 2002. In April 2004 inspections with WANO experts from Moscow, Paris, Atlanta and Tokyo centers and IAEA observers were conducted before reactor 2 of the Khmelnytskyi NPP and reactor 4 of the Rivne NPP became operational.

The IAEA has also played a significant role in improving the safety of Ukrainian NPPs. Over the last fifteen years there were about ten different IAEA missions to Ukraine, a number of projects focused on raising the safety of the reactors have been implemented.

The Chornobyl NPP accident showed that nuclear power is a potentially hazardous technology and ignoring the associated risks can have significant consequences. The safety of operational reactors must be provided by technical and organizational measures.

The Chornobyl accident can be considered as occurring during the pioneer stage of nuclear power development. This stage was rapid, with huge speed of development, from the generation of 5 MW at a

single NPP in 1954 to over 1000 MW at a single NPP by the late 1970s. Obviously, mistakes were made, sometimes their consequences could be tragic. Now there are grounds to believe that the lessons of achievements and failures of the pioneer stage of nuclear power engineering have been learnt. They open the way for the stable and large-scale development of nuclear power.

14.2. Nuclear power engineering development

The impartial data indicate that postChornobyl syndrome is in fact overcome; the world nuclear power engineering begins a new stage of its development, and it will find the deserving place in solving power problems. It is important, particularly against the back site of progressive climatic changes caused, first of all, by burning organic kinds of fuel.

As of late 2003 there were 439 nuclear power units in the world and 35 ones were constructed of total power of 360.3 and 28.1 million kW correspondingly. In 2001, 2500 billion kW·hour was produced, being about 17% of the total electric power production in the world. In a number of countries, such as Lithuania, France, Belgium, Slovakia, nuclear power engineering dominates, it gives over half the necessary electric power. In the West Europe about one third of electric power is produced by NPP.

The estimation of IAEA shows that in spite of the measures on energy-saving, energy consuming in the world has grown with the average rate of 3.3% a year for the recent 30 years. The growth of energy consumption with the rate about 2% a year will continue in future. It is promoted by the Earth population increase and the active growth of developing countries' economies. Nuclear power will play the important role in satisfying energy needs of mankind in future. The rising influence of «greenhouse effect» and the global climatic changes caused by it climatic changes promote it to a considerable degree. One of the main «culprits» of such situation is accumulation of «greenhouse» gases, first of all CO_2, which is a product of organic fuel burning in the atmosphere.

Energy carrier kind	CO_2 emission, g/kW·hour
Coal	980
Gas	500–600
Sun	50–100
Wind	10–30
Atom	5–25
Hydro	3–15

Now practically for all the regions of the world the value of NPP production of electric power is 10-20% less than electric power production with coal and gas. Uranium value grows, but uranium part in nuclear fuel value is only 30–40%.

Fuel component in cost price of nuclear power production does not exceed 30–40%, while for the power production with organic fuel it is 80% and higher. Thus, with growth of organic fuel value and it is an objective process competitiveness of nuclear power will grow. Resources of uranium and thorium provide the scale development of nuclear power in the long-term perspective. Transition to quick neutrons technology allows 60–70 times increase of the resource basis of nuclear power. As a matter of fact nuclear power is one of the recovered sources of energy.

The most essential accumulation of nuclear power is observed in the Asian region. The ambitious plans of nuclear power development are claimed by China, India and Russia. Indonesia and Vietnam claimed their plans of construction of the first NPP. Turkey, Poland, Argentine and Brazil are considering plans of NPP construction. Weakening of Chornobyl syndrome and revival of nuclear power is observed in Canada, Japan and in a number of other developed countries. The construction of earlier «frozen» NPP in Bulgaria and Slovakia has been recovered. The construction of the first for many years NPP in the West Europe (Finland, NPP site «Olkiluoto») has been commenced. The decision to construct two new nuclear power units at NPP site «Flamanville» in France is taken. The USA adopted a law on the development of energy in XXI century, which gives the considerable role to nuclear power. It is envisaged that the USA will have commenced constructing of 4 or 6 new nuclear power units by 2010. The prime minister of Great Britain officially declared recommencement of nuclear power development.

Nuclear power complex dominates in provision of energy needs of Ukraine. NPP parts in electric power production is at the level of 45%, and at the market the part of «nuclear» electric power has been already over 50%. It provides power safety of the country under the conditions of the outdated stock of power plants with organic fuel. Owing to nuclear power engineering, the electric power prices are at the reasonable level, which provides competitiveness of Ukrainian enterprises production.

By production volumes of electric power Ukrainian NPP rank eight after NPP of the USA, France, Japan, Russia, Korea, Great Britain and Germany. Production of electric power and heat energy in Ukraine is provided: 45–50% at the expense of the natural uranium, 26–30% at the expense of coal, 18–20% at the expense of gas, 5–10% at the expense of hydroresources (Fig. 14.2.1).

