ANNEX 7

MEDICAL-BIOLOGICAL PROBLEMS

Contents

ANNEX 7

7.1. DATA ON OPERATIONAL AND EMERGENCY STAFF OF THE NUCLEAR POWER PLANT WHO WERE EXPOSED TO RADIATION: SIZE OF THE DOSES RECEIVED AND THE CONSEQUENCES FOR HEALTH. EXPERIENCE OF TREATMENT

7.1.1. First information about the accident and action taken by the medical staff

The medical and health section serving the plant received information at their station about the accident 15 minutes after it happened (2 a.m., 26 April 1986).

Assistance was given to the first 29 victims leaving the site of the accident by themselves within the first 30-40 minutes by the middle-level medical staff on duty at the health station. The victims threw off their contaminated clothing and shoes even before entering the personnel airlock. Owing to the intense primary reaction, they were immediately sent to the hospital where health procedures and the first medical examinations were carried out.

During the next four hours, first aid teams which had immediately arrived on the scene provided assistance to the victims, removing them from the zone of production operations, carrying out preliminary health procedures in the personnel airlock and transporting persons suffering from primary reactions (nausea, vomiting) to the hospital. Persons who felt that their condition was satisfactory were sent home and, subsequently, actively summoned for examination in the morning of 26 April 1986. By 6:00 on 26 April, 108 persons had been hospitalized and, in the course of the day, another 24 persons from the group which had been examined were hospitalized.

One victim died at 6 a.m. on 26 April as a result of severe burns and one member of the staff who had been working at the time was not discovered. It is possible that his place of work was in the high-activity pile-up area.

Twelve hours from the time of the accident a team of specialists arrived and started to work. The group included physicists, radiology therapists, laboratory assistants and haematologists. Within 36 hours from the time of the accident, some 350 persons had been examined at the medical and health centre on a stationary or out-patient basis and approximately 1000 blood analyses had been performed (no fewer than 1 to 3 for each patient during the first 36-48 hours). The outpatient discharge cards contained entries relating to post-accident clinical indications, complaints, leukocyte number and leukocyte formula.

On the basis of the criteria adopted in the USSR for early diagnosis: times and intensity of the primary general and local (skin) reaction, intensity of leukopenia and neutrophilic leukocytosis towards the end of the first 36 hours were taken as a basis for the timely hospitalization of persons in whom the development of acute radiation sickness was diagnosed as a very high probability. Clinical institutions very close to Kiev and a specialized infirmary in Moscow were selected as the places for hospitalization in order to provide maximum assistance and competent follow-up analysis of the results of examinations.

During the first two days, 129 patients were sent to the specialized infirmary in Moscow. Of these, during the first three days, 84 were classified as having acute radiation sickness (second to fourth degree of severity) and 27 (with first degree severity), which is an indication that the primary classification was adequate.

The diagnosis of acute radiation sickness (second to fourth degree) was made in the first three days; specification of the first degree generally required a longer observation period (up to 1-1.5 months).

In all, 203 persons were recognized as having acute radiation sickness. Persons suffering fromn this condition were not found among the population at large.

7.1.2. Principles of diagnosis and prognosis in the specialized infirmary

The main diagnostic and prognostic criteria, of importance for deciding on the conditions for managing the patients and selecting the methods of treatment, including indication for bone marrow transplantation, decontamination etc., were determined during the first three days of the patients' stay in the infirmary.

The criteria for classifying the patients in the first few days were of clinical and clinico-laboratory nature, based on Soviet experience and on the recommendations of international radiology centres.

In the period from the first few hours to three days, the conclusive factors were the time and severity of the initial general (vomiting) and local (hyperaemia as well as cutaneous oedema and myxoedema) reactions. The intensity of lymphopenia was estimated quantitatively for the days of observation and on this basis a rough estimate was made of the mean dose of total uniform irradiation. The possible dose of bone marrow irradation was determined by the direct method, counting the aberrations in the bone marrow cells.

Supplementing this, during the first 10-14 days, severity criteria were applied for determining the extent of thrombocytopenia and the times at which it appeared, and also the severity of leukopenia and granulcytopenia and the times at which they developed. A quantitative estimate of the dose to bone marrow was made on the basis of the number of dicentrics in cultures of peripheral blood lymphocytes stimulated by PHA.

The dynamics of skin changes from the first few days to two weeks were estimated semi-quantitatively in accordance with accepted clinical parameters.

All these criteria developed by Soviet scientists afforded a means of evaluating the prognoses as to:

- overall clinical course of the pathology;
- the dynamics of the blood picture;
- the possible extent of injury to individual parts of skin and mucous membrane.

To the known extent, it was also possible to make a rough estimate of the mean dose of uniform gamma irradiation of the bone marrow or its equivalent according to individual biological parameters.

The course of the sickness and its possible outcome, specified in the initial stages in accordance with the above-mentioned prognostic criteria, showed satisfactory agreement with this prognosis in its subsequent manifestations.

With respect to the severity of the bone marrow and intestinal syndrome of acute radiation sickness, four degrees were distinguished, on the basis of criteria adopted in the USSR.

The classification extremely severe (fourth degree) was applied to cases of the sickness with a short latent period (up to 6-8 d), with a pronounced, early (in the first half hour) primary reaction (vomiting, headache, rise in body temperature). The number of lymphocytes in the first 3-6 days was less than 100/µL. As from the 7th to the 9th day, pronounced symptoms of enteritis. The number of granolocytes at on the 7th to the 9th day was 500/µL; thrombocytes $\leq$ 40 000/µL from the 8th to the 10th day. Intense general intoxication, fever, lesions of the oral cavity and salivary glands. The condition of 20 of the patients under treatment at the specialized infirmary were assignable to this type of pathology.

A total uniform irradiation dose of more than 6 Gy (up to 12-16 Gy), equivalent to the biological effect in haemopoiesis, was found in 18 patients.

Lethal outcomes in the period of + 10 days to + 50 days occurred in the case of 17 patients. In all these patients, the burns extended to 40-90% of the body surface and in most of them they were extremely severe, virtually fatal, even without taking into account the other clinical syndromes of radiation sickness. In two of the patients of this group, the content of radionuclides was also the highest (see Section 7.1.8). Two other patients with conditions of fourth degree severity died on days + 4 and + 10 at the Kiev hospital as a result of combined thermoradiation injury.

A total of 23 persons was classified as third degree acute radiation sickness patients. The total gamma radiation dose was approximately 4.2-6.3 Gy. The criteria for determining acute radiation sickness of this degree of severity were times of 30 min to 1 h for the development of a pronounced reaction (vomiting, headache, subfebrile body temperature, transient hyperaermia of the skin. Lymphopenia in 3-6 d, 200-100 cells/μL. Duration of latent period: 8-17 d. A characteristic feature is the presence of an epilation effect. Decrease in the number of thrombocytes to ≤ 40 000/μL in 10-16 d, of neutrophils to ≤ 1000/μL in 8-20 d. The climax of the sickness is characterized by pronounced fever, infectiuns complications, hemorrhagic bleeding. This degree of severity was identified on 21 persons at the specialized infirmary and in two at the Kiev hopsital. Seven persons died in periods of from two to seven weeks. Six persons of this group were suffering from severe skin injuries which greatly aggravated their condition and to a large extend predetermined the lethal outcome.

The criteria for the diagnosis of acute radiation sickness of second degree severity was the development of a primary reaction in 1-2 h: lymphopenia within a period up to 3-6 d of the order of 500-300 cells per μL. The length of the latent period was 15-25 days. The decrease in neutrophils in 20-30 d to 1000 cells per μL, thrombocytes in 17-24 d to 40 000 per μL. In the period of climax: genuine infectious complications and slightly pronounced symptoms of hemorrhaging. Moderate acceleration of the E.S.R. up to 25-40 mm/h. In the specialized infirmary and in the Kiev hospital, injuries of this degree of severity were found in 53 persons (level of those equivalent in biological effect to 2-4 Gy). There were practically no persons with burns aggravating their condition.

According to karyological data, the dose level in acute radiation sickness patients of first-degree severity ranged from 0.8 to 2.1 Gy. There were no patients with skin lesions substantially aggravating the clinical picture of their condition. The diagnostic criteria for acute radiation sickness of the first degree were: the presence of a primary general reaction in periods 2 h after the moment of exposure, the absence of a general skin reaction, a latent period longer than 30 d, a decrease in the number of lymphocytes in the first few days to 600-1000 cells per μL, leukocytes in the 8th-9th days to 4000-3000 per μL, and in the climax to 3500-1500, thrombocytes to 60 000-40 000 per μL (25-28 days), moderate acceleration of E.S.R. These criteria are used for estimating the degree of severity of the bone marrow syndrome. A very important factor for this group of patients were the data from systematic clinical and laboratory observations over a period of one-and-a-half months (with allowance for the latent period and the availability of data on the frequency of chromosome aberrations in the lymphocytes of the blood and bone marrow).

7.1.3. <u>The scale of biophysical studies and evaluation of the main damage-inducing factors and dose levels</u>

All persons entering the reception room were subjected to dosimetric monitoring by means of the various devices used in the USSR for recording external body radiation (RUP, SRP-68-01, AKTINIYA, TISS and others). This made it possible to estimate the dose rate distribution for the body (region of the thyroid gland, chest, back, wrist, hands, feet, legs etc.) and to obtain indications for repeat treatment and decontamination of integuments.

The dose rate measured by a device was dependent on the incorporation of radionuclides and, in part, on the residual contamination of the integuments of the persons concerned. The use of masks and washing by means of moistened tampons and aluminium metal filters (screens) in the measurements on apparatus permitted a rough estimate to be made of the contribution to the radiation from the body of the radionuclides incorporated in it and applied to the skin. The first determinations, as well as the examination and interrogation of the patients in the reception room, confirmed that most of them, in addition to being exposed to external gamma and beta radiation, had immediate contact with beta- and gamma-active nuclides, and in some cases these nuclides entered the organism.

Although in most cases there was a combination of two or three of the above-mentioned factors, the leading ones exhibited by the patients were external beta, gamma whole-body radiation and, in addition, greater irradiation of the integuments by relatively weakly penetrating radiation. Curves plotted for the decay of radioactive substances contained in urine samples of the patients from as early as two days after the accident, confirmed the presence in the victims' bodies of radionuclides with half-lives of 185-190 hours or approximately 8 days, and mainly isotopes of iodine.

The patients were carefully washed again and accommodated in wards, the potassium iodide treatment which was already started in the first four days was continued (0.25, twice a day). Treatment of the burns was started and continued; the same applied to the oropharyngeal syndrome which was also observed in this period in a considerable number of the patients.

Special diagnostic procedures, of both the general clinical and the biophysical types, were developed for determining possible dose level and nature of irradiation more specifically.

A combination of methods and various types of equipment were available for implementing the biophysical studies.

1. A scintillation detection unit (64 x 64 mm) housed in a lead collimator was used for measuring the content of ^{131}I in the thyroid gland. The radiation was collimated in such a way as to cut off the photon radiation from the human body, and to separate out only the radiation coming from the thyroid gland. The measurements were carried out in a narrow window (approximately 364 keV-^{131}I peak. The estimate of the addition on account of ^{131}I incorporated in the blood flowing through the region of the neck, was made by measuring the content of ^{131}I in the patient's forearm. Calibration was performed by means of point source of ^{131}I located in a phantom of the human neck.

2. The content of radioactive substances in urine samples was measured by devices for biosubstrate analysis: B10-1 and SICH (whole-body counter) 2.1. The former has a large-volume scintillation-type detection unit; the latter uses a semiconductor

detection unit based on a drift-type semiconductor unit. The same devices were used for measuring the gamma radiation from samples of dissected material. They were calibrated by means of certificate controlled gamma radiation sources in a geometry approximating the real one as closely as possible.

3. A SICH 2.2 device and a semiconductor unit with local shielding were used for measuring the activity incorporated in the human body. The former instrument uses a large-volume scintillation-type detector unit, the latter a semiconductor detection unit based on pure germanium. The devices were calibrated by means of phantoms of the human body, prepared from standard receptacles filled with calibration solutions of various radioactive substances.

4. Multichannel amplitude analysers (memory capacity up to 8000 channels) were used for collecting and analysing the gamma spectra obtained; the spectrometric channel of the devices was built from high-resolution spectrometric apparatus produced by the "Nokiya" company (Finland) and RT (USA).

The spectrometric information obtained from all the above-mentioned devices were recorded on magnetic tape.

To determine the total content of gamma activity of transplutonium elements in the excreta who were victims of the Chernobyl' accident, a study was made of urine samples of ten of the patients under examination who had been exposed under various conditions. In no case was plutonium found in the urine (sensitivity of the method: 0.2 disintegrations/min from a 500 mL sample).

Three patients whose levels of alpha-active radionuclides in the urine when they entered the infirmary (on 28 April 1986) were, respectively, 2.0, 0.67 and 0.1 nCi per 1 mL of urine, were given a diagnostic test involving the use of pentacine to accelerate the elimination of plutonium from the organism. In no case was any effect observed from administration of the preparation three times.

Examination of the organs of a patient who died (content of beta- and gamma-active radionuclides on entering the clinic on 28 April 1986 was 1.5 nCi/mL urine) showed, just in the lungs, a total alpha activity of transplutonium elements in the amount of $\leq$ 3.4 nCi/organ and trace amounts in the urinary bladder. No analysis was made of bone tissue.

Alpha spectrometry of lung samples showed approximately 90% ^{242}Cm and around 10% plutonium and americium. With a plutonium content at this level (in combination with transplutonium elements) and the low constant of its elimination from the organism, the level of clearance of the nuclide from the urine is below the sensitivity of the method of determination applied.

Immediately after hospitalization, simultaneously with the primary dosimetric monitoring by means of gamma radiometers for the purpose of estimating the level of radioactive contaminations, blood and urine samples were taken for biophysical examinations (measurements of total activity, gamma-spectrometric measurements). The studies of total activity were conducted in a biophysical laboratory and involved the use of precise radiometric equipment; the determination of the isotopic composition of the samples studied was carried out with a gamma spectrometer based on a semiconductor detector with pure germanium.

One to two days after the victims entered the infirmary, they were examined for content of radioiodine in the thyroid gland; this was determined by means of a gamma radiometer of the Gamma Co. (Hungarian People's Republic). In the days that followed, these examinations were repeated a few (4 to 6) times to obtain information concerning the half-clearance of radioiodine from the thyroid gland. The consolidated results of the measurements of radioiodine content in the period from 29 April to 6 May 1986 (day +3 to day +10) show that in the majority of victims (94%) the content of radioiodine in the thyroid gland on 29 April 1986 was less than 50 µCi; in 6% of those examined, these levels were 2-4 times higher (Figs 7.1.1 and 7.1.2).

A few days after entry into the infirmary, when the levels of residual surface contamination were close to the background values, a majority of the victims (except for persons in an extremely serious condition) were examined in stationary whole-body counters. The gamma-ray spectra from their bodies showed peaks of more than 20 different radionuclides, but the main ones determining the internal irradiation dose of the victims were ^{131}I, ^{132}I, ^{134}Cs, ^{137}Cs, ^{95}Nb, ^{144}Ce, ^{103}Ru and ^{106}Ru. The characteristic radiation spectra are shown in Figs 7.1.3 and 7.1.4.

At the autopsies of all the persons who died, specimens were taken of various organs and tissues for subsequent determination of their content of radionuclides (up to 35 samples from one person, including 17 samples from different parts of the lung, Fig. 7.1.5). Tentative results were obtained from the determination of individual radionuclides in five victims who died of acute radiation sickness in periods of 17 to 19 days. A standard sample analysis chart in relative units per 1 g of tissue is shown in Fig. 7.1.4.

The spectra of the radiation emitted by the human body varied in the individual observations.

The analysis of the data and evaluation of the individual irradiation doses of the organs and tissues is being continued. Only in one case, with a maximum content of radioactive substances in the organisms, was there reason to think of a contribution of internal radiation in the early clinical manifestations of injury to the respiratory organs and the digestive tract.

Results of the examination of biosubstrates for sodium-24

The first samples of biosubstrates (urine and blood) were received on 27 April 1986 at 3 p.m. They were subjected to spectrometric study for photon radiation emitted. The photon spectrum obtained was of a very complex

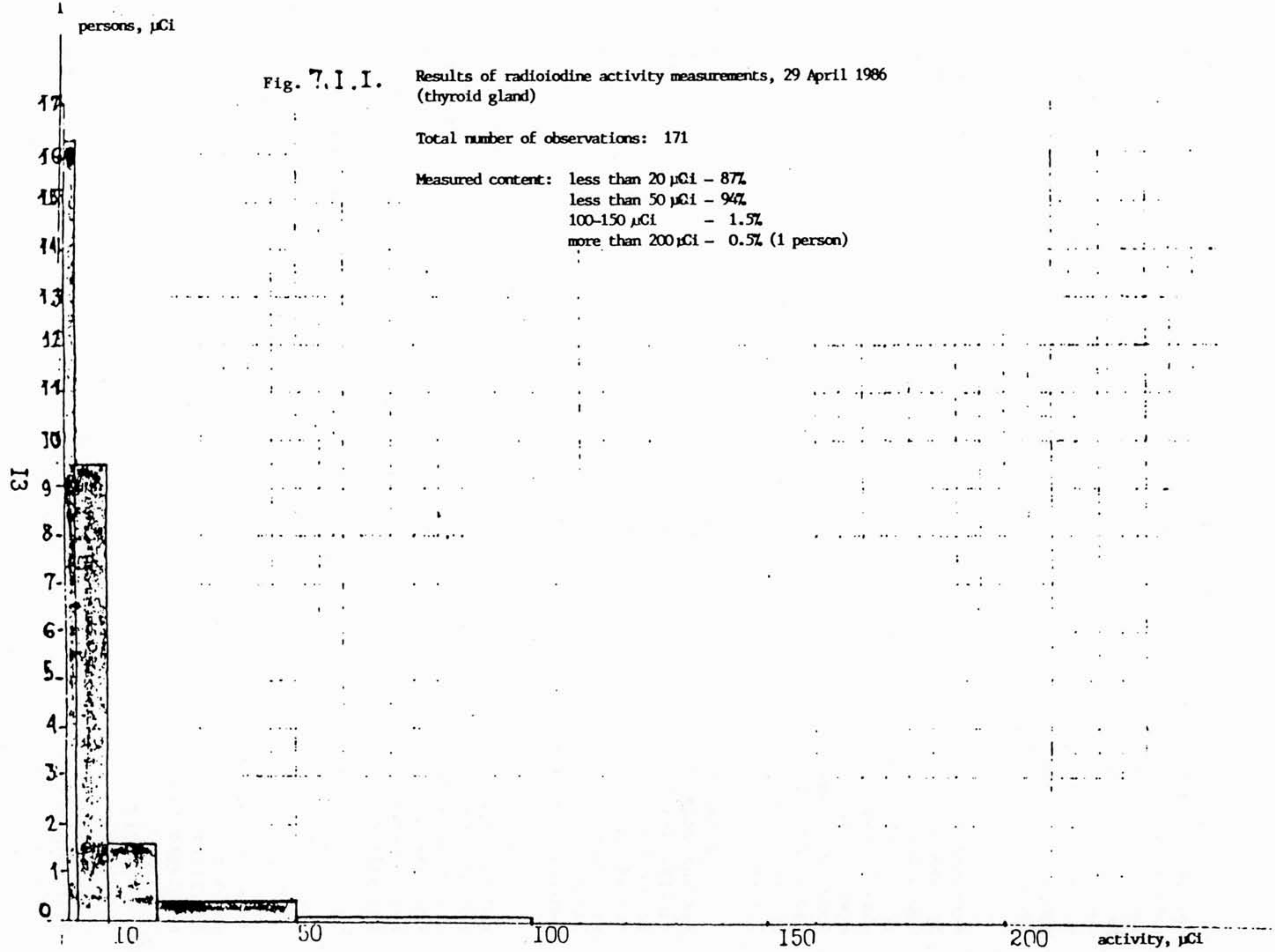


Fig. 7.I.I. Results of radioiodine activity measurements, 29 April 1986 (thyroid gland)

