Radiological consequences of the Chernobyl accident in the Soviet Union and measures taken to mitigate their impact

Analysis of data confirms the effectiveness of large-scale actions to limit the accident's effects

by L.A. Ilyin and O.A. Pavlovskij

As a result of the accident that occurred at 1:23 a.m. on 26 April 1986 at Unit 4 of the Chernobyl nuclear power plant, a significant quantity of the radioactive materials accumulated in the reactor during its operation escaped from the plant. Because of the meteorological air mass transfer conditions prevailing, the cloud formed at the time of the accident left a radioactive trail over the area to the west and north of the plant. In the following 10 days, an intense release of radioactive gases and aerosols continued, resulting in the contamination of terrain in different directions and at considerable distances from the plant. The total release of radioactive substances (excluding radioactive noble gases) was calculated on 6 May 1986 to be about 1.9 EBq (exa-becquerel, or 10^{18} Bq), or 3.5% of the total inventory of radionuclides in the reactor at the time of the accident. Releases of the biomedically most significant nuclides such as strontium-90, iodine-131, and caesium-137 amounted to 8.1, 270, and 37 PBq (peta-becquerel, or 10^{15} Bq), respectively.

Decision to evacuate

In the first hours after the accident the cloud bypassed the town of Pripyat. But later when the height of the release from the damaged reactor declined substantially, changes in wind direction in the ground layer caused the radioactive plume to envelop the territory of the town for a period of time, gradually contaminating it. In the period up to 9:00 p.m. on 26 April 1986 the gamma radiation dose rate measured at a height of 1 metre above the ground in some streets in the town was between 14 and 140 milliroentgen per hour (mR/h). During the night from 26 to 27 April the radiation situation in the town began to worsen. By 7.00 a.m. on 27 April the gamma radiation dose rate in the area closest to the plant (Kurchatov Street) had reached 180–600 mR/h, while on other streets it ranged between 180 and 300 mR/h. In the light of predictions that the external exposure received by the public in the first few days after the accident might exceed the level used in the Soviet Union as the criterion for a decision on the introduction of emergency measures to protect the public, it was decided to evacuate the inhabitants of Pripyat and a few nearby population centres.* The evacuation began at 2:00 p.m. and was completed by 5:00 p.m. on 27 April. The gamma radiation dose rate in the town had by that time reached 0.36–0.54 R/h, and in the area of Kurchatov Street 0.72-1.0 R/h. By 6 May radiation levels in the town had dropped by about a factor of three.

The assessment based on off-site radiological monitoring and direct data from readings from personal dosimeters used by members of radiation safety services and emergency teams showed that the maximum doses received by critical groups among the inhabitants of the town could have reached 0.1 gray (Gy) for external radiation and approximately 1 Gy for beta radiation to the skin.

Profs. Ilyin and Pavlovskij are with the Institute of Biophysics, USSR Ministry of Public Health, in Moscow. This article is based on their presentation to the IAEA's International Conference on Nuclear Power Performance and Safety, which was convened in Vienna from 28 September to 2 October 1987. Proceedings of the conference may be purchased from the IAEA.

* See "The adoption of urgent measures to protect the population in the event of an accidental release of radioactivity into the environment", by I.K. Dibobes, L.A. Ilyin, V.M. Kozlov, et al., *Handling of radiation accidents*, proceedings of the IAEA's international symposium, Vienna (1969), p. 547 (in Russian).

The damaged Chernobyl reactor has been encapsulated in a structure called an "envelope" (generally referred to as the "sarcophagus"), which is intended to contain radioactive materials and prevent environmental contamination.

It should be stressed that the vast majority of the population of Pripyat, and especially children, were exposed to much lower doses than the maximum estimated values. The public were advised, immediately after the accident began, to restrict the time spent outdoors and not to open windows. On 26 April all outdoor activities at children's institutions in the town were forbidden. Also, iodine prophylactics were distributed by medical teams at all children's institutions. As a result, people who stayed mostly indoors during the day on 26 and 27 April were exposed to a gamma radiation dose two to five times lower than the levels recorded outside. On the basis of the above, there is reason to assume that the probable exposure levels for the vast majority of the population of Pripyat were 15–50 mGy for gamma radiation and 0.1–0.2 Gy for beta radiation to the skin.