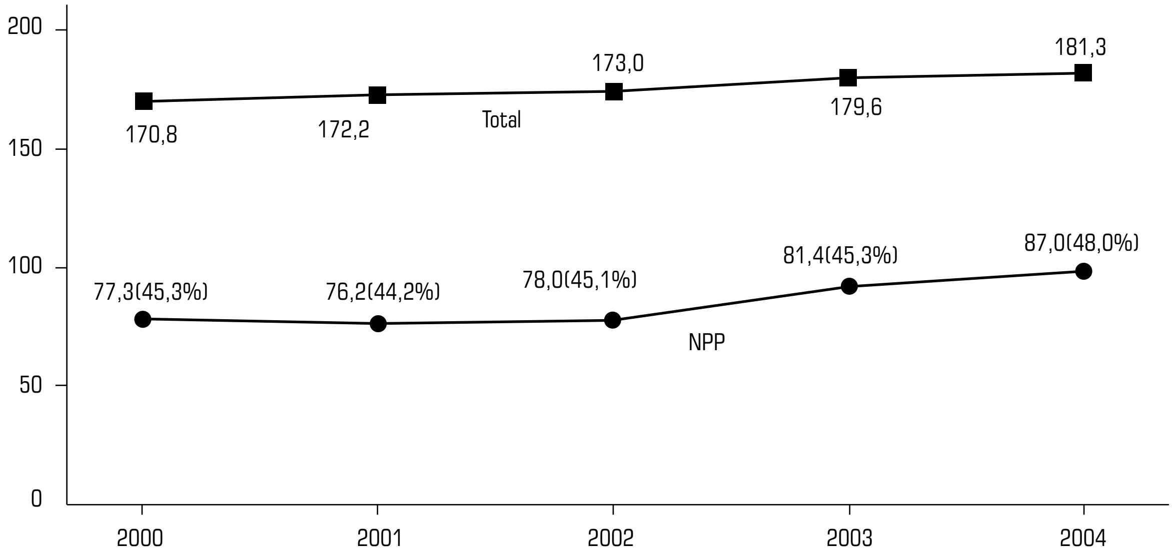


Fig. 14.2.1. Dynamics of NPP electric power production in comparison with the total electric power one in Ukraine, TW·hour

All the acting NPPs of Ukraine are amalgamated into one exploiting organization SE SAEC «Energoatom», which is one of the largest nuclear-generating companies in the world. The determined power of acting NPP as of November 1, 2005 was 13835 MW, which corresponds to 26.1% of the total determined power of electric power complex of Ukraine (Table 14.2.1).

Table 14.2.1

Acting NPP of Ukraine (on November 1, 2005)

NPP name	Unit No.	Reactor type	Determined power (MW)	Date of energy commence	Date of completing term of operation envisaged by output project
Zaporizhzhya	1	PWR-1000/320	1000	10.12.1984	10.12.2014
	2	PWR-1000/320	1000	22.07.1985	22.07.2015
	3	PWR-1000/320	1000	10.12.1986	10.12.2016
	4	PWR-1000/320	1000	18.12.1987	18.12.2017
	5	PWR-1000/320	1000	14.08.1989	14.08.2019
	6	PWR-1000/320	1000	19.10.1995	19.10.2025
South-Ukrainian	1	PWR-1000/302	1000	31.12.1982	30.12.2012
	2	PWR-1000/338	1000	06.01.1985	06.01.2015
	3	PWR-1000/320	1000	20.09.1989	20.09.2019
Rivne	1	PWR-440/213	415	22.12.1980	22.12.2010
	2	PWR-440/213	420	22.12.1981	22.12.2011
	3	PWR-1000/320	1000	21.12.1986	20.12.2016
	4	PWR-1000/320	1000	10.10.2004	10.10.2034
Khmelnytsky	1	PWR-1000/320	1000	22.12.1987	21.12.2017
	2	PWR-1000/320	1000	07.08.2004	07.08.2034

For the years of independence, the progress has been achieved in rising NPP operation efficiency, which confirmed by dynamics of installed capacity utilization factor (ICUF) at Ukraine's NPPs.

The important factor, which provides safe and reliable operation is the constant activity aimed at rising NPP safety and reliability.

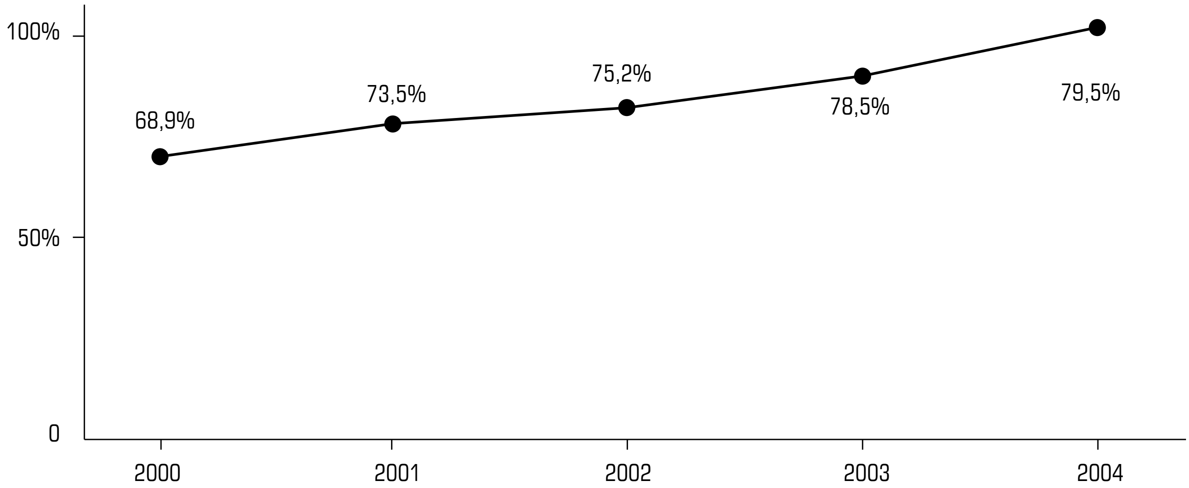


Fig. 14.2.2. Dynamics of changing ICUF of acting NPP of Ukraine in 2000–2004, %

Nuclear industry and engineering of Ukraine arose and functioned within the united and balanced nuclear power complex (NPC) of the former USSR. It influenced, influences and will influence on the state and perspectives of NPC development of the country for a long time. Administrative and social problems of the transition period, the hardest economical crisis at the end of the last century led to the essential efforts of production and technological potential, which Ukraine got in the nuclear sphere. Ukraine does not have research, design and production basis to develop and create its own reactor plants. It caused serious difficulties in providing safe operation of acting NPP. Hopes for the quick creation of the national research and production infrastructure on reactors construction and provision of Ukrainian NPP with its own nuclear fuel failed.