Total number of observations: 171

Measured content: less than 20 µCi – 87%
less than 50 µCi – 94%
100-150 µCi – 1.5%
more than 200 µCi – 0.5% (1 person)

I3

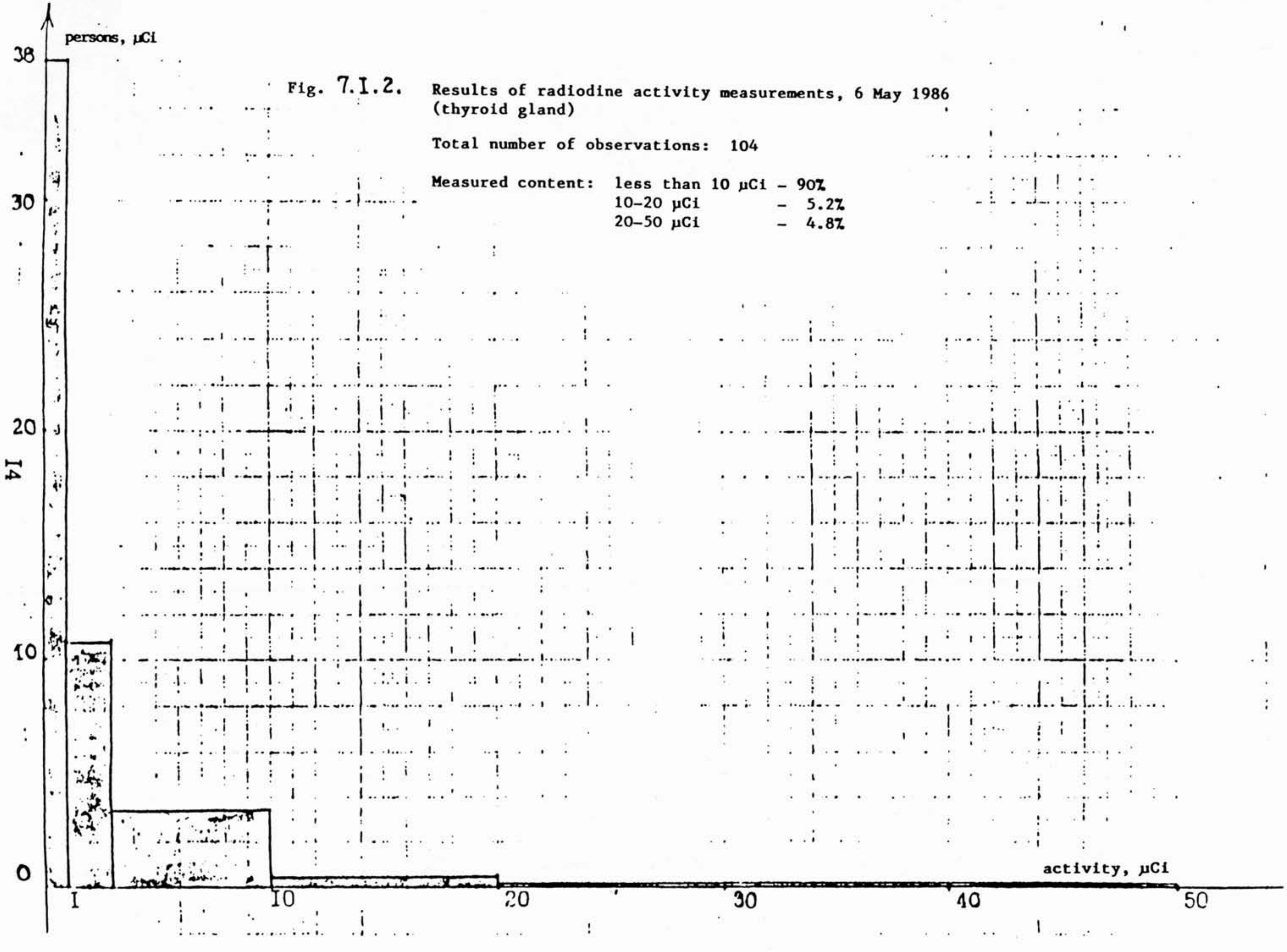


Fig. 7.I.2. Results of radiodine activity measurements, 6 May 1986 (thyroid gland)

Total number of observations: 104

Measured content: less than 10 µCi - 90%
10-20 µCi - 5.2%
20-50 µCi - 4.8%

Spectrum magnified two times with respect to Y

10 V

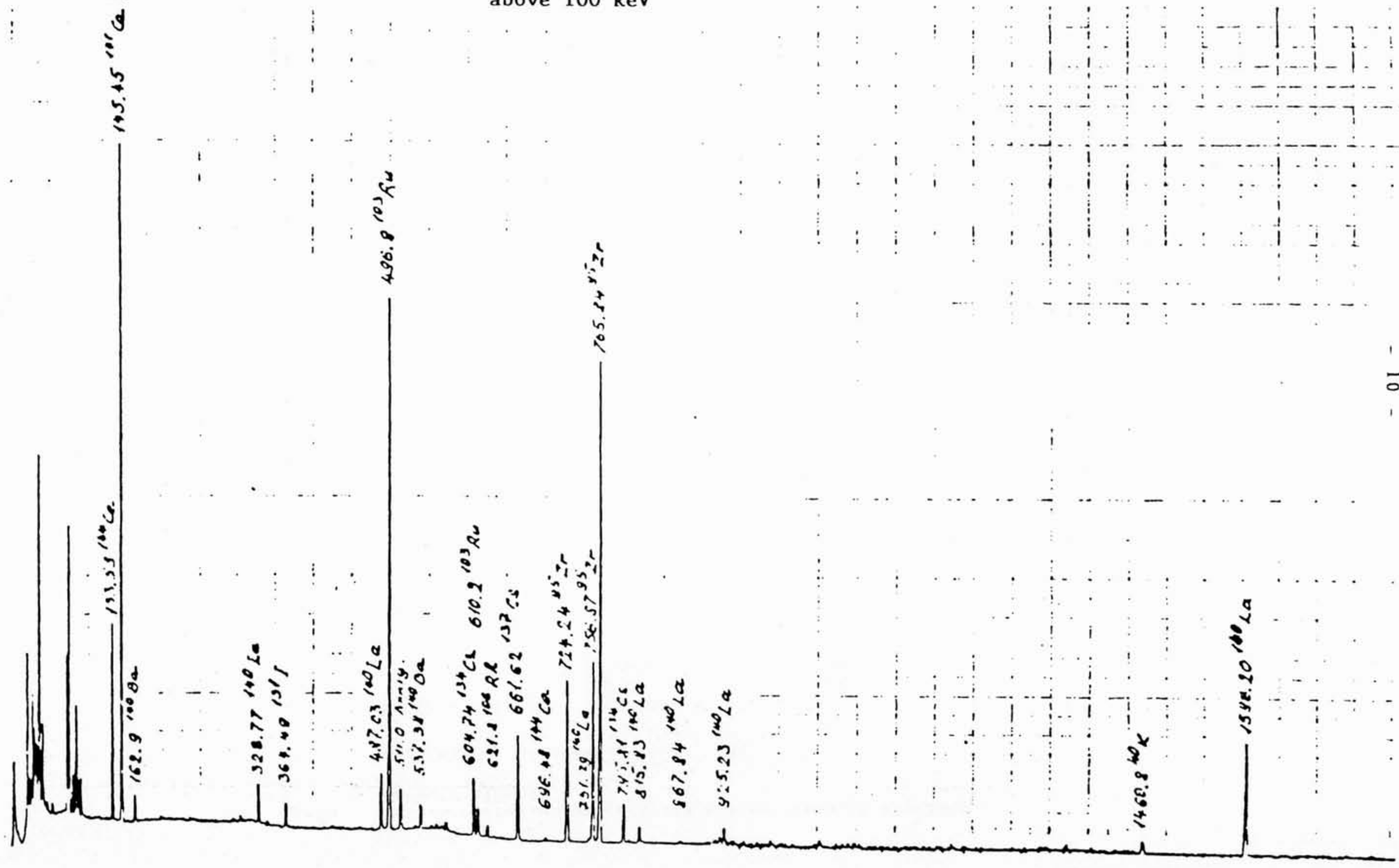


Fig. 7.1.3 Spectrum of photon radiation of an incorporated mixture of radionuclides. Semiconductor detection unit based on pure germanium, with a sensitive volume of 60 m^3. Energy range above 100 keV

Spectrum magnified two
times with respect to Y

Fig. 7.1.1. Spectrum of photon radiation of an incorporated mixture of radionuclides. Semiconductor detection unit based on pure germanium, with a sensitive area of 260 cm^2. Energy range below 100 keV

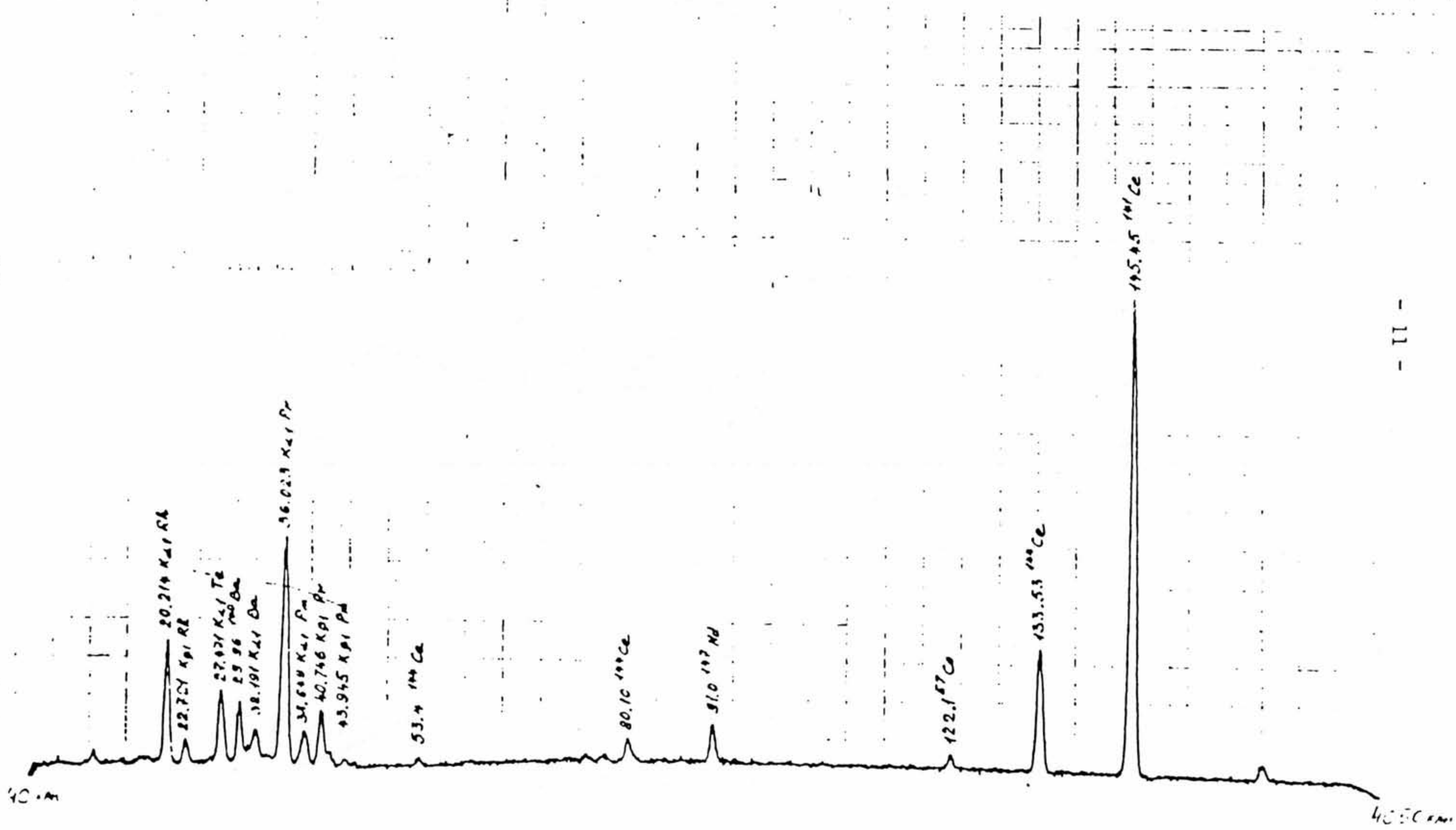


Fig. 7.1.5. Scheme for selection of samples of dissected lung material

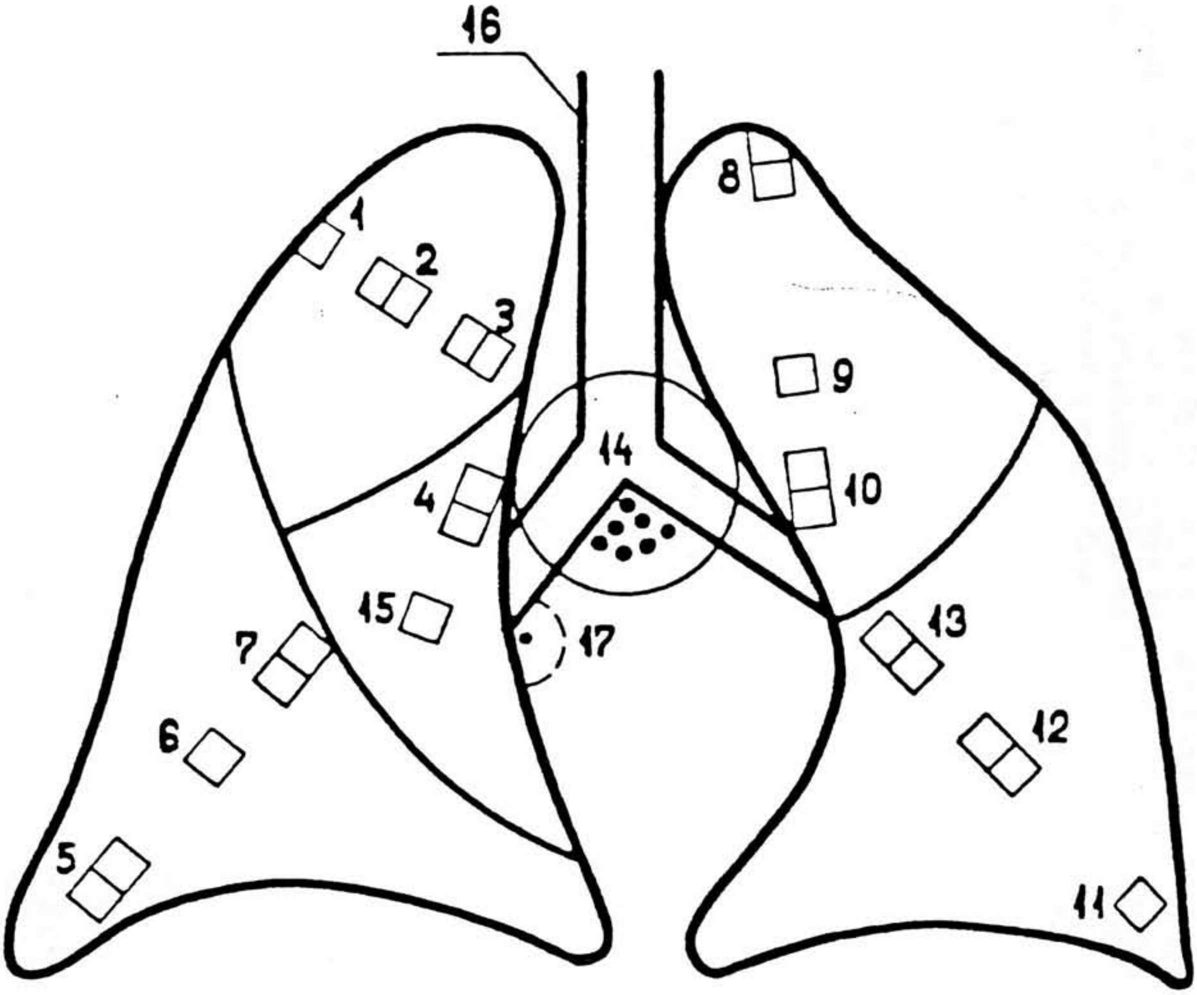
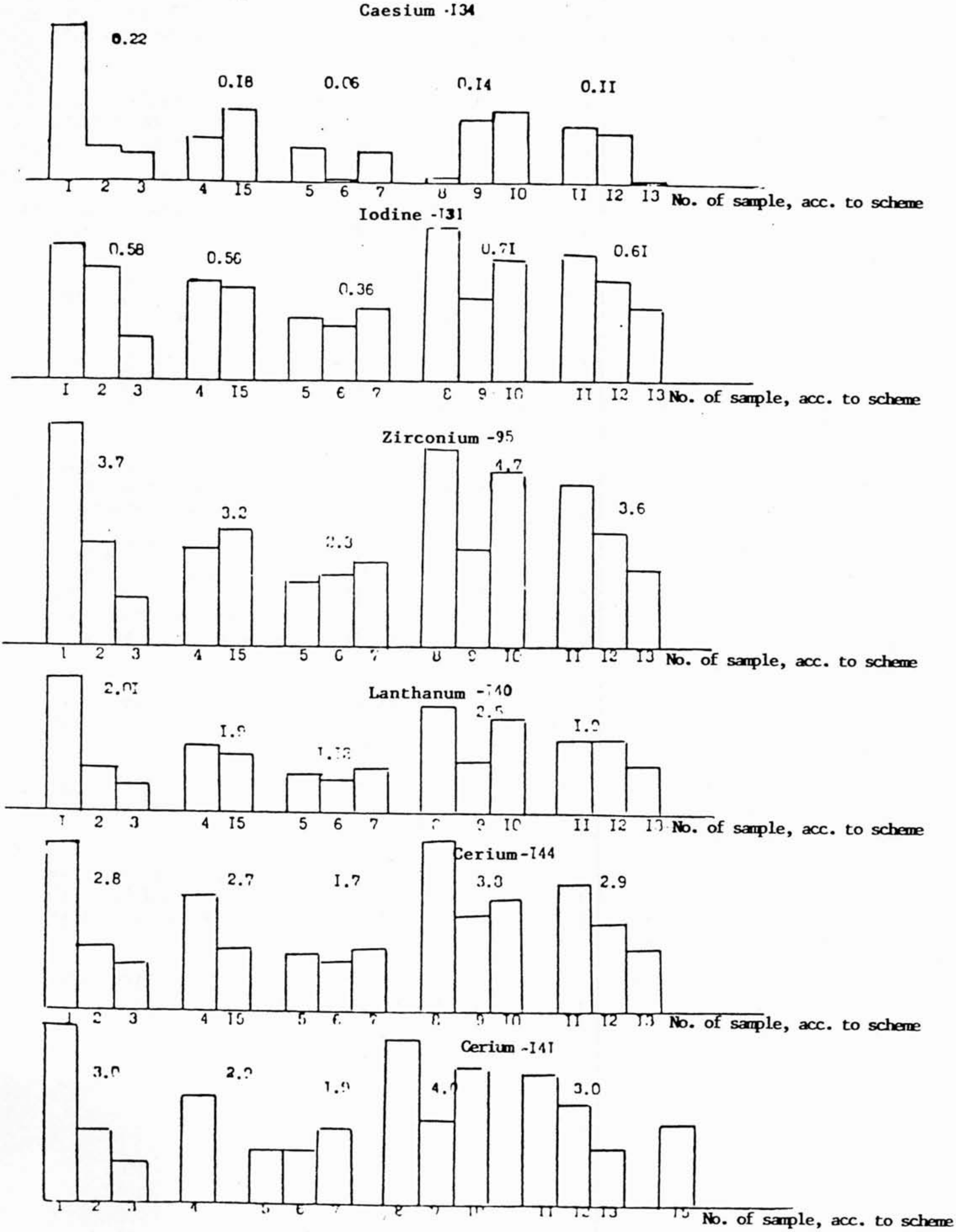