Subsequent examinations of the chromosome aberration rate in peripheral blood lymphocytes carried out by specialists from the Genetics Institute of the USSR Academy of Sciences confirmed these estimates. These studies indicated that even for the town's most critical population group (people who spent prolonged periods in the open air after the accident and who were actively travelling around the town — doctors, members of the militia, municipal workers, etc.) the average absorbed dose calculated on the basis of this biological method was 0.13 ± 0.03 Gy. Also, there was a high degree of convergence between the "biological" dosimetry methods used and the traditional "physical" methods. A paired comparison of these doses for 93 people who were involved in eliminating the consequences of the accident yielded a mean dose ratio of 0.98, with a standard deviation of 0.51.

In view of the duration of the release of radioactive gases and aerosols from the damaged reactor and on the basis of existing material and special calculations for the whole contaminated area, it was concluded that a further evacuation from the accident zone should be conducted.* As a result of these actions, the total number of evacuees rose to 115 000. Fifty settlements and 13 000 farm-type houses were constructed for the evacuees, and 8000 apartments were made available in Kiev and Chernigov.

An important role in this crucial stage of implementing measures to protect the population was played by criteria which constitute the approved standard in the Soviet Union.** *(See accompanying table.)* When these criteria were being developed, it was recognized that the most urgent measures are those which are needed to protect the public from the dangers that arise when the cloud released by the accident is passing, namely inhalation and external exposure. Less urgent are measures to prevent the contamination of milk and its use in food.

* "Assessment of the radiation consequences of accident situations at nuclear power plants and problems of public safety", by L.A. Ilyin, O.A. Pavlovskij, and I.P. Sayapin, *Nuclear power plant radiation safety and protection*, 8th ed. (Yu.A. Egorov, Ed.) Energoatomizdat, Moscow (1984) 146 (in Russian).

** "Criterion for urgent decisions on measures to protect the population in the event of a nuclear power plant accident", by Yu.O. Konstantinov, *Nuclear power plant radiation safety and protection*, 9th ed. (Yu.A. Egorov, Ed.), Energoatomizdat, Moscow (1985) (in Russian).

Criteria in the Soviet Union for taking decisions on measures to protect the population in the event of a reactor accident

Nature of exposure	Level of exposure A	Level of exposure B
External gamma radiation (rad)	25	75
Thyroid exposure due to intake of radioactive iodine (rad)	25-30	250
Integrated concentration of iodine-131 in air (micro-curie per day per litre)		
Children	40	400
Adults	70	700
Total intake of iodine-131 with food (micro-curie)	1.5	15
Maximum contamination by iodine-131 of fresh milk (micro-curie per litre) or of daily food intake (micro-curie per day)	0.1	1
Initial iodine-131 fallout density on pasture (micro-curie per square metre)	0.7	7

If exposure or contamination do not exceed level A, there is no need to take emergency measures that involve the temporary disruption of the normal living routine of the public. If exposure or contamination exceed level A but do not reach level B, it is recommended that decisions be taken on the basis of the actual situation and local conditions.

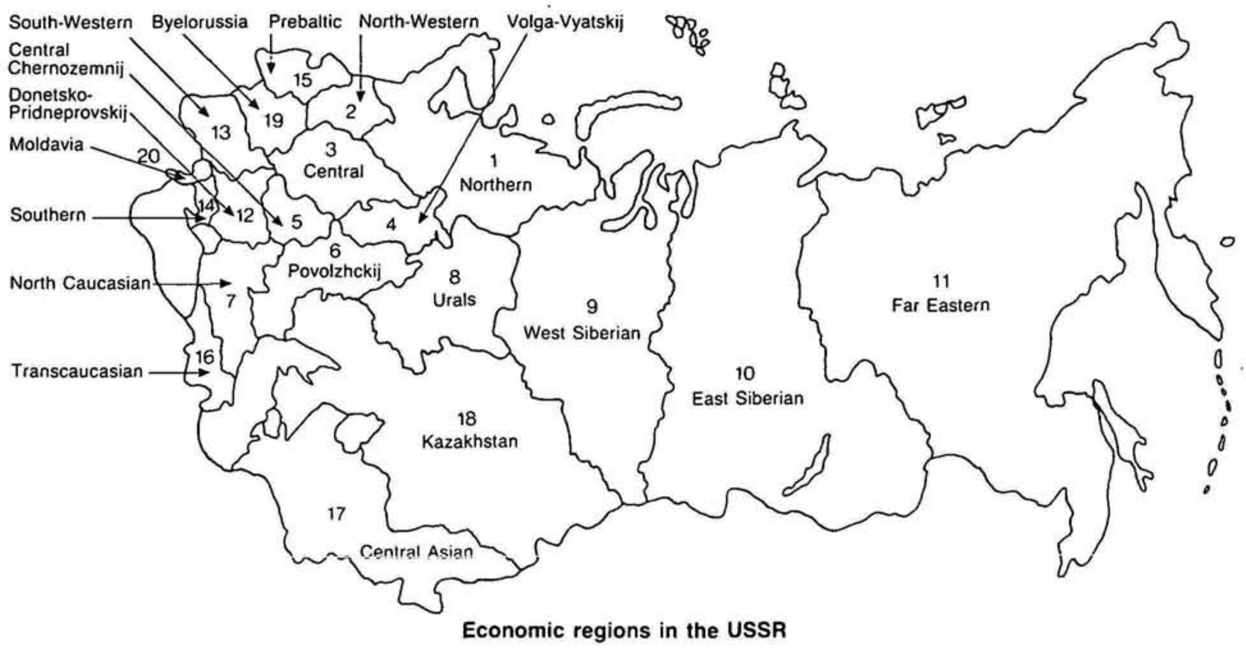
If exposure or contamination reach or exceed level B, it is recommended that emergency measures be taken to ensure the radiation protection of the public: the public should immediately seek shelter indoors; time spent outdoors should be restricted; on the basis of the actual situation, rapid evacuation should be organized; prophylactic iodine should be distributed; the use of contaminated products in food should be banned or limited; dairy cattle should be switched to uncontaminated pasture or fodder.