At the same time, almost half of electric power of the country is produced at NPPs of Ukraine. Ukraine produces uranium and zirconium concentrates, hafnium and a lot of other facilities for NPC. The country has the recognized research and technological potential.

The main aim of the stable development of NPC of Ukraine is to provide power safety of the state. The project of the strategy for the development of fuel-power complex (FPC) of Ukraine envisages the support during the period considered of the part of electric power production at NPP at the level a little over 50% of the total electric power production in the country to 2030 (Fig. 14.2.3).

Such decision is caused by the availability of primary raw resources of uranium and zirconium, NPPs stable operation and their dominating under the conditions of Ukraine technical and economical

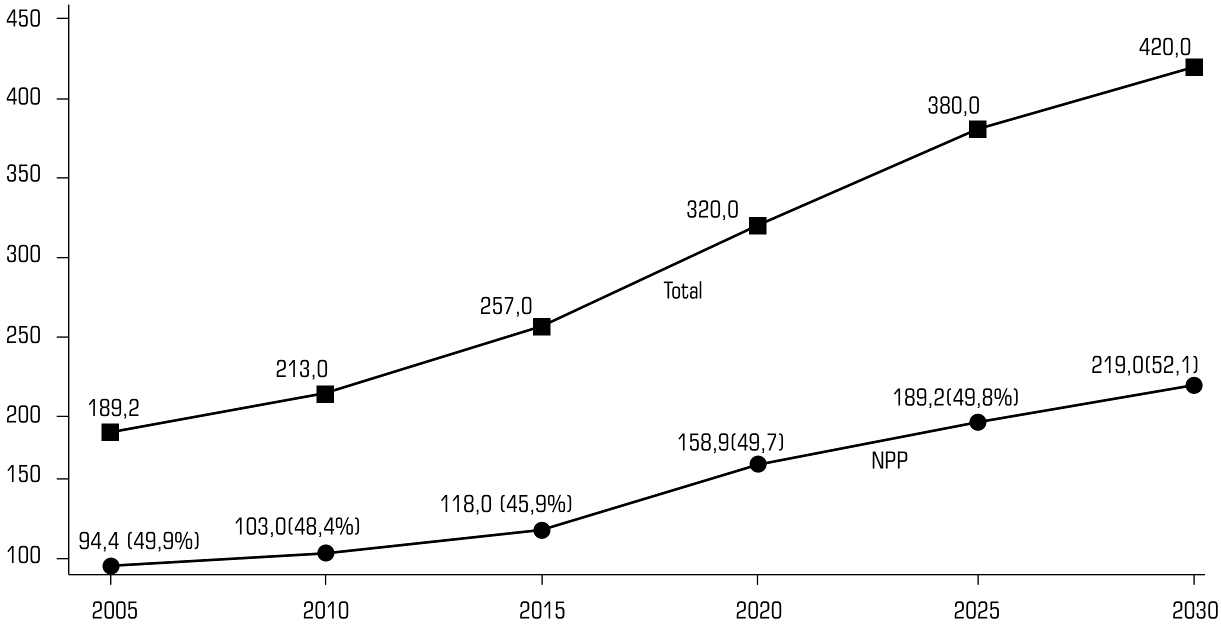


Fig. 14.2.3. The expected production of electric power in Ukraine for 2005–2030, TW a year

indicators in comparison with those of heat energy; potential possibilities of the country to provide new NPP powers; the essential technical, financial and ecological problems of organic fuel power.

Within the Strategy two basic stages of Ukraine's NPC development are considered: short-term period to 2014–2016 and long-term period to 2030 and further. It is necessary for short-term period:

– to provide reliable and safe operation of the acting power units;

– to provide aging control of equipment of the acting power units and prolongation of the period of their operation, first of all power Units 1 and 2 of Rivne NPP and Unit 1 and 2 of South-Ukrainian NPP;

– to commence constructing and to introduce new energy powers (it is envisaged at the site of Khmelnytskyi NPP);

– to construct and put into operation the centralized storage facility of spent nuclear fuel (SNF) for NPPs of Ukraine and provide expansion of SNF storage facility at Zaporizhzhya NPP in the necessary scope;

– to provide top-priority work connected with construction of the new nuclear power facilities (choice of sites, technical and economical assessment development, determination of safety requirements, etc.);

– to solve basic problems regarding management of radioactive wastes (RW) including high-active ones, taking into account the construction of the necessary units at the acting NPP, and the top-priority work connected with the centralized units of RW management and burial;

– to provide research/engineering and design support of NPP by enterprises and organizations of Ukraine.

In the long-term perspective it is necessary:

– to provide construction, put into operation and safe operation of substituting and additional powers, and of acting power units;

– to resolve problems of prolongation of the NPP power units operation periods, which have served the determined by initial projects resource;

– to create the necessary infrastructure and to commence withdrawing power units after accomplishing the operation period;

– to provide safe management of SNF;

– to settle problems of maximum participation of Ukrainian producers in creating new generating capacities and satisfying NPC enterprises needs;

– to provide a necessary level of research/engineering and design support of NPC by Ukrainian enterprises and organizations;

– to accept the strategy of Ukraine NPC development for long-term perspective and to provide the corresponding conditions for it.