Fig. 7.1.6. Distribution of radionuclides over the lungs of a victim (see scheme for selection of lung samples) (in relative units); the indicated values are mean values



nature. However, it was not found to contain a 1274 keV line (sodium-22, half-life 2.64 y), having a yield of 99.95%, nor 1368 keV and 2754 keV lines (sodium-24, half-life 15 h), having quantum yields of 99.87% and 99.99%, respectively.

The measurements were made with a semiconductor detection unit having a sensitive volume of 60 cm^3. The estimated ^{131}I activity in these samples was 0.5 µCi/mL, and the activity of the caesium isotopes (caesium-137 and caesium-134) was 0.1 µCi/mL.

The 511.0 keV line present in the spectrum is of insignificant cross-section and corresponds to annihilation radiation due to one 1597 keV line (lanthanum-140).

Thus, approximately 35 hours after exposure, no appreciable data had been obtained giving evidence of neutron irradiation of the victims.

Estimates of the total activity of iodine-131 and of the isotopes caesium-134 and caesium-137 which had entered the organisms of the victims (two victims who had the highest content of radionuclides in their organisms)

On the basis of the first results of the analysis of urine and blood samples, examples were taken which provided evidence that the persons in question were suffering from very extensive internal radioactive contamination.

The activity of the urine samples was as follows: 0.5 µCi/mL (^{131}I) and 0.1 µCi/mL ($^{134,137}Cs$) for one patient and 0.2 µCi/mL (^{131}I) and 0.07 µCi/mL ($^{134,137}Cs$) for the other. From the spectrometric data for the urine and blood samples, it may be concluded that the isotopes in question account for about 90% of absorbed dose of internal irradiation.

The total activity, according to tentative estimates, was about 30 µCi ^{131}I and 10 µCi of the caesium isotopes for the one patient and 12 µCi ^{131}I and 4µCi caesium isotopes for the second.

Tentative estimates of the dose loads of whole-body internal irradiation, made for ^{131}I and $^{134,137}Cs$, were about 4 Sv (400 rem) for the first victim and about 1.5 Sv (150 rem) for the second.

Spectrometric examination of the urine and blood samples as well as direct spectrometry of the whole body and the thyroid gland confirmed that the level of internal penetration of the radionuclides in the remaining victims was considerably lower (by factors of tens to hundreds less).

The data presented are tentative in nature. The spectrometric information was recorded on magnetic tape and is being processed.

7.1.4. Haematological and cardiological research methods for evaluating radiation sickness prognosis and the total external dose level

The haematology laboratory conducted a study of all those persons who has been exposed to the action of ionizing radiation during the accident and had been hospitalized in a special clinic. The morphological composition of peripheral blood was studied in a special infirmary every day for one-and-a-half to two months (number of erythrocytes, leulocytes and reticulocytes; leukocyte formula, number of thrombocytes and haemoglobin content, together with the ESR).

In the case of some patients the cellular composition of the bone marrow was analysed once every 7-14 days (or more frequently in special cases).

The data obtained were used as a basis for prognosticating the course of the bone marrow syndrome which was later confirmed satisfactorily by actual way in which the acute radiation sickness progressed in the patients, including satisfactory coincidence with the preliminary grouping based on the severity and range of the exposure.

For each patient graphs were plotted showing the dynamics of the bone marrow syndrome in terms of variation in the number of neutrophils, thrombocytes and lymphocytes.

A cytogenetic analysis was made in 154 cases. The material used for the investigation was peripheral blood and bone marrow taken at various intervals of time following exposure to radiation (between 1.5 days and 5 weeks). The peripheral blood and bone marrow lymphocytes were cultured at 37°C in medium 199 containing antibiotics, PHA and 5-bromodeoxyuridine (10-20 µg/mL) for 50-67 hours. The cytogenetic analysis was conducted in 50 cells of the first mitosis (preliminary results). To identify these cells use was made of the method of differential staining of sister chromatids.

An evaluation of the exposure was made from the number of dicentrics calculated per 100 cells. Each tricentric, quadricentric and pentacentric was regarded as 2, 3, and 4 dicentrics, respectively. To calculate the dose use was made of a dose/effect curve for dicentrics (which take account of aberrations more precisely) obtained from studies during remission of acute leukosis patients who had undergone relatively uniform whole-body irradiation for therapeutic purposes in doses of 1.5-5 Gy:$Y = (10.79 \pm 2.00)CrD + (5.16 \pm 0.51)CrD^2$, where Y is the frequency of dicentrics (per hundred cells) and D is the dose (Gy). It was shown that the radiosensitivity of the lymphocytes in the peripheral blood of persons suffering from acute leukosis during remission, and of healthy donors after in vitro exposure to gamma radiation at a dose of 4 Gy is approximately the same.

The uniformity of the exposure was evaluated by comparing the observed distribution of dicentrics over the cells with a theoretical Poisson distribution. As is known, if there is a relatively uniform exposure the distribution of dicentrics over the cells obeys Poisson's law and that if the exposure is non-uniform there is a considerable deviation from the law.

The cytogenetic analysis made it possible to evaluate the absorbed dose in the patients who were hospitalized.

In the case of almost all patients the exposure was relatively uniform: the cell dicentric distribution obeyed Poisson's law or deviated slightly from the theoretical distribution. The severity of the bone marrow syndrome was prognosticated from the most informative haematological indicator - the number of neutrophils in the peripheral blood under dynamic conditions (at various intervals of time following exposure). With this purpose in mind the anticipated neutrophil curve was plotted for a dose calculated from the number of dicentrics and was compared with the actual curve observed in the case of each specific individual. Preliminary analysis showed that when there is uniform exposure the neutrophil curves in most cases coincide satisfactorily with the prognostic curves during the phase in which there is reduction in the number of cells. When there was no uniform exposure, the neutropenia was more marked than at the same level of chromosome aberrations in the case of uniform exposure. Figures 7.1.7 and 7.1.8 show as an illustration the cytogenetic study results and a neutrophil curve for the peripheral blood from patient D. The prognostic curve is shown by a broken line, while the solid line shows an actual curve. It is clear from this graph that both curves coincide quite satisfactorily in terms of the time when neutropenia occurs and the degree to which it is marked. The results of the cytogenetic study were used to select persons requiring a transplant of allogenic bone marrow or embryonic liver cells. Patients receiving a transplant underwent cytogenetic tests to see how effectively the transplant had taken. For this purpose there was periodic study of bone marrow punctates and PHA-stimulated cultures of peripheral blood and bone marrow lymphocytes. When transplanting cells from a donor of the opposite sex, use was made of sex chromosomes as markers, and when transplanting cells from donors of the same sex, radiation-induced marker chromosomes (symmetric interchromosomal exchanges and pericentric inversions) were employed.

7.1.5. Preliminary evaluation of the use of some biochemical and immunological tests in the event of accidental exposure to radiation

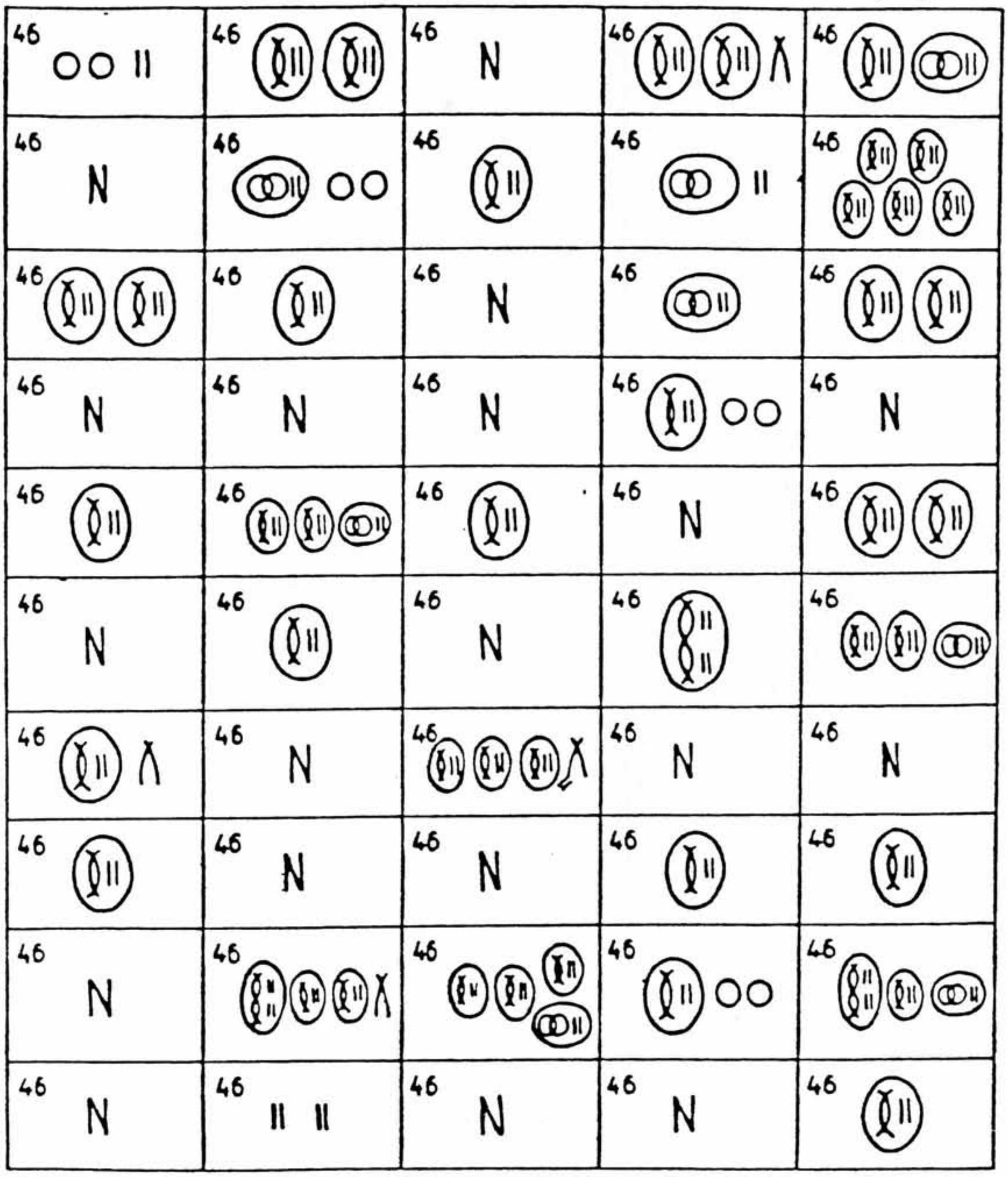
The list of biochemical observation tests corresponded to the one in the USSR for clinical laboratories, and covered about 35 parameters describing the principal metabolic processes, together with 16 tests for the state of the blood clotting system (Table 7.1.1).

The results were compared with control values and norms, as well as with the dynamics of the indicator for the given patient (see the sample recording of the indicator dynamics for patient C in Table 7.1.2). The immunological tests and the trend in the studies are shown in Summary Table 7.1.3. Along with the main laboratories of the specialized clinic a number of other institutions in the country were called upon to assist with

Fig. 7.1.7.

Number of cells analysed - 50

Number of aberrant cells - 31 (62%)



Number of dicentrics -
47 (94 per 100 cells)
Dicentric dose - 3.3 Gy

Since the dicentric distribution over cells conforms with the Poisson distribution, exposure to radiation is relatively uniform.

7.1.8. Diagnosis of the severity of the bone marrow syndrome from the results of cytogenic studies of PHA-stimulated lymphocyte cultures.

Patient D. Relatively uniform exposure to radiation (the dicentric cell distribution obeys Poisson's Law). The dose calculated from the dicentrics is 3.3 Gy. The broken line shows the prognostic neutrophil curve for relatively uniform exposure to gamma radiation of 3.5 Gy, while the solid line shows the neutrophil curve observed in the patient.

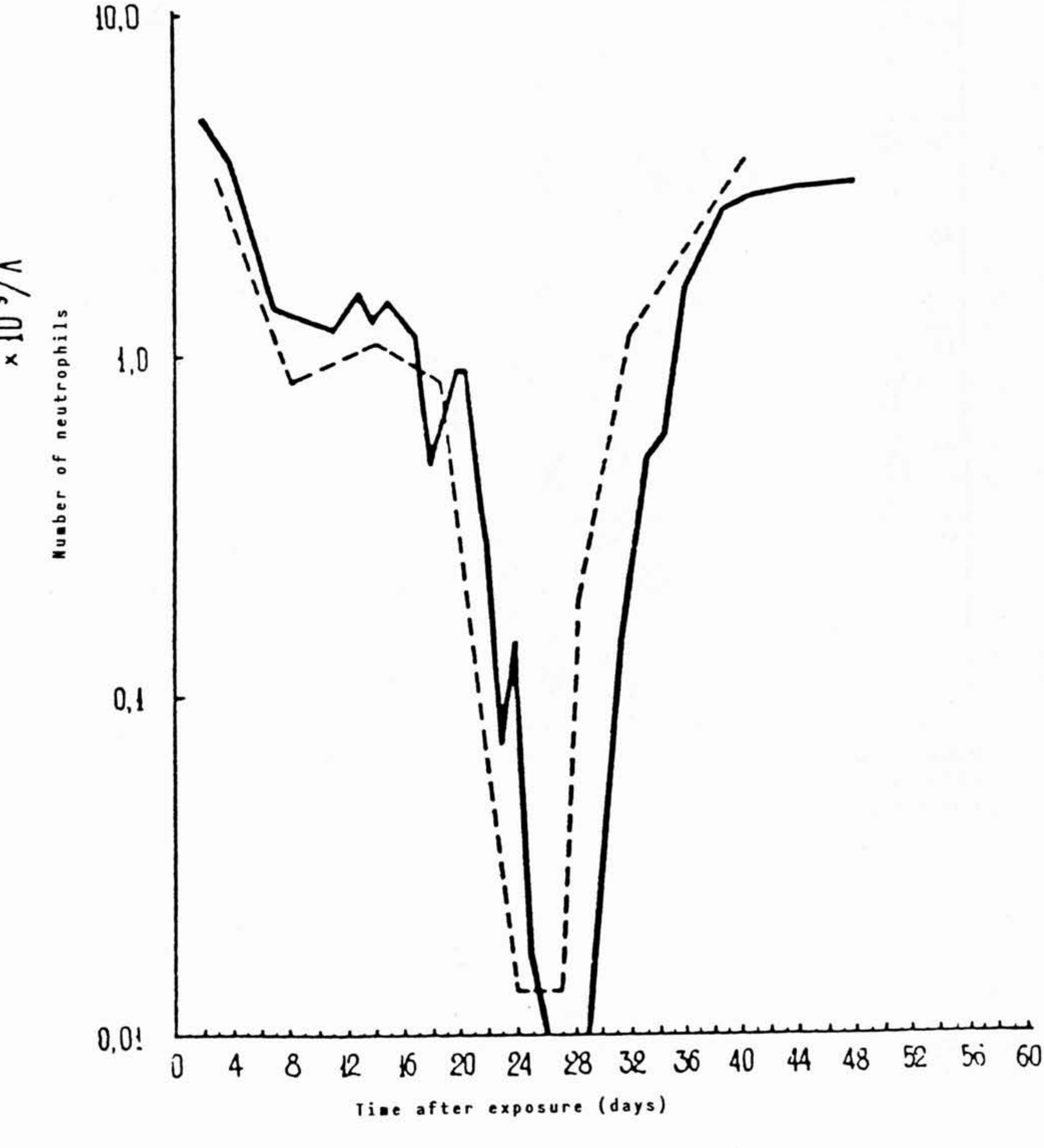


TABLE 7.1.1.