The various measures to protect the public are not of equal value, and this applies also to the unfavourable psychological effect they may have on the public; the most complex action to take from this point of view is the evacuation of the population. It follows that the selection of danger levels warranting the introduction of these or other protective measures should be based not only on considerations regarding the biological risk from exposure, but also on the following factors: extent of the danger involved; the relative urgency of the protective measures; the degree of certainty in the assessment of the evolving radiation situation; the question whether it is really possible to implement a measure on time; the adverse psychological effect and the risk to public health which might arise if a particular measure is carried out. In the light of the above factors, it was considered appropriate, in the case of a measure such as the evacuation of the population to avoid external gamma exposure, to take as the main criterion levels close to the dose threshold at which exposure could have an effect on the human organism. For internal exposure of the thyroid gland due to inhalation of iodine isotopes, it was decided to take as the upper limit of the criterion the dose level at which clinical and experimental data indicate that serious adverse effects on the individual could be expected.

Taking as the basis national and foreign experience in assessing the effect of radiation on the human body, it was decided that the values 0.25 Gy for external exposure of the human body and 0.25-0.3 Gy for internal exposure of the thyroid should be taken as the lower intervention level (level A in the table) which would trigger emergency measures involving the temporary disruption of the population's normal living routine. The upper level (level B), which represents a situation where such measures must be taken, is 0.75 and 2.5 Gy for whole-body and thyroid exposures, respectively. It should be noted that these dose levels are rather close to the range of intervention levels (0.05–0.5 Gy for whole-body exposure and 0.5–5 Gy for thyroid exposure) recommended by the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO), and the IAEA for decisions to evacuate the population at an early stage of an accident.* However, the decision to evacuate the population of Pripyat was not taken when public exposure had reached or exceeded level A, but rather at the point when the radiation situation forecast indicated that there was a possibility that this might happen. This principle was also observed for the evacuation of other contaminated areas, although because the radiation situation in the accident zone was constantly changing it was not possible to prevent all inhabitants from receiving a dose exceeding level A. In some population centres located in the most contaminated parts of the radioactive trail (the villages of Toltstyy-Les, Kopachi, and some others) the external exposures received by the public were 0.3–0.4 Gy, but nowhere did they reach values corresponding to level B in the criteria referred to above. However, even at these levels of external exposure of the human organism there is no danger of acute, immediate somatic effects in exposed persons.

Measurements of the thyroid burden of iodine isotopes in people evacuated from Pripyat to nearby centres in the Polessk region showed that in 97% of those examined the thyroid iodine burden resulted in a dose of under 0.3 Gy, in 2% the dose was in the range 0.3–1 Gy, and in less than 1% the dose was between 1.1 and 1.3 Gy. Here a positive role was played by iodine prophylactics and also by the restrictions imposed on the consumption of milk from cows being reared privately. These data are confirmed by measurements of the thyroid iodine burden in inhabitants of Pripyat evacuated to the town of Belaya Tserkov, where the possibility of consuming food products contaminated by iodine-131 was severely restricted. According to the results of measurements conducted on 7 May 1986, in the majority of those examined the thyroid burden was

* See *Derived intervention levels for application in controlling radiation doses to the public in the event of a nuclear accident or radiological emergency — principles, procedures and data*, Safety Series No. 181, IAEA (1986), and *Nuclear power accidental releases — practical guidance for public health action*, WHO Regional Publications, European Series No. 21, Copenhagen, WHO Regional Office for Europe (1987).