The task of normative and legal assurance of Ukraine's NPC development is important. It is necessary to improve a complex of documents needed for provision of tasks on all the components of NPC. The available normative and legal basis considerably provides the conditions of NPC development and operation, however, it requires improving and adding by means of anticipatory development of new documents and review of acting ones. Requirements of national norms and rules must be harmonized with requirements in documents of European Union countries, other countries with the developed nuclear power, account of IAEA recommendations is necessary. Matching normative documents with new principles of financial and economical activity, for example, tender approach during realization of large power projects, is necessary. Correction of the normative basis, which regulates financial and economical activity in NPC including with determining schemes of financing expensive and resource containing power facilities, is envisaged.

The task of codification of nuclear legislation is of great importance. It should be noted that Ukraine has the developed system of the legislative acts, which regulate relations in nuclear engineering.

However legislative acts developed during a very short period of time, without proper experience, considerably under the influence of instantaneous circumstances and interests. The analysis of the practice of acting laws, their systematization, exclusion of contradictions, synchronization of «nuclear» laws with the laws, which regulate financing and economical activity in the country, are necessary.

Specification and concretization of requirements of the documents, which regulate the process of designing, licensing, affirmation of projects and taking the corresponding decisions at all levels, are necessary:

– with regard for tender procedures;

– with regard prolongation of the terms of power units operation over the project period;

– with regard for location of new construction facilities.

Specification of normative requirements connected with NFW and RW management, including the procedure of their preparation and transfer to RW burial by NPC enterprises, forming funds of NFW and RW management are necessary. Later on, it is necessary to develop normative and legal

assurance of RW management procedures after their long-term storage, the normative and legal assurance of RW final burial in deep geological formations.

The level of safety reached at NPPs of Ukraine, in general corresponds to one of NPPs of the same generation operating in other countries with the developed nuclear power. At the same time, the technologic process allows to put and realize tasks with regard for higher indices of safety.

Raising reliability and efficiency of NPPs operation must be based on transiting to 4- and 5-year fuel cycles, optimizing repair duration with simultaneous improving their quality, reducing extraordinary expenses. The installed capacity utilization factor by 2010–2012 must be increased to 83–85%; the authorized coefficient is considerably reduced. The measures, which provide NPP operation in the switching regime with daily variation of power within 10–20%, are planned.

For Ukraine the prolongation of the terms of NPPs operation is a strategically important task, which provides supporting electric power production at the reached level before introducing new powers at thermoelectric power stations and nuclear power plants. In the period to 2030 the term of operation of all acting power units of NPPs envisaged by the project, will end, except Unit 2 of Khmelnitsky NPP and Unit 4 of Rivne NPP. Prolongation of the service life of the acting NPPs is the necessary condition of assurance of energy safety of Ukraine. The main task of this direction of activity is providing reliable and effective operation of the acting power units after the projected term of operation (30 years), which will allow to raise efficiency of financial resources in comparison with other versions of the country provision with generating capacities in the near decade. The world experience shows that prolongation of terms of acting NPPs operation over the term envisaged by the initial projects, is one of the most effective directions of assurance of recoupment of capital investments in NPC. Besides, the prolongation delays commencement of work on withdrawal of the acting powers and the construction of new powers, provides the time resource to accumulate means, which are necessary for timely work expansion according to the specified directions. The limiting factor at settling the problem on prolongation of the service life of nuclear power unit is availability of elements, which substitution is impossible or requires considerable means. To date, the comprehensive information on the residual resource of such elements (first of all, reactor case), which would give the possibility of unique determination of the deadline of acting NPPs operation, is absent. Conservative estimations allow to accept the averaged term of operation prolongation over the projected resource, the term is 15 years. Other countries experience, tells the term is really reached and it can be increased. In 2006–2008, it is necessary to conduct a complex of investigations to substantiate prolongation of power units service life for longer terms.

Prolongation of acting NPP service life and modernization of organic fuel power plants can be paused. Cardinal solution of a task on reliable energy supply of Ukraine is only possible by constructing of new power units, whose operation along with the acting ones will provide electric power production in the amounts, which are necessary for the country. It is obvious that it is necessary to use power units, which safety level and technical and economical indicators correspond to the advanced world technologies.

In 2006, it is necessary to commence form action of cadastre of sites for new power units, preparation to conduct tenders on design and construction of new nuclear power units. Possibilities of domestic machine-building must be taken into account at most.

Additional powers of total amount of 2000 MW must be introduced to reach for getting the electric power production planned in the country to 2015. All 15 present power units will be in operation. For the future period from 2016 to 2030 substituting and additional powers of total amount of 20000–22000 MW must be introduced.

It is expedient to construct and introduce substituting powers, fist of all, at the existing sites. It will allow to use the infrastructure, personnel potential at most.

Priority tendencies of the world nuclear power development and the long-term experience of operation of PWR reactor plants in Ukraine allow to make a choice in favour of pressurized water reactor units, i.e. type PWR. The power levels of power units planned for construction in Ukraine, are 1000 and 1500 MW. The power units of the set power are being developed, constructed and planned in different countries of the world. The previous estimations show that taking into account all the possibilities of the existing areas 4 new power units of 1000 MW and 10 new power units of 1500 MW can be constructed. Besides, it is necessary to commence constructing no less than 4 power units of 1500 MW each in 2026–2027 to provide stable electric power supply after 2030.

Management of SNF in the long-term perspective is an important problem, which attracts the large attention of the society. Provision of powers for NFW processing is not expedient in Ukraine from both the economical and technical point of view, at least, for the near decades. The powers existing in the world several times exceed the current needs of the world nuclear power. It is expedient before the determining long-term for the period to 100 years and more strategy of development of nuclear power to use the so-called «deferred decision» providing the development of the system of SNF dry storage on

the territory of Ukraine. The first in Ukraine dry storage facility of SNF (DSSNF) has been operated at Saporizhzhya NPP since 2001. Work on the grounds of construction of the centralized storage facility of SNF (CFSNF) for power-generated units of other NPP is being conducted. The possible term of its putting into operation is 2009–2010.