LIST AND NUMBER OF TESTS USED
TO STUDY THE PATIENTS

1.	Total protein -	1471
2.	Albumin -	1491
3.	Protein fractions -	266
4.	Urea -	750
5.	Creatinine -	1505
6.	Uric acid -	38
7.	Total cholesterol -	1014
8.	Total bilirubin -	982
9.	Bound bilirubin -	982
10.	Free bilirubin -	889
11.	Potassium -	889
12.	Sodium -	889
13.	Calcium -	256
14.	Iron	102
15.	Phosphorus -	5
16.	Alanine transaminase -	1335
17.	Aspartate transaminase -	1335
18.	a - amylase -	673
19.	Fructose-1-monophosphate-aldolase -	5
20.	Creatine kinase (CK) -	896
21.	Isoenzyme MV/CK -	14
22.	Gamma GTP -	122
23.	Lactate dehydrogenase (LDH) -	961
24.	Isoenzyme $LDH_{1,2}$ -	68
25.	Alkaline phosphate -	977
26.	Glucose -	1850
27.	Rehberg's test -	2
28.	Blood coagulation time -	10
29.	Bleeding time -	10
30.	Recalcification time -	395
31.	Autocoagulation test -	290
32.	Prothrombin index -	516
33.	Retraction index	234
34.	Fibrinogen -	430
35.	Fibrinolytic activity -	357
36.	Paracoagulation tests (ethyl alcohol) -	676
37.	Thrombin time -	240
38.	Reptilase time -	80
39.	Fibrinogen degradation products -	68
40.	Activated recalcification time -	142
41.	Partial thromboplastin time -	2210
42.	Antithrombin-3	152

Table 7.1.2

CHART SHOWING DYNAMICS OF BIOCHEMICAL INDICATORS

Surname and first name. S.V.I.

Date of admission: 26 April 1986

Diagnosis: Acute radiation sickness

Date of examination and name of test	Norm.	27.04	28.04	29.04	2.05	7.05	II.05	I3.05	I4.05	I5.05	I6.05	I7.05	I8.05	I9.05	20.05
I		2	3	4	5	6	7	8	9	I0	II	I2	I3	I4	I5
Total protein	62-82 r/L	7I		56	70	79	6I	6I	59	53	56	65	47	58	65
Albumin	35-52 r/L			33			3I	26	24	24		27	32	32	28
Al. transam.	up to 40 mU	52	26	20	20	27	22	23	27	I8	I3	I8		II	I4
Aspart. transam.	up to 40 mU	57	28	9	I5	26	I6	27	23	I5	I8	32		43	54
KFK	up to I70 mU	I600	I43		I70	380	89	89		26				28	
LDH	up to 460 mU		282		233	326	266	I60	65					352	
Isoenzyme LDH_1	I,2 up to 280 mU		I33		89	I50	I62							2II	
Isoenzyme LDH_2	3-5 70-I40	20400		I60											
Urea	2,5-8,3 mmole/L	4,9					9,8	I0,0	I0,7	I4,5	22,7	23,4	27,7	8,3	27,2

Continuation of Table 7.1.2

	I	2	3	4	5	6	7	8	9	I0	II	I2	I3	I4	I5
Creatinine	34–I34 µmole/L		94	74	I04	I24	I80	I42	I54	200	265	285	348		270
Total cholesterol	3,5–6,5 mmole/L		3,7	2,6	4,0	3,6	2,3	I,5	2,2	2,0					
Glucose	2,0–3,0 mmole/L					I,9		I,7	I,85			I,9			
Total bilirubin	3,2–5,6 mmole/L	3,9	2,0	2,6	3,85	4,2	4,I	4,6	3,8	4,4	2,8	2,0		2,0	I,8
Bound bilirubin	4,6–I5,I µmole/L	23,9		9,6	I0,3			I8,3	I7,I	3I,3	29,8	33,2	4I,0	38,8	50,8
Potassium	up to 5,0 µmole/L	6,8						I0,8	I3,2	25,8	26,7	3I,3	4,0	30,I	34,5
Sodium	3,5–5,5 mmole/L						5,0	4,0	4,I	3,8		3,2		3,2	2,7
	I39–I53 mmole/L						I34	I36	I40	I42		I50		I52	I60

Table 7.1.3

BASIC TRENDS IN IMMUNOLOGICAL STUDY AND TESTS APPLIED

Group of patients	Blood group and rh factor	Typing from M and A system antigens	Selection of donors from relatives with blood groups and	Typing from erythrocytic antigens	Removal of T-1 from bone-marrow in haplo-identical transplants	Determination of lymphocyte sub-populations	Determination of A, M and S immunoglobulin concentration	Activation of immunity by T-activin	Study of iso-sensitization	Verification of bone marrow taken from erythrocyte chimeras and from M and A	Study of autoimmunity due to damage to central marrow system
Severe cases require bone marrow transplant	All without exception	All during the first few days after admission to infirmary	Obligatory for all	When deciding on transplant	When there is no compatible donor for M and A	During recovery of blood production - once a week	Provisionally once a week	Choice of treatment based on indications	In all patients with blood transfusions as transfusion reactions develop	In transplant of AVO incompatible bone marrow and haplo-identical bone marrow	Twice a week
Severe cases not needing bone marrow transplant	"		On the basis of indicators - once a week			On the basis of indicators - once a week					Once a week
Patients with moderate severity	"										
Patients with slight injuries	"										

the studies. Specialists from the United States took part in the work of typifying the antigenic structure of the lymphocytes and removal of T-lymphocytes from the transplant - haplo-identical bone marrow.

Biochemical study of seriously ill patients and those with a moderate degree of radiation sickness was conducted on a daily basis. First- and second-degree patients were examined twice a week, using the same system.

The number of analyses performed during observation in the case of one seriously ill patient amounted to about 800, while in the case of a first-degree patient it was 200.

The materials are in process of being analysed. Brief preliminary results are shown below.

During the biochemical study of acutely affected persons 36-48 hours after exposure to radiation, pronounced hyperamylasaemia and hyperamylosuria were found. The frequency with which the norm was exceeded matched the serious degree of affliction and in the worst affected group attained a factor of 10-100 times the norm.

In the case of patients with extensive radiation burns, high levels of creatine kinase were determined within a day following exposure. The enzyme activity in certain cases exceeded the norm by a factor of 10-20. Concurrently with these changes there was found to be a moderate increase in aspartate transaminase.

During the investigation (especially when the sickness was at its height) there was noted a fairly clear-cut variation in the protein spectrum: hypoproteinaemia and hypoalbuminaemia.

Seven to ten days after exposure to the radiation many patients showed considerable shifts in the case of a number of biochemical samples and enzymes, which testified to malfunction of the kidney: hyperfermentaemia (aspartate and alanine transaminase, alkaline phosphatase and lactate dehydrogenase) as well as hyperbilirubinaemia with occurence of a direct bilirubin fraction.

Disruption of kidney activity in those seriously ill was manifested by a high increase in the creatinine level (three or four times more than normal).

There were several other special examinations, the results of which are in process of being analysed (determination of the hydroperoxides, succino-oxydismutase, malonic dialdehyde, ceruloplasmin, alpha tocopherol and peroxide haemolysis of the erythrocytes).

When studying the haemostasis system in exposed persons, with effect from the fifth day following the accident there was observed to be activation of the plasma procoagulants which was still preserved even when there was development of marked thrombocytopenia; this is confirmed by the indicators of the autocoagulation test.

By the tenth day most of the patients showed sharply positive paracoagulation test data. There was a drop in fibrinogen and antithrombin III. The drop in the prothrombin index continued until the fourth week of illness, the most obvious being the decrease in the K-dependent factor of the prothrombin complex.

By the end of the month all the coagulation indicators had approached normal in the overwhelming majority of patients. Despite the clinical assumptions with regard to the presence of a DVS syndrome, in no single case was there laboratory confirmation of the dynamics typical for coagulation tests.

The immunological study was used the most in typifying and selecting donors for bone marrow transplants.

The immunological selection and testing of blood groups and the rh factor (in more than 200 persons) made it possible to provide more adequate transfusion treatment (injection of RBC). In a limited number of patients the typifying was based on erythrocyte antigens (Table 7.1.3).

An assessment was made of the isosensitivization to tissue antigens by applying the Coombs' indirect test and by testing the lymphocytotoxic reaction and aggregate haemagglutination. In a handful of cases different methods were used to determine the lymphocyte sub-population. A large number of examinations were carried out to evaluate microdestructive processes in the nervous system, using neuro-immunological cell serum tests for the purpose.

Wide use was made of a bacteriological study of microbial dissemination in the environment for various conditions under which the patients were maintained. Inoculations were made of blood, faeces, urine, mucosa of the oral cavity and throat, and tranmatized surfaces. The concentration in the blood of certain antimicrobial drugs and antibiotics was quantified.

The results are in process of being analysed.

7.1.6. Alteration to the skin and the part they play in the outcome of the sickness

Characteristic features of the reaction by the skin and mucosa in the given situation were the existence of several variations of the lesion, which were sometimes found simultaneously in the same patient:

- Widespread surface injuries predominantly occurring on open parts of the body unprotected by clothing, on the lips, conjunctiva and at the entrance to the mouth;

- Injuries limited to zones of predominantly direct contact with beta and gamma radiation sources (clothing or footwear that was wet and soiled by a service solution, adhesion of dust or touching of contaminated objects);

- Injuries to the skin and mucosa, the stomatopharynx and intestine due to relatively uniform exposure to gamma radiation in doses exceeding the threshold values for those tissues.

Radiation injuries to the skin (beta radiation burns) covering more than 1% of the body surface were observed in the case of 48 persons.

The contribution made by radiation damage to the skin to the overall clinical radiation sickness syndrome with considerable aggravation was determined by the extent and depth (degree) of the injuries. Here the damage to the skin was virtually incompatible with survival in the case of some of the patients (14 persons).

The clinically detectable extent of the skin lesions in the cased of most patients underwent certain dynamic changes in time and was characterized by the occurrence of several, at least two or three, "waves" of erythema and ensuing changes in the skin.

The primary skin erythema detected on the first or second day after exposure was not enough of a reliable criterion for prognosis of the sickness by virtue of its instability and the lack of reliable methods for quantifying the intensity of it.

Between the end of the first and the third week eight persons with damage almost to all the skin (from 60-100% of the total surface area) stood out in terms of the extent and intensity of the main erythema wave. The hyperaemia of the skin in these cases was accompanied by edema and there was early formation of blisters and erosion (erosive-ulcerous dermatitis).

All these persons died within a period of 15 to 24 days. They also had severe and extremely severe damage to the haemogenic system and an intestinal radiation syndrome. We consider it advisable, however, to stress that these patients had damage to the skin that was incompatible with survival.

Damage to an area of 30-60% of the total body surface was detected in the case of 12 patients by the end of the third week. In the majority of these (seven of them) the severity of the bone marrow syndrome was assessed as extremely severe, in three cases as severe, and in one case as moderately severe. In all, it proved lethal in this group in nine cases.

In six patients injuries to their skin were assessed as incompatible with survival (covering more than 50%, early formation of extensive erosive-ulcerated surfaces). These six patients died and in the case of one of them the skin damage was the main cause of death (death occurred on the forty-eighth day, although the peripheral blood picture had fully recovered). Effects of endogenous intoxication were reponsible for the development in this patient of toxic edema of the brain and a terminal coma.

Skin damage covering a total area of up to 30% was noticed by the twenty-first day in the case of 21 patients. Six of these can be said to have had serious aggravation of their overall condition through the extent (25-30%) and the severity of the injuries, with early development of erosive- ulcerous changes. Damage to the bone marrow in this group of patients differed from extremely severe to slight. There were no deaths in this group due to skin damage.

Over a period of 36-45 days (6-8 weeks), i.e. during the complete or almost complete recovery of blood production, there was also observed recovery of the earlier altered integument. At the same time, at a surprisingly late stage, on the earlier unaffected areas there appeared new changes in the form of bright erythema with cutaneous edema. The overall area of the damage increased accordingly: previously assessed at 25-30%, it attained 90-100% of the body surface. In areas of previously unaltered skin there was sometimes reappearance of more intense edema, and the size of the areas of healing ulcers and erosions increased. Some of the patients with these "late" skin injuries had shown no alteration of the skin at all at an earlier stage (up to 3 weeks).

On the thirty-sixth to forty-fifth day the most typical lesions were those in the area of the shins and hips. The patients noticed the occurrence (or intensification) of aching in the legs, to the extent of not being able to stand up, and the lymphostasis and edema in a more distal direction from the "focal point" of the skin damage (edema of the ankles with erythema on the shins), a general reaction in the form of a rise in temperature, inability to sleep, and so on.

Recovery from the skin injuries usually ended by the fiftieth- sixtieth day. It usually took the form of dry or moist desquamation according to the degree of injury. By this time the erosions and surface ulcers had epithelialized in most of the patients.

The absence of active epithelialization by this time over sizable areas (20-25 cm^2) was interpreted as an indication for surgical intervention.

7.1.7. Methods of treatment and preliminary assessment of their effectiveness

The methods used to treat individual acute radiation sickness syndromes were ones that had been tested and used in everyday practice.

The main emphasis was placed on preventive treatment and treatment of infection complications and substitutional therapy using blood cells in the case of the bone marrow syndrome; detoxifying therapy and total parenteral feeding, in the case of widespread burns and oropharyngeal and intestinal syndromes; intensive correction of the water-electrolyte balance in patients with the intestinal syndrome and a toxico-septic status due to burns and agranulocytic infections.

The clinical charts (Figs 7.1.9 and 7.1.10) illustrate the dynamics of the basic manifestations and treatment of the sickness.

Treatment of the bone marrow syndrome:

(a) Supporting and substitutional therapy.

All the patients with a bone marrow syndrome of the second or a higher degree were placed separately in normal hospital wards adapted to ensure asepsis while they were being treated: sterilization of the air by ultraviolet lamps, strict observance by the personnel of the habit of washing their hands when entering and leaving the ward, compulsory use of individual gowns and masks in the ward, wiping of footwear on a mat dusted with antiseptic, and a change of the patient's clothing once a day. In the shortest possible time relatively simple aseptic conditions were created throughout the hospital, enabling specially trained personnel to look after the patients. Contamination by microbes was checked and paper linen and clothing for personnel were worn. The conditions described ensured a low micro-organism content in the air - not more than 500 colonies per m^3.

The diet was normal, but raw vegetables and fruit as well as tinned products were excluded.

The effectiveness of this aseptic regime was clearly demonstrated, as shown by us earlier (A.E. Baranov et. al., 1978, 1982), by the absence of exogenous broncho-pulmonary infections (pneumonia) in patients with acute radiation sickness of the second and third degrees.

In the case of all patients with the bone marrow syndrome of the second to the fourth degree, preventive treatment was provided against endogenous infections using biseptol and nistatin, beginning either one or 2-3 weeks before the development of agranulocytic infection. The comparative effectiveness of the two alternatives for the beginning of selective decontamination of the intestine was evaluated.

When agranulocytic fever occurred, two or three antibiotics with a broad antibacterial spectrum from the aminoglucoside group (gentamycin, amicacin), cephalosporins (cefsol, cefamesin, cefobid) and semisynthetic penicillins with antipyocyanic activity (carbenicillin, pipracil) were given intravenously. In at least half the cases the use of antibiotics stopped the fever. If there was no effect within 24-48 hours when treating the given group, extensive use was made of intravenous injection of gamma-globulin provided by the Sandos company. The gamma-globulin (Sandoglobulin) was given in doses of 6 g four or five times every 12 hours.

A policy was pursued of "early" empirical prescription of amphotericin B if the agranulocytic fever was not cured within 1 week by the antibacterial antibiotics mentioned, combined with intravenous gamma-globulin.

In the prevailing situation, "atsiclovir" was used with good effect for the first time in herpetic infections while treating acute radiation sickness (approximately one third of the patients had at times severe herpes simplex of the skin of the face, lips and mucosa of the mouth). "Atsiclovir" was not used for preventive treatment. Good results in the treatment of virus infections of the skin were obtained with ointments containing "atsiclovir".

This regime of basically empirical antibacterial, antifungal and antiviral treatment proved highly effective - there was hardly any mortality due to infection in the case of the patients with the bone marrow form of acute radiation sickness, even in severe and extremely severe cases (without burns). Furthermore, the autopsy of patients dying from non-bone- marrow injuries did not show any incontestable signs of bacterial or mycotic septicemias.

Both during their lifetime and posthumously, epidermal staphylococci were isolated from the blood of most of those who died. The part played by them as a pathogen in terminal septicemias despite the antibacterial treatment given is being studied.

Several patients with bone marrow syndrome of the fourth degree were found to have acute diffusional interstitial pneumonia, accompanied by the rapid development of hypoxaemia incompatible with survival. The bacterial and mycotic nature of the pneumonia was not confirmed by the autopsy, but acute radiation pulmonitis, with possible activation of cytomegaloviruses, did tend to be found.