Economic regions in the USSR

0.015–0.25 Gy, and only in a few children aged between three and eight was the iodine-131 thyroid burden between 0.17 and 0.24 MBq (mega-becquerel, or 10^6), resulting in an absorbed dose to that organ of 1.5-2.2 Gy. This population distribution for thyroid exposures due to inhalation was roughly characteristic also for the inhabitants of other population centres evacuated from the accident zone.

As a precautionary measure all the children from the evacuation zone (numbering more than 27 000) were sent to State health institutions during the summer of 1986; this operation was organized centrally. Constant medical supervision was provided for children for whom the thyroid exposure before full decorporation of iodine isotopes was estimated to exceed 0.3 Gy. A total of 5.4 million people, including 1.7 million children, received iodine prophylactically. In addition to this emergency measure and on the basis of national and foreign data on the effectiveness of other measures to protect the public, a large number of precautionary and protective measures were taken in regions adjacent to the accident site which enabled the internal and external doses to the public to be reduced substantially.* A detailed description of these actions and their efficacy under the actual conditions prevailing while the consequences of the accident were being eliminated is given below.

* *Planning for off-site response to radiation accidents in nuclear facilities — recommendations*, Safety Series No. 55, IAEA, (1981); *Radioactive iodine and the problem of radiation protection*, by L.A. Ilyin, G.V. Arkhangel'skaya, Yu.O. Konstantinov, and I.A. Likhtarev (L.A. Ilyin, Ed.) Atomizdat, Moscow (1982) (in Russian); *Bases for the protection of the organism from the effect of radioactive substances*, by L.A. Ilyin, Atomizdat, Moscow (1977) (in Russian); "Agricultural produce as a source of radionuclides and some principles for organizing agriculture in the vicinity of nuclear power facilities", by R.M. Aleksakhin, N.A. Korneev, L.I. Panteleev, and B.I. Shukhovtsev, *Nuclear power plant radiation safety and protection*, 9th Ed. (Yu.A. Egorov, Ed.), Energoatomizdat, Moscow (1985) 70 (in Russian).

Assessment of long-term consequences

Information collected from the various sectors of the European part of the Soviet Union showed that radioactive releases from the Chernobyl plant had an effect on the radiation situation not only close to the plant but also at significant distances from it. To assess the long-term radiological consequences of the accident, the whole territory of the Soviet Union was split into 20 regions on the basis of the usual economic regions... *(See map.)*

Analysis of the results of the calculations for each of the 20 economic regions and for the Soviet Union as a whole reveals the following:

- The role of external exposure from the radioactive cloud is not large — 2.5 and 0.8% of the total collective dose to the Soviet population in the first year after the accident or in the lifetime of a man. For areas close to the plant the contribution of this factor is somewhat higher because of the additional dose received by the population evacuated from the 30-kilometre zone around the plant.
- Internal exposure of the organism due to the inhalation of radioactive substances also accounts for a small part of the radiation dose received by the population (4.5 and 1.4% for the annual and lifetime dose). The main isotope contributing to the dose in this case is iodine-131, while the critical organ receiving the maximum exposure is the thyroid gland. It should be noted that the average exposures of the Byelorussian population resulting from this factor were 4.3 mGy for infants

(age 1 year), 3.7 mGy for children aged about 10, and 5.0 mGy for adults. For other regions these doses were much lower.