In the period of 2015–2020, it is planned to complete on withdrawal from the storage facilities and processing the accumulated before virgin RW at NPP sites and complete the infrastructure, which is necessary for transportation of processed RW to burial. It is planned to complete modernization of the existing system and creation of new ones of RW management at NPP, improvement of RW transportation systems, including provision of a necessary container stock to 2010. The task of minimization of operational RW, and the problems connected with air conditioning and burial of RW, which will be solved during power units decommissioning, and the agreement of procedures and conditions of RW acceptance for burial are important.

In spite of the planned prolongation of operation to 2030, a number of NPP power units will be stopped for subsequent withdrawal. The tasks of preparation and work conduction with completing the service life of power units and other facilities become crusial ones for nuclear power of Ukraine. It should be noted that due to the future construction of new powers both at the sites of acting NPP, and at the sites adjacent to the ones of acting NPP, the state when NPP is withdrawn is not predicted, as a whole. The withdrawal of the concrete power units is being considered. The question of withdrawal of the general station constructions and facilities is considered only in the case when taking into account prolongation of the term of acting power units operation the safe operation of these or other general station facilities cannot be provided during the necessary period.

In the near future it is necessary to develop a complex of measures providing preparation of the infrastructure to NPP decommissioning. The task of development and realization of a mechanism of financing activity on decommissioning remains the most important. Two variants of the individual power units decommissioning are envisaged: urgent dismantling and deferred dismantling. The previous estimations made in Ukraine show that these variants are similar by labour and financial expenses, the amount of generated RAW and other indices. The concrete decisions on choosing a variant must be considered and grounded at when developing the programs of individual power units decommissioning.

The most important for Ukraine is the task of developing of the national system of NPC research/engineering and development support. The ways to solve the task are effective planning and coordination of the activity on NPC research/engineering and development support. The task is to provide the maximum possible participation of Ukrainian planning and design organizations in creation of NPC new facilities. The industry of Ukraine has a considerable potential to produce the equipment (except the reactor plant itself), which is necessary for NPP construction and operation including turbo-installations, pump equipment, armature, heat-exchange equipment, electrical equipment, generators and transformers, ACS TP, etc. The considerable effect can be received by cooperation of Ukrainian enterprises and enterprises and providers of other countries.

Development of material and technical basis of the key institutes and the centres of the system of NPC research/engineering and development support is planned they will be equipped with modern program codes and libraries of data on problems of materials durability, nuclear and physical and thermal physic calculations, safety analyses, and the modern tools of design. Creation of branch of scientific and technical centres and base organizations on the most important directions of the activity, the active participation of domestic organizations international projects connected with the perspective development of nuclear power and adjacent branches of Science and technology are important.

Uranium ores resources in Ukraine allow to satisfy demands of nuclear power for our own needs of natural uranium for a long time. Ukraine takes one of the leading places in the amount of prospected resources and has all necessary backgrounds for radical improvement of the state of uranium production and increase of amounts of uranium mining for the near years. In case of transition to fast-neutron reactor units a potential of domestic uranium resources increase in 60–70 times. Ukraine has the source of raw materials and research production of nuclear purity zirconium alloys. The development of uranium production to satisfy of Ukraine NPP demands for uranium raw materials in the full volume to 2015 requires more than three times increase of the annual production of uranium. The development of zirconium production for subsequent nuclear fuel production is planned.

NPC development requires solving a considerable amount of social and economical problems accumulated. It is necessary to settle a problem of creating and developing accompanying productions in the satellite towns, to provide the educational cultural-consumer service institutions, public amenities and sporting organizations in towns and regions of location of NPC acting facilities and constructing ones. Problems of developing programs of medical and retirement insurance, improvement of youth policy in the regions of location or in the satellite towns of NPC enterprises deserve serious attention. The

branch program of staff training and raising the level of their skill, creation of the system of training and managers' skill raising the level are planned.

It should be noted that Ukraine managed considerably to overcome the negative aspects, arisen after the USSR disintegration. The financial and economical state of nuclear energy complex subjects has been essentially improved; the formation of long-term strategy of its development within the united fuel and energy complex of the country has been commenced.

The high power intensity of uranium raw material stuff, the restriction of hydrocarbon resources, ecological problems determine the considerable role of nuclear power in satisfying energy demands of Ukraine today and in future. The strategic task of Ukraine is strengthening and subsequent development of own NPC as a determining link of energy safety of Ukraine. As minimum is the task of assurance of annual production of electric energy at NPPs in 2030 at the level of 219–220 billion kW·hour with NPP installed capacity of 29.5 million kW.

14.3. Nuclear and radiation safety

Problems of nuclear and radiation safety will always be in the centre of the attention of society, politicians and experts in the country, which was affected by the Chornobyl accident. Only introduction of safety culture at all levels of management including higher levels of the state management and in the routine activity can provide the attention, which is adequate to society's expectations, to the extremely important for NPC development problems.

In 1994, Ukraine one of the first countries became the participant of the Convention on nuclear and radiation safety, and then of Convention on safety management of radioactive wastes and safety management of spent nuclear fuel. For the years of independence the considerable amount of the work aimed at increasing of nuclear and radiation safety was done. The priority of nuclear power plants safety is determined in the law of Ukraine «On usage of nuclear power and radiation safety». The important tool for the activities aimed at assurance of nuclear and radiation safety is the government resolution. For example, in August 2002, the Cabinet of Ministers of Ukraine accepted a Complex program of modernization and rising the safety of power units of NPP in Ukraine.