One of the methods used widely - and without a doubt very successfully - for treating these patients with acute radiation disease was that of taking fresh platelets from donors. Platelets were obtained by taking blood four times from a single donor. Indications for a platelet transfusion being required were incipient bleeding or a reduction in the platelet level to

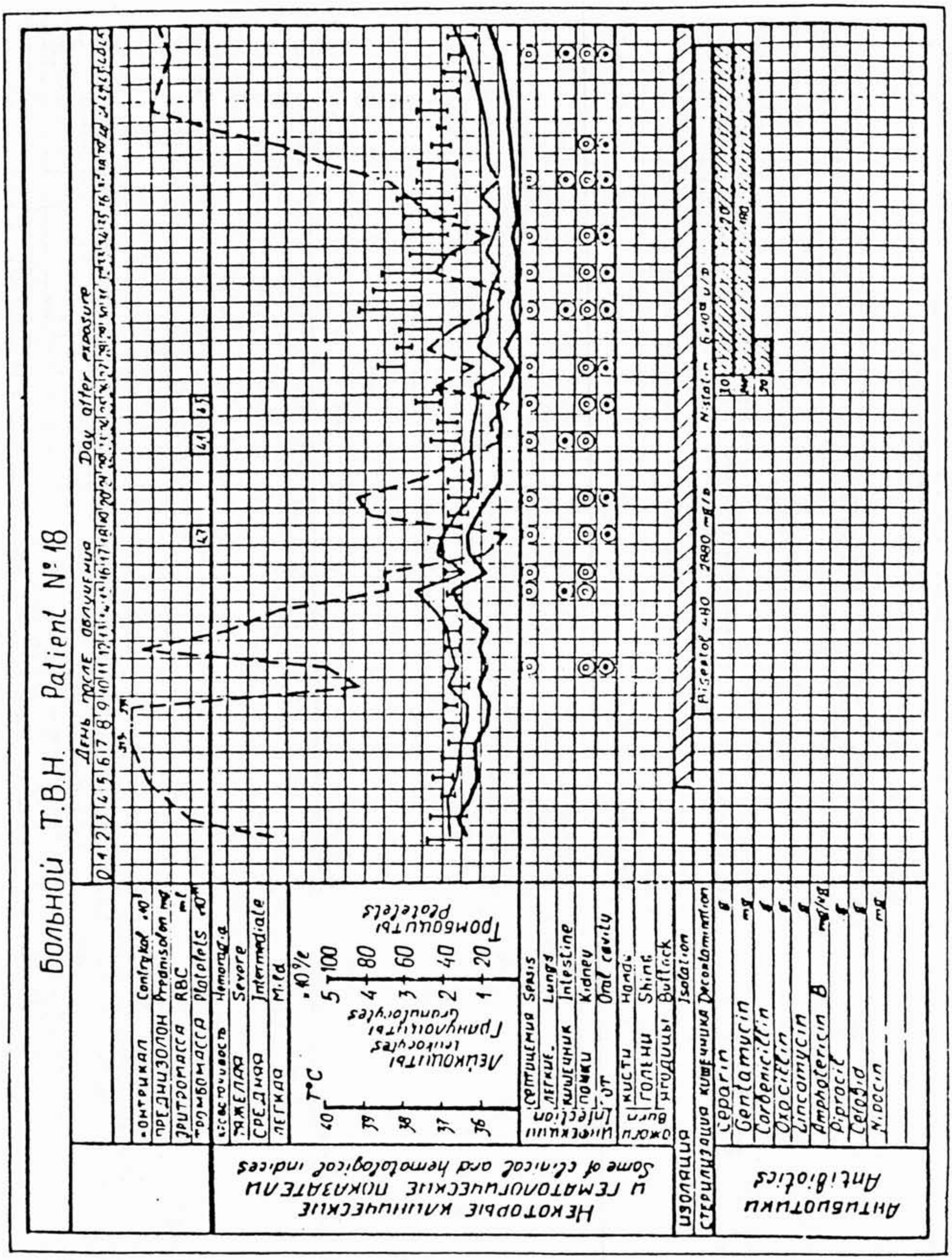
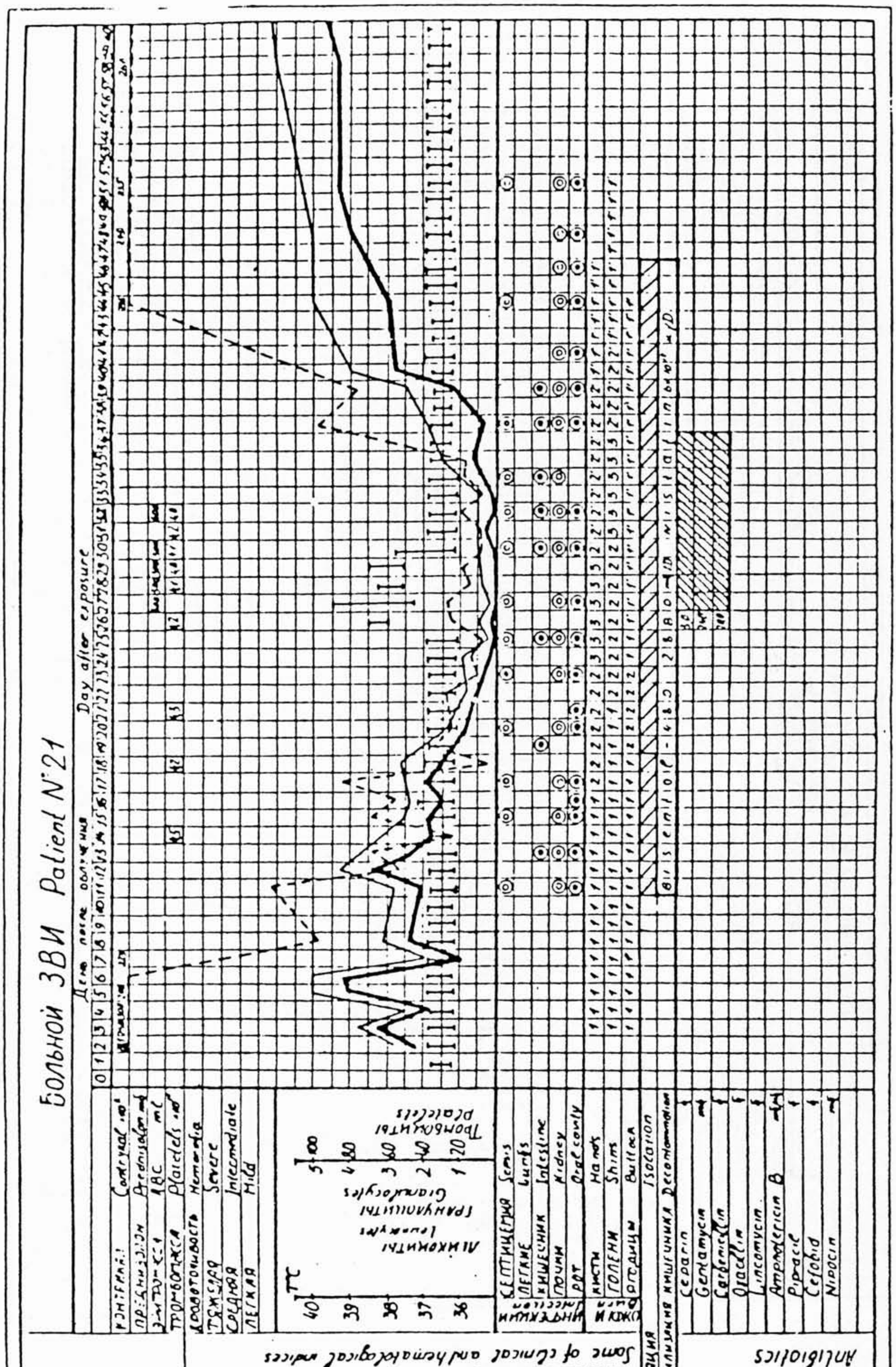

Больной Т.В.Н. Patient № 18
День после облучения
Day after exposure
Некоторые клинические и гематологические показатели
Some of clinical and hematological indices
Антибиотики
Antibiotics

Fig.7.1.9.

Fig.7.1.10.


Больной ЗВИ Patient N°21
День после облучения
Day after exposure
Некоторые клинические и гематологические показатели
Some of clinical and hematological indices
Гранулоциты
Granulocytes
Тромбоциты
Platelets
Контрикал
Contrykal
Преднизолон
Prednisolon
Тромбомасса
Platelets
Кровоточивость
Hemorrhagia
Тяжелая
Severe
Средняя
Intermediate
Легкая
Mild
Септицемия
Sepsis
Легкие
Lungs
Кишечник
Intestine
Почки
Kidney
Рот
Oral cavity
Кисти
Hands
Голени
Shins
Ягодицы
Buttock
Изоляция
Isolation
Стерилизация кишечника
Decontamination
Антибиотики
Antibiotics
Ceparin
Gentamycin
Carbenicillin
Oxacillin
Lincomycin
Amphotericin B
Pipracil
Cefobid
Nipocin

below 20 000 per µL. Usually, blood from a single donor (on average some 300 x 10^9 platelets) was used for each transfusion. The platelet transfusion was repeated after 1-3 days. The platelets and all other blood components were irradiated at a dose of 1500 rad before the transfusion, using a conventional gamma therapy device. This was done in order to prevent secondary disease.

The considerable effectiveness of platelet transfusions carried out in accordance with the principles mentioned is confirmed not only by the absence of dangerous bleeding even in patients with long-lasting (more than 2-4 weeks) and severe thrombocytopaenia (less than 5000-10 000/µL) but also by the absence in most patients of any signs at all of bleeding.

Obtaining the necessary quantity of platelets at the time required during the period of most severe thrombocytopaenia simultaneously in dozens of patients required considerable efforts on the part of the blood donation service. There was no lack of platelets. Moreover, sometimes the supply was "excessive" because of the impossibility of planning requirements precisely one or two days in advance. Because of this, extensive use was made for the first time when treating this group of patients of the method of freeze-drying of both allogenous and autologous platelets, which were then used at the time required with considerable effectiveness.

There were no cases of rejection of blood transfusions as a result of alloimmunization.

On average, 3-5 transfusions of platelets were required to treat one patient with third degree bone marrow syndrome.

Leucocytes were not used for treating agranulocytic infectious complications.

Erythrocyte requirements were found to be much greater than expected, even in patients with acute second- or third-degree radiation sickness with uncomplicated radiation burns because of the development relatively early of severe anaemia.

(b) Bone marrow transplants

During the first three days after irradiation, a first group of patients with irreversible breakdown of myelopoiesis was selected in whom spontaneous restoration of myelopoiesis could therefore hardly be expected.

The diagnosis of the irreversibility of myelodepression was carried out in accordance with rules developed earlier on the basis of criteria such as the onset of vomiting, the number of peripheral blood lymphocytes and an estimate of absorbed dose from the number of aberrations in bone marrow cells taken 36 hours after irradiation.

On subsequent days (from the fourth to the ninth) the same criteria were applied and, in addition, an estimate of dose from chromosomal aberrations in lymphocyte culture and peripheral blood, to gauge the extent of myelopoiesis more exactly and to make a final selection of the group of patients in whom, as a result of extremely severe (and possibly irreversible) myelopoiesis (doses of 6 Gr and more) bone marrow transplants were indicated. At this time an active part in the work was taken by American experts headed by Prof. Robert Gale.

Transplants were taken only from close relatives (natural brothers and sisters or parents) in whom HLA was identical (six cases), haplo-identical (four cases) or haplo-identical plus one common antigen in the second haplotype (three cases). In view of the urgency of transplantation, type testing was carried out only in respect of the A, B and C loci. With transplantation of haplo-identical bone marrow, T-lymphocyte depletion was performed in order to ward off secondary disease.

The main difficulty in matching the HLA of suitable donors was that it was necesary to determine the fenetin HLA in many of the patients in the first three days after irradiation when the number of lymphocytes had not dropped to very low levels.

Considerable organizational difficulties were experienced in connection with the need to find and examine quickly a large number of relatives of patients who constituted potential donors. In this situation 113 donors were examined.

In the end, only 13 transplants of allogenous bone marrow were carried out (between the fourth and sixteenth day after irradiation). In six cases of extremely severe damage to the skin and intestines and extremely unfavourable prognosis, transplantation of human embryo liver cells was performed.

In general, it can be said that bone marrow transplants were not a decisive factor in treatment after this particular accident. All seven patients in whom, in view of their particularly severe irradiation, a donor's bone marrow might have been able to "take" in a stable manner, died earlier (between 9 and 19 days after the bone marrow transplant) from radiation damage to the skin and intestines. At the same time, in the remaining six patients, who did not have skin and intestinal damage incompatible with survival, only a temporary or incomplete "taking" of donor's bone marrow occurred, presumably because the transplantation immunity of these patients was not sufficiently suppressed by irradiation. Despite the unfavourable (insufficient, incomplete or totally arrested) myeloid function of the transplant, the same disorders were observed in all of these patients; they may have been caused by a reaction of the host against the transplant or of the transplant against the host. In two cases these reactions may have contributed to death from a renal and pulmonary insufficiency syndrome of unidentified genesis and from pyocyanic septicaemia which developed unexpectedly against a background of a normal number of neutrophils.

An analysis in retrospect of the initial part of the neutrophil curve in all six patients gives rise to doubt about whether the breakdown in myelopoeisis was irreversible in them. The fact that transplants "took" - even temporarily - and that this gave rise to immunological conflicts would appear to show a negative influence both on the restoration of myelopoeisis and on the course of the disease as a whole (two patients died).

Thus, the experience with transplantation of allogenous bone marrow after the particular radiation accident gives rise to two important conclusions for the future in respect of this method of treatment:

- In radiation accidents the proportion of patients in whom transplantation of allogenous bone marrow is absolutely indicated and for whom this treatment will obviously be beneficial is very small;

- With reversible breakdown of myelopoeisis caused by overall gamma radiation doses of the order of 6-8 Gr, a transplant may "take" but this "taking" will always have a negative effect in therapeutic terms and even endangers life as a result of the high risk of secondary disease developing.

The latter conclusion is essentially a new one since it was assumed earlier that the transplantation of allogenous bone marrow does not give rise to negative effects in the event of insufficient radiation exposure of the recipient in the borderline area zone of radiation doses.

Treatment of radiation damage to skin

In view of the important, and in a number of cases determining, role of local radiation damage in the overall clinical syndrome (intoxication, pain), its treatment occupied an important position in the therapeutic measures taken.

Use was made of basic modern detoxification methods and also of disaggregational, anti-infection and symptomatic therapy; haemosorption, plasmosorption and plasma phoresis were carried out, and direct anticoagulants and means of improving microcirculation (repoliglucin, neogemodes, troxevasin, trental and solkoseril) were applied.

The local treatment methods used were appropriate for the stage and severity of the complaints: initially, spraying was carried out with aerosols with a bactericidal and analgesic/anti-inflammatory effect, including the effective Soviet product "Lioxanol". Use was made of moistening bandages based on tannin solutions with bactericidal properties ("Baliz"). Later, bandages containing ointment with derivatives of hydrocortisone based on propolis and wax with specifically directed antibiotics and antiseptics were applied.

Treatment of oropharyngeal syndrome

The main techniques used for treating severe radiation mucositis were mechanical removal of enormous quantities of rubbery mucus which had accumulated in the nasopharynx, washing this mucus away and bathing the erosive surfaces with solutions of mucolytics with antiseptics.

Experience shows that mucolytic preparations and techniques for using them with a view to rapid and reliable removal of mucus from the buccal cavity, the vestibule of the larynx and the nasopharynx are particularly in need of improvement.

Treatment of intestinal syndrome

The main technique used for the treatment of intestinal syndrome was total parenteral feeding with intensive correction of the volume of nutritive liquid and electrolytes, which in the present case also proved to be highly effective. Experience has shown that it is necessary to have a large reserve of mixtures for parenteral feeding ready if plans are to be laid for providing specialized assistance to patients with acute radiation damage to the intestines, mouth and gullet.

In conclusion, it should be noted that every patient with bone marrow syndrome of the third and fourth degree of severity, which was mostly accompanied by radiation burns, required individual round-the-clock attention from a nursing unit consisting of highly qualified nurses specialized in intensive care in order for the treatment described above to be provided. As a result of considerable efforts - which are, of course, feasible only in peacetime - it was possible to provide such specialized nursing units for each patient with acute radiation disease of the third and fourth degrees.

As a whole, the effectiveness of treatment can be considered entirely satisfactory: none of the patients with second-degree acute radiation disease (doses of 2-4 Gr) died. In 19 cases the deaths of patients with third and fourth degree acute radiation disease occurred only as a result of severe damage, which was incompatible with survival to 50-90% of the surface of their bodies and was itself of between the second and fourth degrees of severity.

CONCLUSION

Of the operative and accident management staff who took part in operations at the Chernobyl' nuclear power station on 26 April 1986, 203 were found to have acute radiation sickness. The clinical manifestations (syndromes), degree of severity and outcome for different patients were varied. All those affected were identified in good time and admitted for treatment to qualified Soviet institutions.

Of the 22 patients suffering from an extremely severe degree of acute radiation sickness, 19 died. In 14 cases, death was caused by severe radiation and thermoradiation damage to the skin, against a background of severe blood formation depression and, in some cases, of damage to the digestive tract.

Of the 23 patients with severe bone marrow syndrome, seven died. In six cases the outcome of the illness was also determined by the presence of widespread and severe radiation damage to the skin, with the attendant pronounced overall intoxication.

There was not a single death among patients with first and second degree illness.

For the majority of patients, clinical recovery occurred toward the end of the second month following the accident. There are at present 30 people undergoing hospital treatment.

The main harmful factor for all victims was the relatively uniform gamma- and beta-radiation effect in a dosage which, according to biological criteria, exceeded 1 Gy, and which, in the case of 35 people, exceeded 4 Gy (up to 12-16 Gy). Fifty people suffered additional beta-irradiation of significant areas of their skin, while in the case of a number of people this extended to the mucous membranes of the naso-pharynx and gastrointestinal tract.

Radiation damage to wide areas of the skin (up to 50-90% of the surface) was one of the main factors contributing to the overall severe condition of the patients, and was a determining factor in the main fatal complications (cerebral oedema, toxic encephalomyelopathy, renal and liver function insufficiency and damage to the myocardium).

In the case of certain patients, in the maximum dose range for external gamma-irradiation (~8 Gy), the terminal period was characterized by the development of pulmonitis and pronounced respiratory insufficiency.

In the case of practically all patients, without there being any apparent link with either the presence or degree of severity of acute radiation sickness, a complex mixture of nuclides was found to have entered the organism, these being mainly isotopes of iodine, caesium, zirconium, niobium and ruthenium. However, their quantities and the dose levels in all except one patient, were lower than those clinically indicated to have direct effects. In the first 10 days following the accident, the content of iodine isotopes in the thyroid gland of 94% of individuals did not exceed 50 μCi.

With the help of previously-acquired experience it has been possible to formulate a timely and sufficiently complete prognosis of the course of the illness in the overwhelming majority of cases. Within the first 24 hours it proved possible to determine correctly which individuals required urgent hospitalization, and, in the first three days, to determine the appropriate level of medical assistance required. It subsequently proved possible to achieve certain therapeutic results.

In the course of intensive clinical observation and active medical attention a great deal of data has been accumulated and is now being processed.

The preliminary results can be reduced to the following main points:

1. The previously formulated main diagnostic principles and prognostic criteria relating to the course of illness through bone marrow syndrome have justified themselves;

2. In the accident situation under consideration, a certain aggravating role was played by widespread beta-damage to the skin. In a considerable number of cases such damage determined the severity and outcome of the illness;

3. At the forefront of therapeutic measures taken, in accordance with the structure and syndromology of the injuries, were those concerned with preventing and treating the complications connected with severe but reversible blood formation depression, detoxification therapy and the local treatment of skin damage;

4. The nature of the damage (relatively superficial but very widespread beta-dermatitis) called, for the most part, for conservative therapy; surgical intervention has only been required in exceptional cases (five people so far);

5. Bone marrow transplantation was indicated (dosage above 6 Gy) and feasible (absence or only minor indication of reasons for unsuccessful outcome) only for a very limited group (13 individuals). On account of those reasons, and given the remaining possibility of self-repair, albeit slow and incomplete, transplantation has only been moderately effective;

6. All patients are now being actively monitored. This will make it possible to determine the complete course of their rehabilitation and the need for preventive treatment.

7.2. Data on the doses from radiation exposure to the population in the thirty-kilometre zone around the nuclear power plant in different regions of the European part of the USSR, radiation consequences of the accident

7.2.1. Introduction

Immediately after the accident, measures were taken to implement continuous effective monitoring of the parameters of the radiation conditions both at the site of the Chernobyl' nuclear power plant and in the neighbouring populated areas. Particular attention was paid to the town of Pripyat' which had about 45 000 inhabitants who were mainly plant personnel and members of their families. As the radiation conditions developed, the scale and volume of dosimetric monitoring increased significantly over the course of time. In the end, more than 7000 subdivisions of radiation laboratories, epidemiological centres and also many groups of radiation safety experts from a large number of scientific and practical establishments and organizations throughout the USSR were mobilized to carry out the monitoring.