● Taking into account all measures which have already been carried out or which it is planned to implement in future, the main contribution to the dose received by the Soviet population was external exposure from radioactive fallout deposited on the ground. Its relative contribution will rise from 53% in the year following the accident to 60% of the dose commitment to the public. It should be noted that the contribution of the external exposure of the Soviet population in the first year after the accident constitutes 26.7% of the public dose commitment. Of these 26.7%, 20.2% is accounted for by iodine-131 and other short-lived isotopes and the remaining 6.5% is distributed almost equally (3.5% and 3%) between caesium-134 and caesium-137. For the lifetime dose, of course, the main role is played by caesium-137, whose contribution to the overall external exposure of the public from radioactive fallout deposited on the earth's surface as a result of the accident represents 70%. In calculating the short- and long-term exposures from caesium-137, account was taken of shifts in both overall population levels and in the relative size of the urban population in individual regions of the country. It should be pointed out that decontamination work played a major role in reducing the external gamma radiation exposures received, particularly in regions near the Chernobyl plant. The decontamination of more than 600 population centres, the removal and subsequent burial of contaminated soil, the suppression of dust over large areas, the asphalting or covering of contaminated sectors with gravel, chippings, sand or fresh earth, the designation of exclusion zones and the restrictions imposed on productive activity and other similar measures enabled the average public exposure in these regions to be reduced by a factor of two to three.

● Internal exposure resulting from the ingestion of radioactive substances was the most "controllable" element in radiation exposures. The main nuclides contributing to exposures resulting from the accident were iodine-131, caesium-134, and caesium-137. Before the accident standards were in force in the Soviet Union, as in other countries, only for the permissible annual dietary intake of radioactive substances. A level for the permissible concentration of nuclides in drinking water was also established. There were no regulations governing the radionuclide content of individual foodstuffs. Standards to be applied in the event of an accident were in place for the critical product (cow milk) and for the nuclide which is of the greatest importance in an accident, namely iodine-131.

Standards for foodstuffs

In the wake of the Chernobyl accident, the questions of inspecting and banning the consumption of specific foodstuffs had to be dealt with effectively. Since the main threat in the early stages was the intake in the spring-summer period of iodine-131 principally via milk, but also via green leaf vegetables, standards were introduced immediately after the accident for the permissible content of iodine-131 in milk and dairy products (curds, sour milk, cheese, and butter) and in edible green leaf vegetables. The standards were calculated so as to prevent thyroid doses in children from exceeding 0.3 Gy. This condition was satisfied in the case of a permissible concentration of iodine-131 in milk of 3.7 kBq/L. A similar standard was introduced in England in 1957 following the Windscale accident. Standards were also imposed for the permissible level of iodine-131 in meat, poultry, eggs, berries, and raw materials for medicines. In the second half of May 1986 data were obtained which indicated that, in conjunction with iodine-131 decay, caesium-137 and caesium-134 were playing an increasing role in the contamination of meat and other produce; evidence was also found of the presence in foodstuffs of isotopes of rare earth elements. In order to carry out large-scale monitoring and inspection of foodstuffs during this period, standards were required which enabled monitoring to be performed using the simplest instruments, in other words the standards had to relate to the total content of beta activity. Such standards were approved by the Ministry of Public Health on 30 May 1986. They maintained a certain continuity with the earlier standards of 8 and 12 May, covered a wider range of products and reflected changes in the radiation situation observed by the end of May. The permissible whole-body exposure used as the basis for calculating these standards was 0.05 sievert (Sv).

In the first days and weeks after the accident radioactive contamination of foodstuffs was mainly due to iodine-131. It appeared in the milk of cows which grazed on pasture land 2-3 days after the accident. Levels of iodine-131 contamination in milk in southern Byelorussia, northern parts of the Ukraine and provinces of the Russian Soviet Federated Socialist Republic (RSFSR) adjoining the accident region reached 0.04-0.4 MBq/L during this period, that is tens and even hundreds of times higher than the established standard. Milk from cows kept in stalls was much less contaminated, however. In each of the provinces affected by radioactive contamination daily checks were carried out on hundreds of milk samples, which made it possible to obtain detailed information on changes in the contamination of agricultural produce both in individual regions and the country as a whole. An analysis of these data confirmed the log-normal distribution of the iodine-131 concentration in cow milk and established that the integral of iodine-131 concentration in milk put on sale to the public through the centralized system were approximately 107 $Bq \cdot a \cdot L^{-1}$ for the Gomel'skaya province of Byelorussia, about 230 $Bq \cdot a \cdot L^{-1}$ for the Mogilevskaya province of Byelorussia, and 10, 100 or even more times lower for other provinces and republics. At the same time it should be noted that on 17 May

1986, for example, between 20 and 30% of milk had an iodine-131 content exceeding 3.7 kBq/L in the above-mentioned provinces of Byelorussia.