At the same time, the experience of developing reports on the analysis of safety of reactor facilities of type PWR-1000 and PWR- 440 of Ukrainian NPP, and the world experience of the activities on rising of NPP safety require the additional introduction of organization and technical measures on the most important directions of increasing the safety.

The most important role in providing safety, undoubtedly, belongs to the human factor. In Ukraine, the perfect system of operations staff's training is created, a network of schools on experts' training for enterprises and organizations of nuclear power and industry has been developed. A system of licensing NPP staff that is occupied by the most responsible functions on nuclear plant management, which influence its safety, is developed and introduced in the country. Full-scale simulators have been put into operation at all NPPs of Ukraine, functional and analytical simulators at Chornobyl, Rivne, Khmelnytskyi and South-Ukrainian NPPs. As a result of purposeful work on the staff training the amount of erroneous actions, which lead to violations in NPP work have considerably reduced for the recent years.

A quality control system of the operating organization SAEC «Energoatom» essentially affects safety. In January 2000, a project aimed at improving management and introducing system of quality was commenced; the aim of the project was to develop methodological and organization principles of the quality management system, to rise efficiency and safety of Ukraine NPPs operation. At SAEC «Energoatom» the service of departmental supervision has been created, its main task is to monitor company structural subsections activity on realization of the rules, norms and standards on nuclear, radiation and technical safety, and of environment protection, fulfillment of license conditions the operating organization. The services of departmental monitoring exist at all NPPs constant control of the operation modes, equipment and systems conditions, which are important for safety.

The nuclear safety regulation body on realizing inspection of NPPs safety according to the affirmed plans and inspection schedules. Within cooperation with WANO (World Association of Nuclear plant Operators), the inspection has been conducted at Zaporizhzhya NPP and Rivne NPP, the missions of technical support were conducted at South-Ukrainian NPP and Zaporizhzhya NPP. Within cooperation with IAEA, ASSET seminars and missions were conducted at South-Ukrainian NPP and Chornobyl NPP, OSART missions were conducted at Zaporizhzhya, Khelmilnitskyi and Rivne NPPs.

Ukraine is a participant of «Convention on operative communication on nuclear accidents» and «Convention on assistance in case of nuclear accident or radiation situation». Bilateral agreements on notification on nuclear accidents and mutual help in case of such accidents are signed by the governments of Austria, Hungary, Germany, Norway, Poland, Slovakia, Turkey, Sweden and Finland.

15. CHORNOBYL'S LESSONS.
TOPICAL ISSUES: WAYS AND METHODS OF THEIR RESOLVING

1. The Chornobyl NPP accident demonstrated that the least probable events may occur in nuclear power engineering. It stressed the necessity to create a national system for affronting of the possible manmade accidents and for maintaining of its permanent readiness, as the costs of preventive and preparative measures for affronting radioactive accidents are much lower than those needed for liquidation of their consequences.

2. The identifying of the accident on the early phase as an on-site accident rather than as a catastrophic nationwide event, lack of understanding of all its negative influence on the population and the environment, increased the damage to the society, state economy, and resulted in irreparable injury to the population's health, in particular, through significant irradiation of thyroid gland and following boost of thyroid cancer incidence rate.

3. The absence of an adequate system of emergency reaction provoked the mobilisation of the personnel who was unprepared to work in conditions of nuclear emergency. Such a decision was ineffective and wasn't worth the health of those people.

4. The bulk of radiation dose was formed in the acute accident phase, hence, population healthcare had to be of the top priority as far as the reaction was concerned. The evacuation process of the Prypiat residents and the 10-km zone of the ChNPP population was warranted and effective. However, the delayed organisation and management of the mentioned process, and, at the same time, the late determination of the temporary accommodation of the evacuees, of the relocation of farm animals etc, prevented from achieving of the maximum effect. In particular, as the population exposure dose, so the expenditure, could have been lower.

5. The vague and timely not corresponding information of the population about the ChNPP accident by the state administration bodies caused social and psychological stress in the society.

During and after the Chornobyl accident, as during and after all other manmade and natural disasters in the World, the dominant human reactions were fear, distress, depression and despair etc. Their intensity increases drastically with the lack of appropriate information. The adverse stress-induced influences on the society might be more important than those caused by radiation exposure of the population. The group of the stressed people includes not only the evacuated from the exclusion zone, the recovery workers and people who inhabited (or are inhabiting) the territories related to the radioactive contaminated zone, but almost all the population of Ukraine.

The lack of the explanatory and necessary information about the radioactive state caused during the evacuation process an inadequate response of the population (increase of abortions percentage and of self-restraint in consuming some types of food) and development of health concern (both for oneself and family). All this resulted in a dramatic degradation of the living standards of the people. Such a conclusion may be made: information should be timely, clear, unambiguous.

6. The creation of the Chornobyl exclusion zone was a forced measure related to the extremely high level of radioactive contamination of that territory. This was also conditioned by the necessity to perform a wide range of activities, first of all: to use that territory as a barrier to the migration process of the radionuclides; to convert the object «Shelter» into an environmentally safe facility; to deal with the radioactive waste from the ChNPP accident; to decommission the ChNPP; other activities for keeping this territory in safely. It is and it will be necessary for the personnel to be always present in the zone. Therefore, an important issue is an adequate radiation protection of workers, which calls for respective organisational and regulatory support.

7. The approbation of the legal acts aimed to support the elimination of the Chornobyl accident consequences had a positive effect, on the whole. At the same time, the approbation of the poorly scientifically grounded legal norms for decision-making on radiation and socioeconomic protection resulted in misbalanced state budget expenditures, the majority of which were allocated to social compensation. An extremely low share was allocated to countermeasures and the treatment of the Chornobyl accident victims.