The primary most important radiation monitoring tasks were:

- to evaluate the possible external and internal exposure of staff at the Chernobyl' nuclear power plant, of inhabitants of Pripyat' and of the population which was subseqeuntly evacuated from the 30-kilometre zone, in order to identify those persons in need of medical assistance;

- to predict the possible levels of exposure of the population in regions of high radioactive contamination outside the 30-kilometre zone in order to decide whether it was necessary to carry out a further full or partial evacuation or to make appropriate temporary recommendations regarding the diet and activities of those living in the region;

- to prevent the spread of radioactive materials by menas of contact from the contaminated regions and also the consumption of food products with a radionuclide content higher than the regulatory values.

In order to deal with these problems, systematic monitoring was set up to check:

- the gamma radiation levels throughout the Eurpoean part of the USSR using aerial and land radiation monitoring;

- the concentrations and radionuclide composition of radioactive substances in the air at various points in the 30-kilometre zone, primarily in places where work was carried out to eliminate the consequences of the accident and where personnel were stationed, and also outside the 30-kilometre zone in populated areas where high radiation levels were observed;

- the density of radioactive contamination of the soil and vegetation and the radionuclide composition of this contamination;

- the radionuclide content of drinking water reservoirs and also of food products reaching shops;

- the iodine radionuclide content which accounted for the main internal exposure during the initial period after the accident in the thyroid gland for the population evacuated from the 30-kilometre zone and that living in regions of high gamma background levels;

- the radioactive contamination levels of overalls or personal clothing and footware, of external and internal surfaces of transport vehicles on the borders of the controlled zones (established on the basis of the nature of the work and the developing radiation conditions) and at airports, railway and bus stations.

7.2.2. Level of external exposure of the population of the town of Pripyat' from the time of the accident until the time of evacuation

From the beginning of the accident at the fourth unit and during the fire which followed, the wind carried radioactive products past the town of Pripyat'. Subsequently, when the height of the products released from the stricken reactor dropped considerably, the radioactive plume gradually covered the area of the town and contaminated it as a result of a change in the wind direction in the near-ground air. From 9.00 p.m. on 26 April 1986 the gamma radiation exposure dose rate measured 1 m from the ground in different streets of the town was within the limits 14-140 mR/h.

Subsequently, the radiation conditions in the town worsened. On 27 April 1986 at 7.00 a.m. in the region closest to the power plant (Kurchatova street), the gamma radiation dose rate reached 180-600 mR/h and at other streets 180-300 mR/h. The tendency for the radiation conditions in the town to get worse during 27 April 1986 continued and at 5.00 p.m., i.e. after complete evacuation of the population it was 360-540 mR/h and in the Kurchatova street area 720-1000 mR/h. Evacuation of the population began on 27 April 1986 at 2.00 p.m.

(36h)

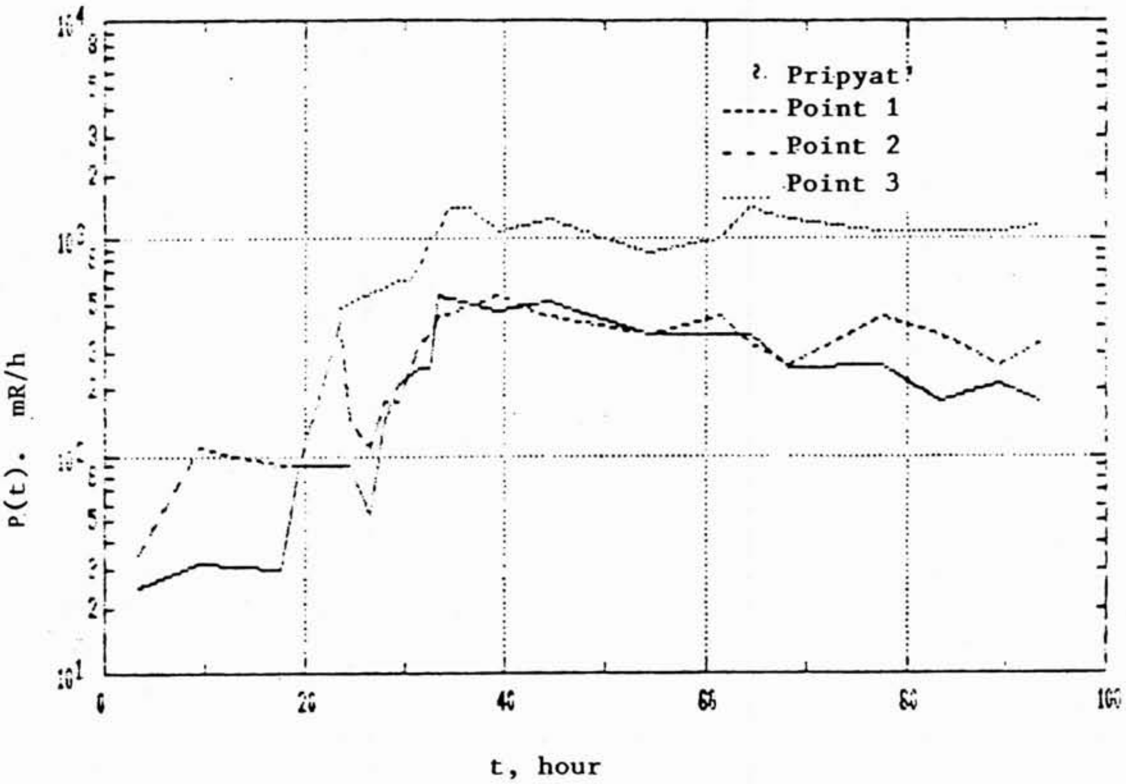


Fig. 7.2.I Dynamics of the change in dose rate in Pripyat' during the first four days after the accident

→ 1000 fois l'ambiant

Figure 7.2.1 shows data on the change in the radiation conditions of various areas of the town of Pripyat' from the beginning of the accident until completion of evacuation. The gamma radiation dose rate during this time was 5.9; 7.1; and 20.3 P at points 1, 2 and 3 respectively. By 6 May the radiation levels in Pripyat' had dropped by a factor of three. Purely rough calculations make it possible to assume that the external gamma radiation dose from the passing cloud of effluent during the first hours after the accident was close to 10-15 R.

The estimate of the exposure levels of the population of the town was based on the possible pattern of behaviour on 26 and 27 April and on the readings obtained from personal dosimeters of workers in the radiation safety services and in the accident brigades.

Immediately after the beginning of the accident, the population in Pripyat' was recommended to minimize the time spent outside and to keep windows closed. On 26 April all open-air activities were banned at all crèches, kindergartens and schools and in addition, iodine prophylactic treatment was given there. Thus the population, most of whom remained inside during the day on 26 and 27 April was exposed to a level of gamma radiation which was 2-5 times less than that measured in the street. In view of this, there is reason to assume that for the vast majority of the population of Pripyat', the probable dose levels were likely to be 1.5-5.0 rad for gamma radiation exposure and 10-20 rad for beta radiation exposure of the skin.

Consequently, these evaluations show that the possible doses from external radiation exposure to the inhabitants of Pripyat' are significantly lower than those which might cause any immediately changes in their health. A subsequent medical examination of the inhabitants of Pripyat' confirmed this conclusion.

Measurements of the content of iodine isotopes in the thyroid glands of people evacuated from Pripyat' to neighbouring populated areas in the Polessk region showed that in 97% of the 206 examined, the iodine content of the thyroid gland indicated a dose of less than 30 rad. Here the iodine prophylactic measures played a positive role as did the restrictions introduced regarding the consumption of milk from cows for personal use.

The measurements of the iodine content of the thyroid glands of the 20 inhabitants of Pripyat' who were evacuated to Belaya Tserkov', where there was a ban on the consumption of products contaminated by radioactive materials, also give an indication of the possible exposure level resulting from inhalation of iodine. Measurements taken (on 7 May 1986) for the majority of people examined indicated that the thyroid gland dose burden may be 1.5-25 rad.

7.2.3. Exposure of the population in the 30-km zone around the Chernobyl' nuclear power plant

On the basis of the analysis of the radionuclide composition of the radioactive fallout at various points in the 30-km zone around the Chernobyl' nuclear power plant, an estimate was made of the decay dynamics for the dose rate from external gamma radiation from the surface of the earth. This relationship is shown in Fig. 7.2.2 by the continuous line and the dots indicate the actual measured values of the dose rate in relative units. The reasonable agreement between the calculated curve and the data obtained experimentally made it possible to make definite extrapolated estimates both for a long time (up to a year or more) after the accident and for the period during the passage of the cloud of effluent. After appropriate corrections for the actually observed values of the parameters analysed calculations made using a specially developed computer program provided the following relationships between the gamma radiation dose rates at districts on the fifteenth day after the accident ($P\gamma$, 15 mR/h) and the dose for external radiation dose from the radioactive cloud (D_{cl} R), the dose from the radioactive fallout at various times after the accident (D_{fall} P) and also the dose for internal radiation exposure of the thyroid gland in children (D_{tg}, rad) as a result of inhalation and consumption of contaminated cows' milk:

D_{cl} (10-30 km) = (0.28-0.07).$P\gamma$ 15

D_{fall} (7 days) = 0.7.$P\gamma$ 15

D_{fall} (1 month) = 1.2.$P\gamma$ 15

D_{fall} (1 year) = 2.5.$P\gamma$ 15

D_{fall} (50 years) = 8.$P\gamma$ 15

D_{tg} (inhal.) = 10.$P\gamma$ 15

D_{tg} (peroral) = 1000.$P\gamma$ 15

The last value relates to the case where there is no limitation on the consumption of contaminated cows' milk, which is naturally possible only in zones with very low levels of ^{131}I contamination of vegetation.

In addition to the calculated doses from external radiation exposure caused by the cloud of effluent and internal exposure of the thyroid gland in children as a result of inhalation of iodine, Table 7.2.1 gives a comparison of the doses for external radiation exposure to people in some of the

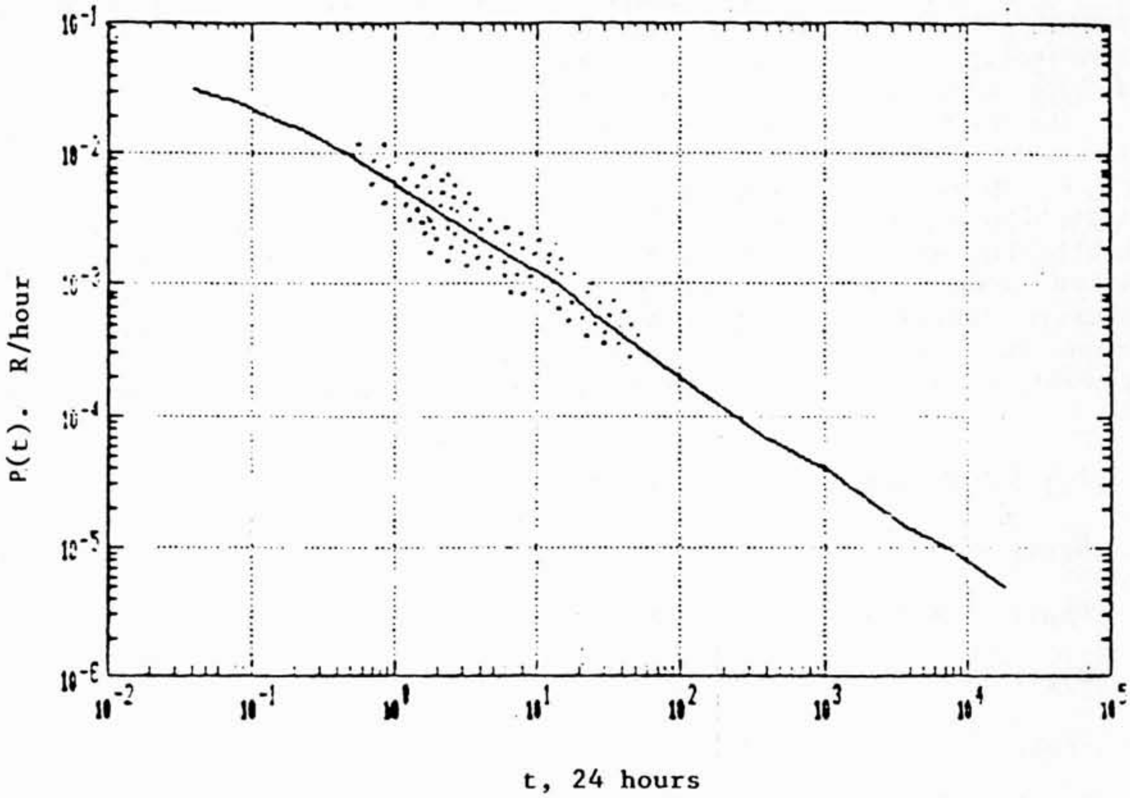


Fig. 7.2.2 Change in gamma dose rate on the path of the radioactive effluent from the Chernobyl, nuclear power plant

debit de dose le 15e jour ?

Table 7.2.I

Estimated doses to people in some of the populated areas in the 30 km zone around the Chernobyl NPP

Pγ 15   0,28 Pγ 15   0,7 x Pγ 15

POPULATED AREA	DISTANCE FROM CHERNOBYL NPP	DOSE RATE "D" mR/hour	DOSE FROM CLOUD OF EFFLUENT	DOSE TO THYROID GLAND OF CHILDREN, RAD	DOSE FROM FALLOUT OVER A TIME OF 7 DAYS	
					ESTIMATED	MEASURED
CHISTOGOLOVKA	5,5	I2	I0	I20 3,6	8,4	3,2
LELEV	9	25	7	250 7,5	I7	I0
CHERNOBYL	I6	8	I,2	80 2,4	5,6	3,0
RUD'KI	22	8	0,6	80 2,4	5,6	2,2
OREVICHI	29	2,5	0,2	25 0,75	I,8	4,4

dose efficace

populated areas in the 30-km zone around the Chernobyl' plant calculated using the above relationships and the actual dose values obtained from gamma radiation dose rate measurements (see Fig. 7.2.3).

Analysis of the data in this table shows that the calculated and experimental dose values coincide within a factor of two. This meant that already in the first days after the accident it was possible to make similar estimates for the whole 30-km zone around the Chernobyl' plant based on the available data on the developing radiation conditions. These estimates are given in Table 7.2.2 which contains data for the 71 populated areas in this zone with an indication of the calculated range of external gamma radiation doses in the open.

The fairly wide range (within two orders of magnitude) of changes in the dose for each zone around the Chernobyl' NPP is linked to the considerable unevenness in the radioactive contamination for various sections of the path formed by the effluent released (see Annex 5). On the basis of similar estimates and taking into account the discharge of gases and aerosols from the accident zone which continued during the first few days after the accident, it was decided that it would be wise to proceed to a further evacuation of the population from the area of the accident. In the first few days after the accident, 90 000 people were evacuated from the 30-km zone around the Chernobyl' NPP. Together with the 45 000 people evacuated on 27 April from the town of Pripyat', the total number of those evacuated was 135 000.

This emergency measure made it possible to guarantee that the dose levels of external gamma radiation from the cloud of effluent and radioactive fallout for the vast majority of the population did not exceed 25 rem and only for certain populated areas in the most contaminated parts of the radioactive path (the villages of Tolstyj Les, Kopachi and some others) people may have been exposed to 30-40 rem. However, even for these doses for external radiation exposure there is no danger of acute immediate somatic effects for those exposed. The estimates for the maximum collective dose to the evacuated population (see Table 7.2.3) suggest that the collective exposure dose is 1.6 million man.rems. Taking into account the fact that spontaneous deaths from cancer over a 70 year period for the 114 000 evacuated people may be about 14 000 cases, the natural death rate from cancer among the exposed population will be increased by less than 2% as a result of the the accidental release from the Chernobyl' NPP.

A more exact definition of the radionuclide composition of the contamination of the surface of the earth and the nature of the decay in the gamma-radiation dose rate in the area (see Fig. 7.2.2) will make it possible to introduce subsequent corrections to the expected doses for external radiation exposure to the population and to determine how long it may take before people can return to their place of permanent residence.

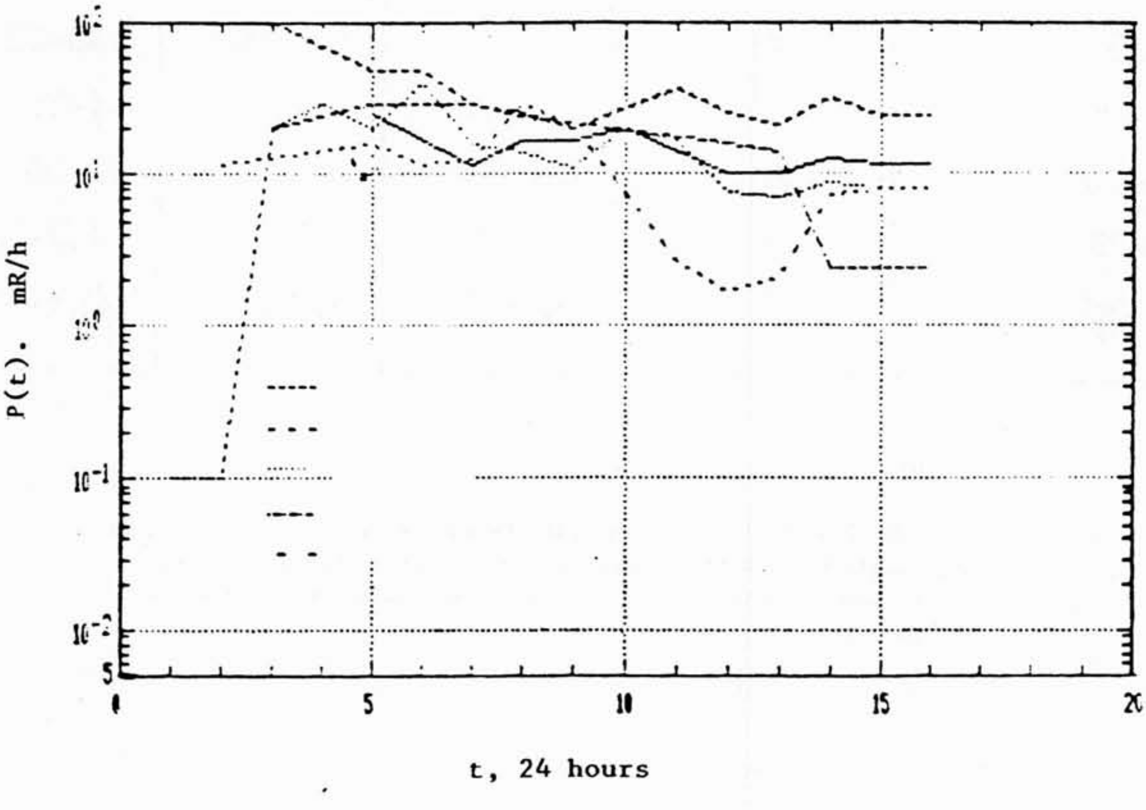


Fig. **7.2.3.** Dynamics of the changes in the gamma dose rate for some of the populated areas in the 30-kilometer zone

A <u>30 km</u> du réacteur.
En 2 heures le débit de dose est passé à 30 mRem/h soit 0,7 Rem/jour.
(en contradiction avec le tableau de la page 43)

Table 7.2.2

Calculated doses from external radiation exposure of the rural population*
in the 30 km zone around the Chernobyl' nuclear power plant, rem.