The implementation of a whole range of actions to control iodine-131 contamination of milk made it possible to reduce substantially the significance of this factor in the exposure received by the public. Assessments have shown that, in comparison with regions where such measures were not taken because the absolute levels of iodine-131 contamination of milk were not high, a reduction by a factor of 5–20 was achieved in individual doses received by the public in the most heavily contaminated areas. The overall contribution of iodine-131 intake by ingestion to the total dose received by the Soviet population was 2.5% (1.1% in Byelorussia), while the maximum individual thyroid exposures were recorded in the South-Western economic region, which includes 13 provinces of the Ukraine (including the Kievskaya, Chernigovskaya and Zhitomirskaya provinces — i.e., those provinces directly adjoining the accident region). The average of such exposures for the region were 26 mGy for children aged 1, 8.2 mGy for children aged 10, and 2.6 mGy for adults.

Direct measurements of the concentration of iodine isotopes in the thyroid conducted in the first months after the accident on 330 000 people (63% of whom were children) living in the immediate vicinity of the 30-kilometre evacuation zone showed that the average iodine-131 activity for this organ was less than 0.1 MBq. This corresponds to exposure levels approximately 10 times higher than the average values given above for the whole South-Western economic region.

To evaluate the level of caesium isotope ingestion through contaminated foodstuffs, information on the contamination of milk, meat, and vegetables in all regions of the Soviet Union was used. It was shown that, when the country-wide average geometric value for the ratio of the caesium-137 concentration in milk (in Bq/L) to the density of ground contamination (in kBq/m^2) was 21, the ratio in the most heavily contaminated regions was close to 5 for milk put on sale to the public through the centralized system. It was also demonstrated that the distribution of samples of caesium-137 activity in milk sold to the public was in good agreement with the log-normal law, with a geometric average of 43 Bq/L for Byelorussia, 30 Bq/L for the South-Western economic region, and 12 Bq/L for the Central economic region (which includes the 12 provinces of the RSFSR). These values were 2-4 times higher for caesium-137 in meat. More than 300 000 measurements of the content of caesium isotopes in the human organism were conducted in 1986 and 1987, and these indicated that in almost 80% of cases the caesium-137 activity in the human body did not exceed 1 kBq, whereas the level expected on the basis of model calculations was 10-15 kBq. For the country as a whole, the contribution of caesium-134 and caesium-137 ingestion to the dose one year after the accident was 13% and 20% respectively.

Estimation of caesium's future doses

A more difficult task is that of predicting the radiation effect of caesium isotopes on the human organism in the near and long term. To prepare this estimate, it was decided to use the coefficients for caesium-137 transfer to the main types of agricultural produce derived in 1964-86 from analyses of data on the monitoring of the contamination of Soviet territory by fallout from nuclear tests. It was established from these studies that the half-life of caesium-137 in milk in the Soviet Union is 8.4 years, in other words the "uncontaminated" soil component of the decontamination model for caesium as a chemical element is 0.06/a^{-1}. On the basis of the above, the integral intake of caesium-134 and caesium-137 was taken to be 2.5 and 12% of the intake levels for these nuclides during the second year after the accident. The calculation of collective doses also allowed for growth in the populations of various regions of the country, but the pattern of food consumption was taken as remaining the same as in 1986. The latter assumption may lead to some underestimation in the results of the calculations since the clear trend in the Soviet Union in recent years has been for increased consumption of meat and dairy products and a rather marked decrease in the annual consumption of potatoes and bread.

On the basis of the above, the collective committed dose for the Soviet population arising from the ingestion of caesium isotopes is estimated at 117 000 man·Sv, of which only 27% is attributable to the first year. It follows that the main contribution to this dose will arise in the second and subsequent years after the accident, that is during a period when the radiation exposure of the population can be actively controlled by strictly monitoring agricultural produce and by introducing agrotechnical measures on contaminated land, including even the restructuring of farms.

In accordance with guidelines issued by the USSR State Commission for the Agricultural Industry, a range of agrotechnical and agrochemical measures designed to make agricultural products fit for consumption were implemented in contaminated regions of the Ukraine, Byelorussia, and the RSFSR in 1986 and 1987. Deep ploughing was carried out and large quantities of inorganic fertilizer were applied to hundreds of thousands of hectares of contaminated land in these republics. Work is under way to ameliorate meadows and pasture land. Steps are being taken to reduce the transfer of radioactive substances from the soil to crops by applying lime, phosphoric and potassic fertilizer, and certain sorbents (zeolite) to the soil. In the first year following their implementation, these measures have reduced the levels of radioactive contamination of agricultural produce by a factor of 1.5 – 3. The full implementation of all the measures stipulated by the USSR State Commission for the Agricultural Industry will probably result in a substantial reduction in the exposure of the population from food.