The approbation of laws is an insufficient factor to make a recover from the after-effects of catastrophic disasters of both man made and natural origin provided the mechanism of their implementation and realisation is scientifically unsound and poorly financed.

8. Radioactive contamination of territories, where millions of people lived, required implementation of wide-scale programs for radiation protection that had to be based on the results of widespread radiation monitoring.

Insufficient coordination of actions of different departments involved in radiation monitoring on

the early stage after the accident, resulted in the lack of information on the scale of radioactive contamination. The effectiveness and timely implementation of countermeasures for mitigating the adverse impact of accidents depend on the smooth functioning of a scientifically proven monitoring system.

During the past years, huge arrays of data about migration process of radionuclides in the environment and in the landscape, soil, food chains, and the aqueous and geological environment in particular, have been accumulated. The maps of Ukraine's territory contamination with the most significant accidental radionuclides, have been developed according to the world standards. The plan of the actions directed to the health protection of the population and territories rehabilitation, is based on the data referred.

Unfortunately, the obtained material, unique of the kind, was not completely taken into account during the elaboration of as regulatory and methodical documents, so of the state and departmental programs.

9. The implementation of the water-protection measures in the Dnipro-Prypiat hydro system prevented from the biggest part of the collective dose of the population. The 20-years experience confirms that it is necessary to take into consideration the entire spectrum of the landscape, geological, hydrogeological and hydrological peculiarities of the radiologically contaminated territory, while the water protection measures are planned and implemented. The state has to provide the population with a reserve of drinking water prevented from contamination.

10. For 20 years, all the population cohorts have received the exposure doses that exceed the 80% level of the life dose (70 years), which may be formed by «Chornobyl» radionuclides.

To bring the radiation situation in compliance with legislatives norms in the future, priorities should be placed on countermeasures eliminating the key factors contributing to doses.

It's worth mention that, with the whole expanses of the State Budget of Ukraine aimed at the minimization of the accident consequences in the sum of 3.5. billions dollars, there're only 12.7 millions dollars given for covering all the measures for improvement of the ecological state of the contaminated territories, agricultural countermeasures with a high level of effectiveness included. As a consequence, the inhabitants of some 250 settlements of the Polissia region, children in particular, drink the milk with ^{137}Cs content exceeding its permissible level twice as high. In 15 of the settlements the ^{137}Cs content exceeds its permissible level in 4 or even more times.

11. The medical service of the country (of the former USSR) was not informed in time and was not ready to eliminate or minimize the medical after-effects of a wide-scale radiation accident. Stable iodine treatment was not sufficiently widespread, and sometimes delayed. The children of iodine-endemic regions were affected mostly heavy.

Thus, to be prepared for emergencies in Ukraine, it is necessary to develop a corresponding normative spectrum of laws and to create groups of professionals prepared for emergency reaction, providing them with the necessary base and organising for them regular training and testing.

12. In the conditions of a radiation accident, especially during the works at the «Shelter» object, as it's impossible to provide the safety of the works according to the established standards of those in conditions with open sources of high-activity of ionising radiation combined with general-industry adverse factors and intense psycho emotional stress, the medical and biophysical control over the health and professional capacity of the personnel according to the special program, should be effectuated.

13. Almost all the Chornobyl problems could have been resolved more effectively and adequately in case of the immediate opening of the victims monitoring registry after the accident. That's why, it's necessary to organise an efficient functioning of the State Registry of the population of Ukraine affected by the Chornobyl catastrophe. The Registry should be provided with funds, have proper dosimetry and scientific support, establish interrelations with the Oblast and regional levels of the Registry, and interact with them.

The medical monitoring system, and the annual medical observations within it, has demonstrated its efficiency in making early diagnosis of cancer and non-neoplastic diseases, allowing, in such a way, a full-providing treatment. Its functioning should be continued and provided with timely and adequate financing.

14. The cause of the health changes is both of the radiation and non-radiation nature: among the latter the worsening of life conditions and diet standards, long emotional and psychological stress, changes in the social and psychological state and ineffective measures on elimination of the effects of adverse factors of the Chornobyl catastrophe should be underlined.

As far as the priority of the prophylaxis of the illnesses is concerned, the following should be done:

– improvement of the employment rates as a basis for family income and health;

– reduction of the accidental exposure rates of the population of some settlements till the levels set by RSSU-97, and total exposure dose rates of the victims from all sources of irradiation;

– renovation of the sanitary and information services;

– elaboration and implementation of the countermeasures on illness related to the endemy of the territories;

– health protection and recovery of the children affected by negative factors of Chornobyl accident as a State priority;

– organisation of prophylaxis of spontaneous abortion and inherent damages of the new-bornes' development on the contaminated territories in the frame of a target program for genetic monitoring in Ukraine.

15. The majority of the victims are still in the state of social and psychological disadaptation because they are not ready for effective enterprising behaviour in the short term. The social consequences of the accident were especially acute for the rural population which inhabits the contaminated territories of Polissia (the northern regions of the Volynska, Rivnenska, Zhytomyrska, Kyivska, and Chernihivska Oblasts) where agriculture is the key economy sector.

The state social policy should be based on social rehabilitation of the people and communities, rather than on medical and financial aid only. The unemployment issue has to be addressed immediately. It is necessary to develop business initiatives, and organise retraining and advanced training for the majority of able-bodied population in all contaminated territories.

16. The results of implementing radiation control measures and autorehabilitation of natural environment processes on the contaminated territories were poorly presented in public. It is necessary to ensure state support of the trusted information sources, such as medical, ecological and legal professionals. The crucial experience of Centres for social and psychological rehabilitation and information for affected populations should be spread throughout the country.