Distance from the Chernobyl' nuclear power plant, km	Number of populated areas	Dose from external radiation resulting from fallout for the period:		
		7 days	I month	I year
3-7	5	6-80	I0-I30	25-300
7-I0	4	I0-60	I6-I00	35-230
I0-I5	I0	I,2-75	2-I20	4-250
I5-20	I6	0,3-25	0,5-40	I-90
20-25	20	0,4-35	0,6-60	I,3-I20
25-30	I6	0,I-I2	0,2-20	0,4-40

x)

*Obtained taking into account the pattern of life of the rural population and the protection coefficients created by rural buildings. For urban conditions these values will be about half the size.

Calculated collective doses from external radiation exposure of the evacuated population.

Area around the Chernobyl' nuclear power plant	Size of population, 1000 people	Collective dose, million man-rem	Dose mry (rem)
	45	0,I5	3,33
3 - 7 km	7,0	0,38	54,3
7 - I0 km	9,0	0,4I	45,6
I0 - I5 km	8,2	0,29	35,4
I5 - 20 km	II,6	0,06	5,2
20 - 25 km	I4,9	0,09	6,0
25 - 30 km	39,2	0,I8	4,6
TOTAL:	I35	I,6	11,9

While the stricken reactor continued to release considerable quantities of radioactive products into the atmosphere for a relatively long period (8-10 days), the picture of the contamination of the environment, both in terms of the activity level and in terms of the radionuclide composition, was complicated by the changing meteorological conditions, height and intensity of release. In particular, abnormally high local contamination was observed in different parts of the area. Certain difficulties also arose in establishing a typical radionuclide composition for the radioactive impurities in the air and over the contaminated area. Thus, for example, the iodine-131 content in air and soil samples varied from 8-40% and the caesium from 1-20%. This made it difficult to estimate the possible exposure level to the population resulting from the intake of radioactive products.

Nevertheless, there are fairly good reasons for maintaining that at this stage of evaluation of the dose burdens it is not necessary to take account of the intake of radionuclides by inhalation for people living along the radioactive path. This is confirmed by data which show that the activity of the air in the 30-km zone (Chernobyl', Zorin, Skazochnyj pioneer camp, and the town of Pripyat') from 3 May to 3 June was 10^{-2}-10^{-4} Ci/L for the total beta-activity of the radionuclides. Table 7.2.4 gives an example of the relative contribution of gamma-active radionuclides in the air samples taken from different populated areas around the Chernobyl' NPP.

Thus, for the population living in the contaminated area and consuming locally produced products, the main source of internal exposure consists of the radioactive substances contained in these products. The calculations certainly have to include radioactive substances which were inhaled during passage of the cloud. However, as will be shown below, the doses for internal exposure resulting from this are significantly less than those resulting from consumption of contaminated products.

In the first stage after the accident (about 2 months) the main radionuclide component of the dose was iodine entering the organism mainly through milk from grazing dairy cattle and the critical organ receiving the maximum dose burden was the thyroid gland.

These circumstances predetermined the scale and type of dosimetric and medical examination of the population. The staff and resources of brigades from the specialized institutes of the USSR Ministry of Health were used to examine the iodine content of the thyroid gland for the population evacuated from the 30-km zone, and also for the inhabitants of a number of populated areas in the Ukrainian Soviet Socialist Republic (SSR), the Byelorussian Soviet Socialist Republic (SSR) and the Russian Soviet Federative Socialist Republic (RSFSR) where high radiation levels were recorded but where evacuation was not necessary. Special attention was given to children which belong to the group of high radiation risk, because the accumulated radiation

Table 7.2.4

Relative content of the gamma-ray-emitting radionuclides
in aerosol samples taken from the air

Date of sampling	Place of sampling	Total β activity of sample Ci/L	Relative radionuclide content %											
			I^{I3I}	Cs^{I34}	Cs^{I37}	Ba^{I40}	La^{I40}	Ce^{I4I}	Ce^{I44}	Zr^{95}	Nb^{95}	Ru^{I03}	Ru^{I06}	Te^{I32}
I4.05	Zorin	$I,5 \cdot IO^{-I3}$	20,0	-	4,0	-	5,0	I2,0	-	8,0	20,0	30,0	-	I,0
3.06	Town of Pripyat'	$4 \cdot IO^{-IO}$	-	I,2	0,8	I,I	2,5	II,2	I2,I	I9,2	26,I	I9,I	6,7	-
3.06	Skazochnyj pioneer camp	$6 \cdot IO^{-I3}$	0,46	3,9	7,7	I8,8	27,9	3,5	3,2	I7,0	2,0	4,9	4,6	-
3.06	Chernobyl'	$4,0 \cdot IO^{-I2}$	5,9	0,8	I,6	3,7	5,0	II,2	9,0	I8,6	22,9	II,7	9,6	-

Note: A dash indicates that the radionuclide was not detected in that particular sample.

15000 Bq/m³

dose in the thyroid gland for the same radioiodine content is 8-2 times greater in children from the age of 2-24 respectively than in adults. In addition, it should be noted that children consume great quantitiies of milk products.

Where possible, together with the examination of the iodine content in the thyroid gland, there was selective determination of the content of other radionuclides in the organism from excretion activity (urine, faeces) and also the possible intake into the organism of various radionuclides was estimated from data about the isotopic composition of the soil and food contamination. In the period following the accident, the radioiodine content of the thyroid gland was determined directly for a large number of inhabitants including almost 100 000 children. Almost all the children (up to 15 years old) and part of the adult population evacuated from the 30-km zone and populated areas on the path of the radioactive cloud where high radiation levels were recorded were examined. It should be noted that the above population consumed locally produced products prior to the evacuation (4-5 May) for 9-10 days, including milk and milk products, the proportion of which is significant in this region.

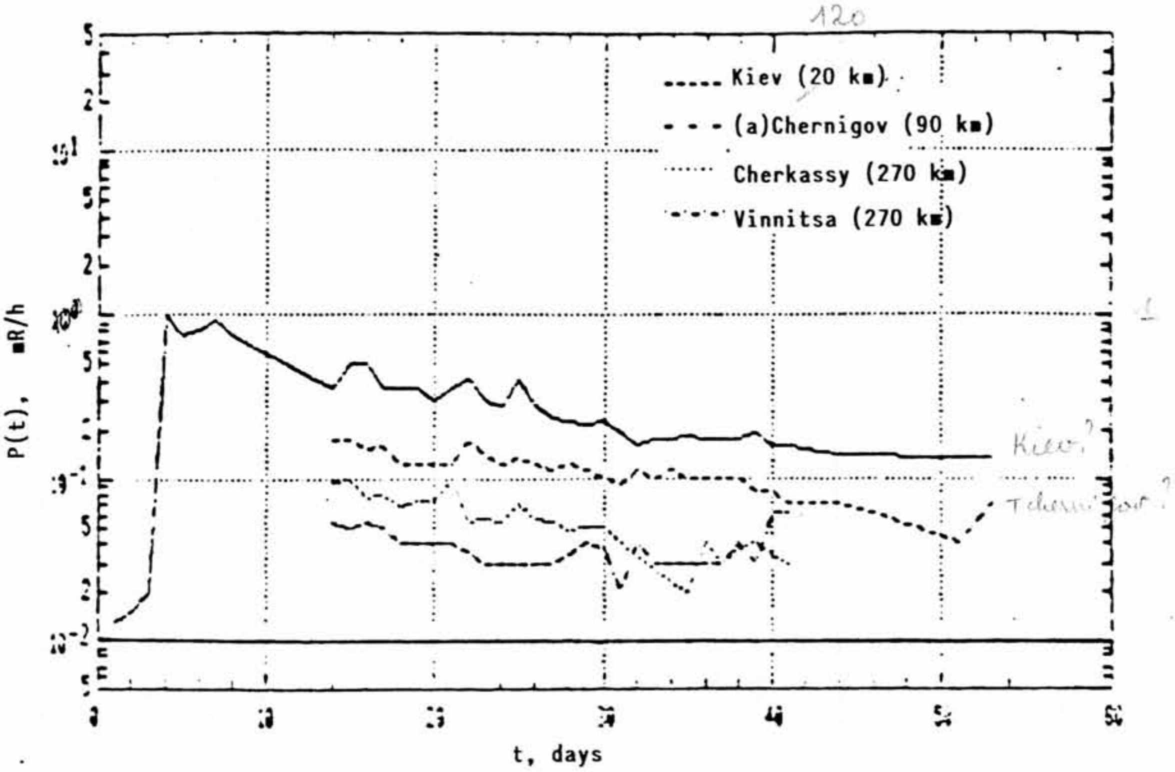
The measurements showed that for the vast majority of people evacuated from the 30-km zone, the thyroid gland dose burdens as a result of intake of radioactive substances by consumption of locally produced products is significantly lower than those which could cause any change in their health.

The relatively high thyroid gland dose burdens observed sometimes is evidently the result of the uncontrolled consumption of milk from cows for personal use despite the ban issued by the health authorities on 1 May 1986 on the consumption of whole milk with a radioiodine concentration higher than [illegible] Bq/lit 1.10^{-7} Ci/L. This requirement was strictly adhered to within the centralized milk supply. Furthermore, additional measures were taken for strict monitoring of the sale and consumption of milk from cows for personal use.

For prophylactic purposes all the children from the 30-km centralized evacuation zone were sent to summer sanitoriums in the country. There is constant medical observation of children for whom the estimated thyroid gland exposure dose prior to complete clearance of iodine isotopes may exceed 30 rem.

7.2.4. Radiation consequences of the accident at the Chernobyl' nuclear power plant for the population of different regions in the European part of the USSR

As was indicated in the previous sections of the report, the radioactive releases resulting from the accident at the Chernobyl' nuclear power plant affected radiation conditions not only near the plant but also conditions considerable distances from it. Figures 7.2.4 and 7.2.5 show the



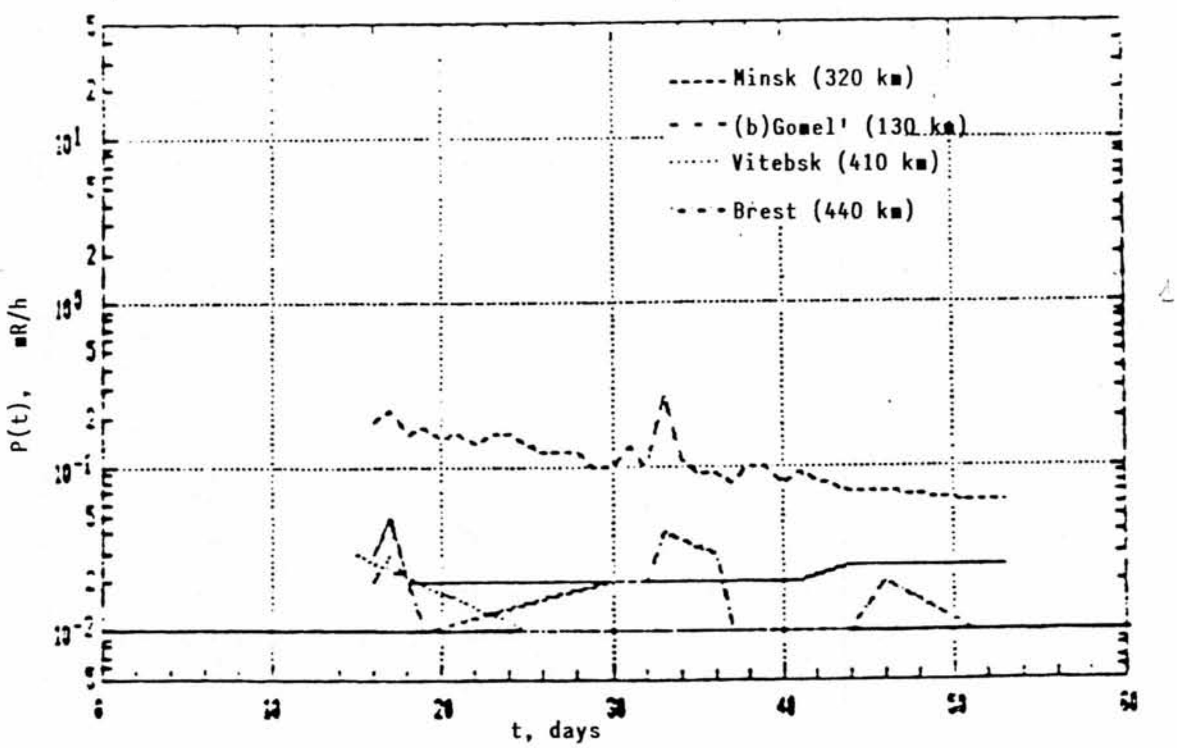
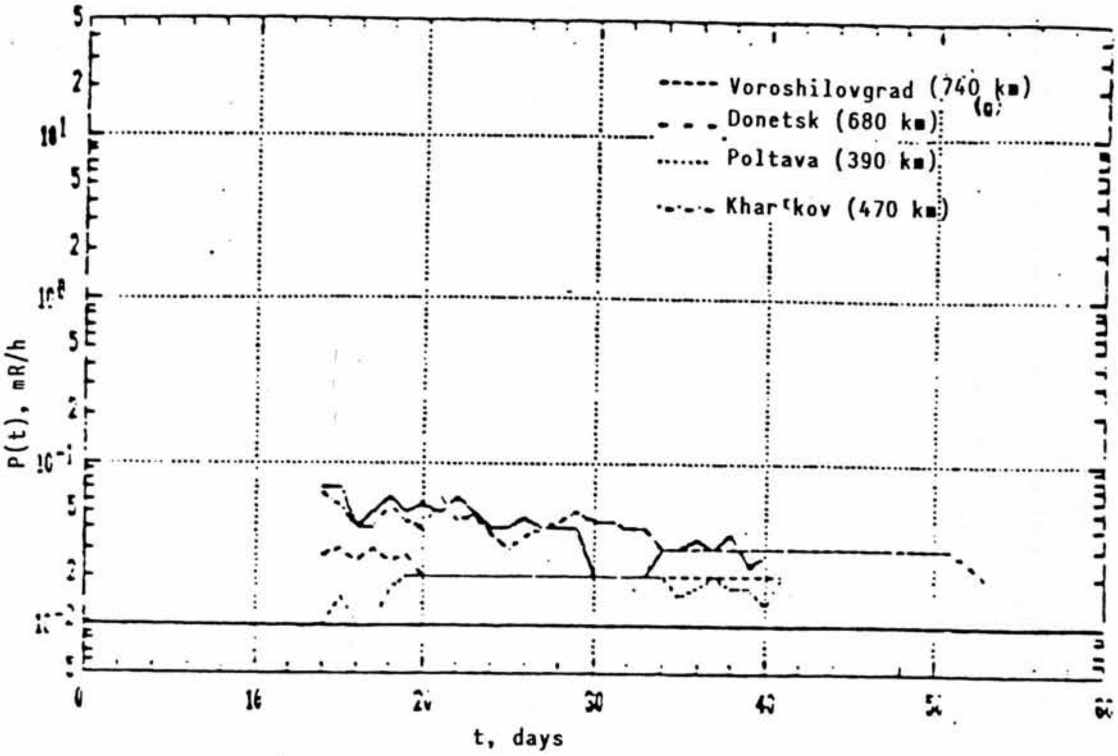


Fig. **7.2.4** Dynamics of the changes in the gamma dose rates in the open for regional centres in the Ukrainian SSR (a) and the Byelorussian SSR, near the Chernobyl' nuclear power plant.



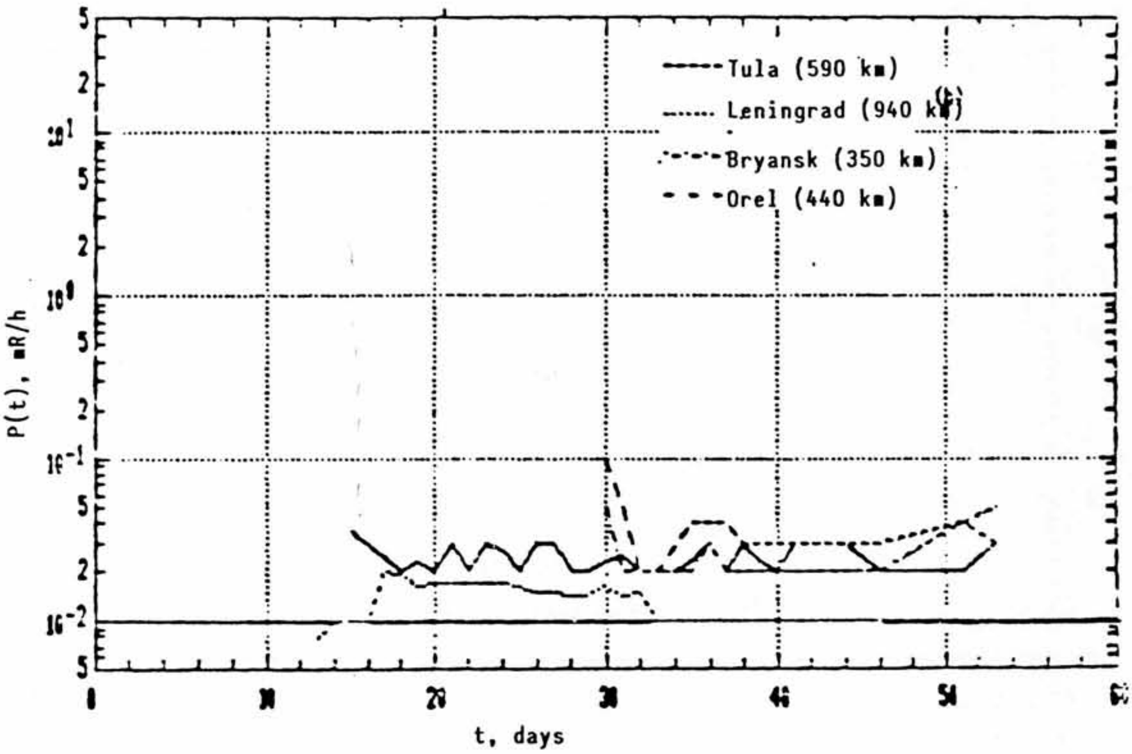


Fig. 72.5. Dynamics of the changes in the gamma dose rates in the open for some regional centres in the Ukrainian SSR (a) and the Russian SFSR (b).

change during the course of time in the gamma radiation dose rate in the open at some regional centres of the Ukrainian SSR , Byelorussian SSR and the RSFSR at distances of 100-1000 km from the Chernobyl' plant. The diagrams show that at virtually all these populated areas, the dose rates for external gamma radiation was several times greater than the natural background radiation characteristic for that area of the European part of the USSR (8-12 μ R/hour - the thick lines on the diagrams). By averaging the numerous results of gamma radiation dose rate measurements for areas within the regional administrative boundaries it was possible to identify the ten (see table 7.2.5) which had the maximum levels of radiation caused by the products released to the population during the accident.