Average per capita dose commitment

The overall average per capita dose commitment for the Soviet population will be about 1.2 mSv which, given an annual total background radiation in the Soviet Union of 1 mSv/a, will result in an overall addition of about 2% to the dose due to natural background radiation. This figure is approximately 2–3 times higher than the dose received by the population of Hungary and of Italy, Sweden, and other Western European countries which were affected by the accidental release from the Chernobyl plant.

After all these measures had been taken, the main contributor to the dose commitment for the Soviet population was external gamma radiation from accident fallout deposited on the ground (about 60%), with about 38% being due to internal exposure from the consumption of contaminated foodstuffs. It is worth noting that, in those population centres where preventive measures were not taken because of the low absolute levels of radiation and food contamination, there were cases where the ratio of internal to external exposures of the organism one year after the accident was close to 10. In virtually all population centres where the contamination of agricultural produce was monitored and where those foodstuffs which did not meet the established standards were rejected, the ratio of external to internal exposures was close to 1.

Establishment of health register

Special scientific centres and complex scientific programmes were established for the long-term biomedical observation of the public and workers. One of the most important features of this work is the establishment of an all-Union register of all persons subjected to radiation exposure. Included in the register will be all residents, all those who were there temporarily, the teams brought in to fight the accident and its consequences, the children and grandchildren of the above groups (at a later stage), and those evacuated from contaminated areas. To help establish the register, registration and dosimetry cards have been elaborated which are to be filled out for each person under observation.

The registration card contains the following information: surname, first name and patronymic, date and place of birth, sex, place of residence, place where subjected to radiation, duration of exposure, anamnestic information on state of health, whether pregnant when exposure began (how many weeks) or having become pregnant after exposure started, outcome of pregnancy, data on child, cause of death (adults, children, newborns), measures taken (hospitalization, prophylactic iodine).

The dosimetry card contains details of the public health characteristics of the region and the extent of the radiation exposure of the individual (contamination of clothing, shoes, and integument before and after decontamination). The card gives information on the iodine-131 thyroid burden, which is a dosimetric parameter for the clinical examination of persons being checked up, and information on personal dosimetry (measurement of biosubstrates, measurements using a whole-body counter, and other instruments).

The registration and dosimetry cards are to be filled in by local health authorities and are then sent to the Ministry of Public Health of the relevant republic and to the USSR Ministry of Public Health. All the information recorded on the registration cards will also be entered in a register which is to be kept permanently on the premises where examinations are conducted. The frequency of examination will be determined from the results of the first examination and the assessment of the dose received. Account is taken of the precautionary and protective measures implemented (iodine prophylactics, evacuation, limitation of intake of radionuclides through inhalation and ingestion).

As part of the work on the register, medical examinations of all types were conducted on almost one million people, of whom 700 000 (including 216 000 children) were subjected to thorough dosimetric and laboratory analytical tests. Thirty-two thousand people, including 12 300 children, were examined as in-patients.

In 1986 and 1987 teams of highly qualified specialists (haematologists, endocrinologists, paediatricians, radiologists, and so on) working directly in the regions affected by contamination conducted an analysis of the state of health of children and adults in the population which confirmed the absence of deviations in the health distribution of these groups compared with the control group.

No discrepancies were observed in the pattern of morbidity or the child mortality rates when these were compared with data from medical records for the 5-6 year period preceding the accident.

An expert evaluation showed that pregnancy, birth, and puerpurium trends in the women examined did not differ from those in the control regions or from the trend in the years preceding the radiation incident. The number of children born in 1986 in contaminated regions did not differ from the average. The proportion of still-born children did not exceed the corresponding figure in the control region. In Kiev, information on all women who were pregnant at the time of the accident is being collated by the Maternity and Child Protection Centre. Data from the Centre have confirmed that no teratogenic effects were observed in any child born (these are effects resulting from the irradiation of the foetus in the mother's womb during the Chernobyl accident).

The endocrinological study conducted over the period referred to above did not reveal any cases of hypothyroidism in new-born children and their mothers as a result of radiation, and no increase in the incidence of hypothyroid disease was recorded for the exposed population.

The analyses in 1986 and 1987 of many tens of thousands of haemograms of inhabitants of the contaminated areas showed that the frequency of deviations in blood values from the average falls within the normal distribution function for practically healthy people. None of the studies carried out revealed any difference in the frequency of particular variations in blood analyses conducted on exposed persons as compared with the control group.