17. The most effective way for recovering of the contaminated territories in the future is the way of integrated social and economic development. An appraisal of effectiveness of countermeasures should include consideration of the manner in which the population accepts these measures. This may be the decisive factor while implementation of countermeasures.

The procedures of evacuation and resettlement sometimes ruined family values. For instance, they failed to take into account victims' choice of resettlement locations and failed to provide jobs. A lesson to learn is the necessity of taking into account the desires of different victim cohorts when making decisions on changing living conditions (resettlement, employment, the social policy, etc.)

18. The transfer to the next phase of recovering and developing affected territories calls for revising the boundaries of contaminated zones and improving the state policy and legislation in this area.

19. The Chornobyl catastrophe inflicted huge social and economic damage on the most affected countries: Ukraine, Belarus and the Russian Federation.

Due to direct loss of physical and economical facilities, as well as the expenditure associated with accident mitigation and recovery operations, the total damages for Ukraine in 1986–1989 exceeded USD 10 billion without accounting for significant consequential damages due to loss of production output and products in power engineering, agriculture, forestry, water industry, fish-breeding, and other losses. The cost of mitigating the ChNPP accident consequences will bear heavily on the country's economy for years to come. The total economic loss for Ukraine is up to 2015 in the form of direct losses, financial expenditures and consequential damage due to the Chornobyl' catastrophe is estimated to be USD 179 billion. This sum exceeds the actual economic potential of Ukraine, calling for international aid in addressing Chornobyl issues.

20. The object «Shelter» constructed in 1986 in extreme emergency conditions is a source of persistent potential danger. Hence, the highest priority task is stabilising its condition and building a safe new confinement as an engineering complex for ensuring long-term storage of fuel-containing materials and long-lived radioactive waste.

Developing the technology of extracting and container storage of fuel-containing materials to create an additional barrier to virtually open nuclear-hazardous fissile materials should be of the top priority for activities in converting the Shelter object to a safe structure after a new confinement is built. The prerequisite to solving this task is developing an infrastructure and storage facility for interim controlled storage prior to disposal in stable geological formations.

There is no long-term state program for ChNPP decommissioning and converting the object «Shelter» into a safe system. This complicates the coordination of tasks performed within the framework of SIP and other international projects, and prevents focusing efforts in key activity areas. SIP activities are progressing with considerable slippage. The effectiveness of project management is inadequate because national practice in managing such activities is not adapted to the Western and EBRD procedures.

21. The analysis of the train of events in the country after the accident has shown that, to date, not

all the Chornobyl's lessons have been learned, whilst many of them have been already forgotten. This is demonstrated by such facts:

• In the current late ChNPP post-accident stage, the major contribution to medical after-effects is made by nonstochastic effects in the form of a wide spectrum of nonneoplastic somatic and psychosomatic diseases. In the majority of cases, they cause physical disability and mortality. Effective medical care of the victims in the next years and decades will demand development and adoption of a clear state program for recovering from the medical consequences of the catastrophe.

• The special cohort of the Chornobyl liquidators (recovery operation workers) who, at a risk to their life, stopped the disaster, largely believe that they have been forgotten by society. Preventing social oblivion, especially in a situation when the world is trying to forget Chornobyl, is of a prime importance for Ukraine. Our state has to do its best to conserve the memory about the consequences of the Chornobyl catastrophe to the people of Ukraine.

• Before the Chornobyl accident, there was no experience in managing huge amounts of emergency radioactive materials in the world. Disposal of radioactive waste from the ChNPP accident were conducted in extreme conditions without adequate waste isolation technology and classification and registering of waste (its amount and activity). The possible environmental impact of storage sites was not considered. Even today, the majority of storage facilities require in-depth investigation. However, there is still no state-wide strategy in management of radioactive wastes and spent nuclear fuel. The laws that have been approbated have no effective enforcement mechanisms.

• Development of nuclear power engineering, together with the development of the national fuel economy, is Ukraine's strategic task. Limited hydrocarbon resources determine the significant role of nuclear power in meeting Ukraine's energy demand and ensuring its energy security today and in the future. The Chornobyl accident has initiated a process of in-depth critical analysis of the situation in nuclear power engineering, implementation of safety measures, and activities focused on increasing reliability and effectiveness of nuclear power units. However, even today, considerable efforts are required to implement recommendations on enhancing NPP safety and upgrading plants. Certain provisions of nuclear legislation have not been implemented in practice, and the regulatory basis needs in-depth revision.

• The collaboration of the scientists from special branches make it more effective to affront accidents of such characteristics as the ChNPP accident. Since the late '90s, there has been a significant reduction of financing, followed by the limitation of the variety of research and monitoring activities done. In recent years, scientific support of decisions and actions at state levels has been almost suspended, and scientific follow-up on decisions implementation has almost no financing. The disintegration of the existing systems of monitoring, scientific follow-up and scientific potential is taking place in Ukraine. Although, its scientific potential is a unique to both national and world science.

• The emergency dosimetry in Ukraine, as a branch of knowledge, has achieved a high level of development. Its results have been acknowledged worldwide and provided information support for all state plans and actions in this area. The experience gained indicates that population exposure dose evaluation and health impact appraisal call for continuous scientific follow-up to refine and upgrade the relevant techniques.

The Chornobyl catastrophe has demonstrated the necessity to conduct researches in enhancing reactor safety and simulating off-site accidents. Prior to the Chornobyl accident, these activities were not of high priority.

The Chornobyl lesson is sad, painful and tragic. It has shown that, to overcome such a tragedy, huge finances and resources, and much time is needed.

The experience gained should necessarily be taken into account when planning actions to eliminate the impact of all possible accidents of human and natural origin.

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Chapter 5

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