Detailed studies in 1986 and 1987 indicated that children exposed to radiation showed no increase in general morbidity nor any increase in such nosological forms as pneumonia, allergic and auto-immune processes, congenital heart and vascular anomalies, or other diseases. An analysis of the incidence of infectious diseases in the population living in contaminated areas indicates that the level and structure follow the general pattern for both the regions in question and the country as a whole. A comparison of oncological disease rates in the regions under consideration and in the control areas revealed no significant variations. The level of malignant neoplasms of blood-forming and lymphatic tissue showed no increase. Not one case of leukaemia was recorded among the children exposed in 1986-87.

The analysis of statistical data revealed no increase in the psychoneurological disease rate in the population of the regions studied. However, it was established from the questioning of part of the population examined that in the early period following the accident some suffered from asthenic symptoms which took the form of mental and physical sluggishness and vegetative disorders. At the time examinations were conducted, an increase in the level of anxiety due to worries about the health risks to children and to the disruption of the normal daily routine was observed in the adult population living in contaminated areas outside the 30-kilometre zone around the Chernobyl plant. This tension and chronic state of stress are causing radiation phobia syndrome in part of the population and may, in the current radiation situation, pose an even greater threat to health than exposure to radiation itself.

Effectiveness of measures taken

On the basis of the above information, it can be stated that the systematic monitoring of the health of the population and of the radiation situation in population centres within the contaminated zone has confirmed the effectiveness of the precautionary and protective measures taken in these areas; of these measures, particular mention should be made of the decontamination of population centres, the removal of children and pregnant women over the summer period for health reasons, the universal and regular monitoring in 1986 and 1987 of the level of contamination of locally produced foodstuffs, the switching of dairy cattle to uncontaminated pasture or fodder, and the ban on the consumption of contaminated foodstuffs. All these actions significantly reduced the radiation exposure of the public, bringing the average figure for the most heavily contaminated regions of the Gomel'skaya, Kievskaya, Bryanskaya, and Mogilevskaya provinces down to 10-15 mSv, less than 50% of which was due to internal exposure from caesium-134 and caesium-137. Only in 0.5–1% of those examined did the internal exposure exceed 50 mSv. As further studies demonstrated, the high levels of caesium isotopes ingested by the latter group are the result of their ignoring bans on the consumption of contaminated produce from their own farms. This group, which consists mainly of pensioners, includes a number of young people (machine operators, livestock breeders) who openly disregarded the instructions of the local public health bodies regarding the need to replace contaminated local foodstuffs with uncontaminated produce brought in from elsewhere.

Evaluations show that the range of precautionary and protective measures implemented reduced the individual external exposures by a factor of 2–3 compared with the dose predicted, and lowered the internal radiation doses to the public by a factor of 10 or more. The agrotechnical and sanitary measures that, as mentioned above, are to be taken in future years will probably lower the dose commitment for the population of individual regions and of the Soviet Union as a whole compared with the values given here.

In conclusion, it is important to emphasize the need to conduct in the coming years a thorough and comprehensive analysis of the vast amount of experience gained from the work carried out to eliminate the consequences of the Chernobyl accident. In this paper an attempt has been made only to identify features which were new in the theory and practice of radiation protection and to point out those aspects of the scientific work that existed before the accident which proved particularly effective in the post-accident period. The most important examples of these are as follows:

- In the overall range of measures taken to protect the population, the distribution of prophylactic iodine proved highly effective in the very unusual circumstances of the accident, which involved the prolonged release of gases and aerosols from the reactor zone.
- It is essential to establish standards for the permissible radioactive contamination of specific types of food and to develop systematic principles for the large-scale monitoring of compliance with these standards using very simple equipment.
- Experience confirmed the value of dividing the contaminated area around the damaged reactor into zones and of implementing special dosimetric controls to prevent the transfer by man of radioactive substances from the "contaminated" to the "clean" zone.
- It is possible to carry out a large amount of decontamination work over large areas, thus reducing external exposures by a factor of 2 or 3 and significantly reducing the possibility of the inhalation of radionuclides by man as a result of secondary dust formation.
- By imposing limitations on the consumption of contaminated foodstuffs and by introducing special agrotechnical measures, it is feasible in practice to reduce internal exposures resulting from ingestion of radionuclides by a factor of 10 or more.