The data in table 7.2.5 show that the regional averages values of external exposure for 1986 do not exceed (taking into account the population's way of life) 1.5 rem and for 50 years - 5 rem. Thus there is no danger to health for the population living outside the 30-kilometre zone around the Chernobyl' plant resulting from the levels of external gamma radiation of the products released during the accident. A more complex situation arises when estimating doses of internal exposure resulting from the intake of radionuclides through consumption of contaminated locally produced food products.

Before the accident at the Chernobyl' plant, in the Soviet Union, as in other countries, regulations were established only for the permissible annual intake of radioactive substances in food products. The permissible concentration of nuclides in drinking water had also been established (Radiation Safety Standard-76). There were no regulations governing the content of nuclides in different forms of food products. In the event of an accident, norms had been established only for the critical product (cows' milk) and the most important nuclide in an accident - iodine-131). In the radiation conditions prior to the accident, the content in all types of food products, strontium-90, caesium-137 and even more in the case of other nuclides, was many times lower than the established annual limits on intake of nuclides through food consumption. These standards were based on the principle that groups of the population receiving the greatest exposure should not receive a dose of more than 0.5 rem per year and for critical organs of the second group (including in particular the thyroid gland) - 1.5 rem. It was established that these exposure doses should not be exceeded for any combination of radiation action - i.e. both external exposure and internal exposure (inhalation, intake through water and food). These standards were worked out on the principle unconditional and complete prevention of the immediate specific consequences of exposure (radiation sickness, cataract, radiation burn, injury to the haemopoietic system, lowering of the immunoreaction). Moreover these norms which are established considerably below the levels capable of causing the reactions mentioned above, are based on the need to limit the risk of late radiation effects occurring - cancer and genetic disturbances. The Radiation Safety Standards-76 for a restricted part

Radiation levels and predicted doses from external radiation exposure to the population in the 10 regions which had the highest radioactive contamination caused by the products released from the Chernobyl' NPP

Regions	Regional average dose rate 15 days after the accident mR/hour	Dose to the population in 1986 rem		Dose over 50 years rem	
		rural	urban	rural	urban
Gomel'skaya	0,83 x)	I,39	0,74	4,7	2,5
Kievskaya	0,44 x)	0,74	0,40	2,5	I,4
Bryanskaya	0,30	0,50	0,27	I,7	0,92
Zhitomirskaya	0,20	0,34	0,I8	I,2	0,63
Mogilevskaya	0,I5	0,25	0,I4	0,86	0,46
Orlovskaya	0,I4	0,24	0,I3	0,8I	0,44
Chernigovskaya	0,I4	0,28	0,I2	0,78	0,42
Tul'skaya	0,I2	0,20	0,II	0,67	0,37
Cherkasskaya	0,09I	0,I5	0,082	0,52	0,28
Brestskaya	0,08I	0,I4	0,073	0,46	0,25

x) Outside the 30-km zone around the Chernobyl' NPP.

of the population (0.5 rem for the whole body) correspond to the upper boundary of probability for the incidence of cancer which is 50-500 additional cases per million population per year. The actual levels of exposure of the population before the Chernobyl' accident from water and food products were tens and hundreds of time lower than the regulatory levels.

After the accident it became necessary to find effective solutions to problems associated with sorting and prohibiting the consumption of specific types of food products. Since initially the main danger was that of iodine-131 incorporated into the human organism during the spring-summer period primarily through milk and also through leafy green vegetables, standards were introduced immediately after the accident governing the permissible content of iodine-131 in milk and milk products (cottage cheese, sour cream, cheese, butter) and also in leafy green vegetables. The standards were designed to ensure that thyroid gland exposure of children (the critical organ for iodine-131) did not exceed 30 rem. This condition was observed by establishing the permissible content of iodine-131 in milk at 1.10^{-7} Ci/L. A similar standard was introduced in England in 1957 after the Windscale accident. In addition, standards were introduced governing the iodine-131 content in meat, poultry, eggs, berries, and raw materials used for medical purposes. During the second half of May, data were obtained which indicated that as the iodine-131 decayed, caesium-137 and caesium-134 were playing an increasing role in the contamination of meat and a number of other types of foodstuffs and also indicated the presence in food products of rare earth isotopes - cerium-144, ruthenium-106, zirconium-95, barium-140, lanthanum-140, cerium-141, ruthenium-103, niobium-95. The latter were found in significant quantities together with caesium in green vegetables ($1\ 10^{-6}$ Ci/kg or more). At many places during May the concentrations of iodine in milk products remained high. During this period in order to carry out wide-scale monitoring and sorting of food products, it was necessary to establish standards which would make it possible to carry out monitoring using the simplest equipment, in other words, standards governing the total beta-activity content. These standards were issued by the USSR Ministry of Health on 30 May 1986. They were a continuation of the earlier standards of the 8 and 12 May but contained a wider selection of products and reflected the changes in the radiation conditions established at the end of May. The permissible whole body and internal organ exposure dose on which these standards are based is 5 rem.

37000 Bq/kg

In the first days and weeks after the accident, the basic activity of food products was accounted for by iodine-131. It appeared in the milk of cows kept out at pasture two-three days after the accident. The iodine levels in the south of Byelorussia were established at 10^{-6} Ci/L. The milk of cows which were kept inside remained much freer. The same and even higher contamination levels - up to 10^{-5} Ci/kg were recorded in green vegetables.

Lait dans le sud de la Biélorussie 10^{-6} Ci/litre → 37000 Bq/l
dans les végétaux verts 370 000 Bq/kg

As is well-known, during migration of radionuclides - from the first link in the chain, i.e. the fallout and soil to the last one - the human organism - separation occurs together with a reduction in the content of some nuclides and an accumulation of others as a function of the physical and chemical properties of the nuclide and a number of other factors (soil composition, quantity and time of fall of atmospheric precipitation, the composition of the diet of agricultural animals and so on). Therefore, the fullest composition of nuclides may be recorded in food products contaminated from the surface, i.e. direct sorbing nuclides contained in the atmosphere and settling from the air. These products include lettuce, fennel, kinza, tea, and so on. Table 7.2.6 shows, as an example, the nuclide composition found in surface-contaminated representative vegetation from regions close to the Chernobyl' plant.

On the other hand, in a number of other products where the radioactive substances face biological barriers the radionuclide composition is considerabaly limited. Thus at the beginning and in the middle of May only caesium and iodine-131 isotopes were found in meat and at the end of May and in June almost only caesium-137 and caesium-134 (in a 2:1 ratio) were detected. However, the content of radioactive caesium in meat (beef) was fairly high - 10^{-8} - 10^{-7} Ci/kg.

The data in table 7.2.7 show the amounts by which the levels in food exceeded the standards prevailing in May.

As has already been indicated above, monitoring of the iodine-131 contamination of milk showed that in many regions of the Ukrainian SSR, Byelorussian SSR and the RSFSR in the period May-June 1986, the concentration of this nuclide in milk exceeded the established standards (0.1 μ Ci/L). By analysing the contamination levels of the soil, vegetation and milk samples and linking them with the gamma radiation dose rate in the area, it was possible to estimate the possible concentrations of iodine-131 in milk in various regions of the country. An example of such an estimate is given in Table 7.2.8 where estimated iodine-131 contamination levels of milk samples are given for 10 regions based on the actual or regional average external gamma radiation dose rates alongside the values actually observed in May 1986. Similarly, information was prepared for other regions in the European part of the USSR with a population of about 75 million (see Fig. 7.2.6). In this drawing and in the table given below, 11 regions are selected (4 in the Ukrainian SSR, 2 in Byelorussian SSR and 5 in the RSFSR) which are interesting either because they have fairly high radioactive contamination levels or because they have large populations.

The estimate of the radiation consequences of external gamma radiation for the population of these regions resulting from the radionuclides which fell in the area is given in Table 7.2.9. The Table shows that the expected average dose values for the external exposure for each region in 1986 is

bœuf 370 à 3700 Bq/kg

Table 7.2.6

Radionuclide content in vegetation near the Chernobyl' NPP

Type	Place of sampling	Date of sampling	Nuclide	Content Ci/kg	Bq $10^{?}$
Clover	Chernobyl'	26 (284 j	Cerium -I44	$2 \cdot 10^{-6}$	74
		33 j	Cerium -I4I	$1,4 \cdot 10^{-6}$	51,8
			Iodine-131	$1,3 \cdot 10^{-6}$	48,
		40 j	Ruthenium-103	$1,2 \cdot 10^{-6}$	44,
		1,0 an	Ruthenium-106	$7,9 \cdot 10^{-7}$	29,
		12,8 j	Barium-140	$6,7 \cdot 10^{-7}$	24,
			Caesium-134	$3,2 \cdot 10^{-7}$	11,8
			Caesium-137	$2,5 \cdot 10^{-7}$	9,3
		65,7 j	Zirconium-95	$1,5 \cdot 10^{-6}$	55,
		35 j	Mobium-95	$2,0 \cdot 10^{-6}$	74
		40 h	Lanthanum-140	$5,3 \cdot 10^{-7}$	19,
			Total	$12 \; 10^{-6}$	44[illegible]

Table 7.2.7

Agricultural products in which a higher than permissible level of radioactive contamination was detected

Republic	Region	Product and the proportion (%) which did not corresponds to the norms					
		Meat	Milk & milk products	Green vegetables	Root vege-tables	Berries	Fish
Byelorussian SSR	Minskaya	IO	5	-	-	-	-
	Gomel'skaya	40	30	I5	IO	5	90
	Brestskaya	IO	50	5	3	5	-
	Mogilevskaya	20	IO.	-	-	-	-
	Godnenskaya	-	5	-	-	-	-
RSFSR	Tul'skaya	-	I5	-	-	-	-
	Bryanskaya	-	30	-	-	-	-
	Kaluzhskaya	-	20	-	-	-	-
	Kurskaya	-	30	-	-	-	-
	Orlovskaya	-	IO	-	-	-	-
Ukrainian SSR	Kievskaya	-	IO	20	-	20	-

Note: a dash indicates that data are not available.

$5\,10^{-4} \times 9.5\,10^{6} = 4\,800$ cancers supplémentaires pour $29\,10^{6}$ rem → risk factor $4.8\,10^{3}/29\,10^{6} = 1.66\,10^{-4}$ (idem to ICRP)

generally lower than the annual dose limit for category B workers (restricted group of the population) in accordance with regulation Radiation Safety Standard-76. The collective dose for this population group is 8.6 million man.rem in 1986 and 29 million man.rem for a period of 50 years after the accident. For the purposes of comparison it should be noted that the annual collective dose from natural background radiation for the same number of people is 10 mllion man.rem, i.e. it is comparable with the annual dose resulting from the accidental release for 1986. Over a period of 50 years, the natural background radiation dose will be almost 15 times greater than the corresponding collective dose from the Chernobyl' accident. In this connection, the calculated increase in the mortality rate, based on the non-threshold hypothesis of the dose-effect relationship, is less than 0.05% by comparison with the mortality rate from spontaneous cancer (about 9.5 million cases after 70 years) for the same population.

The risk of mortality and the estimate of the number of cases of curable forms of cancer and benign tumours of the thyroid gland among people who have consumed iodine-131 contaminated milk was calculated on the basis of the following data:

- The actual concentration of iodine-131 in cows' milk or its estimated content based on the external gamma radiation dose rate for the area;

- The size of the population and its composition in terms of sex and age;

- The age dependance for the consumption of milk, the dose coefficients and the risk of mortality coefficients, and the risk of curable diseases of the thyroid gland based on data of the ICRP, UNSCEAR and Soviet publications.

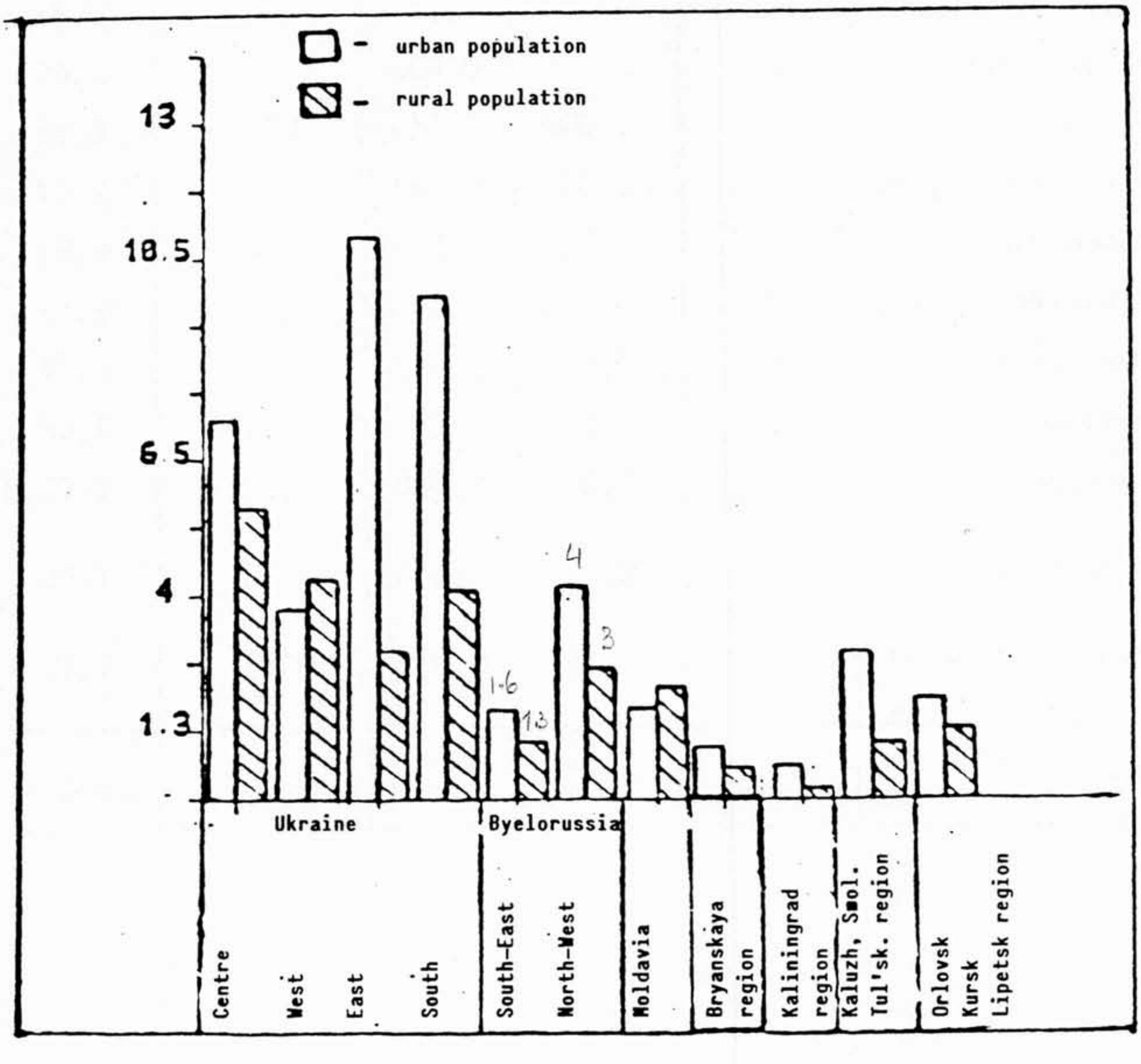
General data on the iodine-131 concentration levels in cows' milk for the regions examined are shown in Fig. 7.2.7. The diagram shows that in a number of regions of Ukrainian SSR, Bylorussian SSR and RSFSR, the iodine-131 concentration in different samples exceed the established standard (the thick line in the diagram) by 20-100 times or even more. Since milk sold centrally had a concentration not greater than 0.1 μCi/L it was assumed that the urban population of these regions and most of the rural population consumed this type of milk. For the remaining small group of the rural population with their own dairy cattle it was assumed that in some cases the 100% ban on the consumption of milk with a concentration of iodine-131 higher than the permissible level was not fully applied. This assumption means that in a number of the regions which were more heavily contaminated with iodine-131, the maximum calculated doses for internal exposure of the thyroid gland could have reached hundreds of rads.

Table 7.2.8

Region	Calculated levels	Actual measurements
Gomel'skaya	0,2-I4	0,02-I0
Kievskaya	0,06-7,3	
Bryanskaya	0,04-5,0	0,02-I,3
Zhitomuskaya	0,03-3,3	
Mogilevskaya	0,02-2,5	0,02-2,0
Orlovskaya	0,02-2,3	0,0I-0,8
Chernigovskaya	0,02-2,3	
Tul'skaya	0,02-2,0	0,06-6;5
Cherkasskaya	0,0I-I,5	
Biestovskaya	0,0I-I,3	0,2-9,0

Comparison of calculated and actually observed iodine-131 contamination levels in milk in May 1986 in the 10 regions which had the highest radioactive contamination caused by products released from the Chernobyl' NPP µCi/L

Fig. 7.2.6. Population in different regions of the European part of the USSR (in millions of people)



Expected doses from external radiation exposure to the population
in different regions of the European part of the USSR

Region	Population, millions of people	Dose for 1986 rem/year		Collective dose 10^6 man-rem	
		rural	urban	for 1986	over 50 years
Central part Ukrainian SSR	I3,6	0,27	0,I5	2,75	9,3I 0,685
West. part Ukrainian SSR	8,3	0,067	0,036	0,44	I,47 0,177
East. part Ukrainian SSR	I4,5	0,077	0,04I	0,75	2,52 0,174
South. part Ukrainian SSR	I4,4	0,045	0,024	0,73	2,47 0,172
South-East Byelorussian SSR	2,9	0,98	0,52	2,05	6,94 2,40
North-West Byelorussian SSR	7,0	0,094	0,050	0,47	I,58 0,276
Moldauskaya SSR	4,I	0,084	0,045	0,27	0,92 0,224
Bryanskaya reg.	I,5	0,50	0,27	0,44	I,49 1,00
Kaliningrad. reg.	0,8	0,0I2	0,003	0,006	0,02 0,025
Kal. Tul'sk, Smotensk reg.	4,0	0,I2	0,064	0,32	I,08 0,27
Orl. Kursk. Lipetsk. reg.	3,4	0,I4	0,075	0,35	I,I7 0,344
Total:	74,5	-	-	8,6	29,0 0.39

[illegible] 0,39 rem

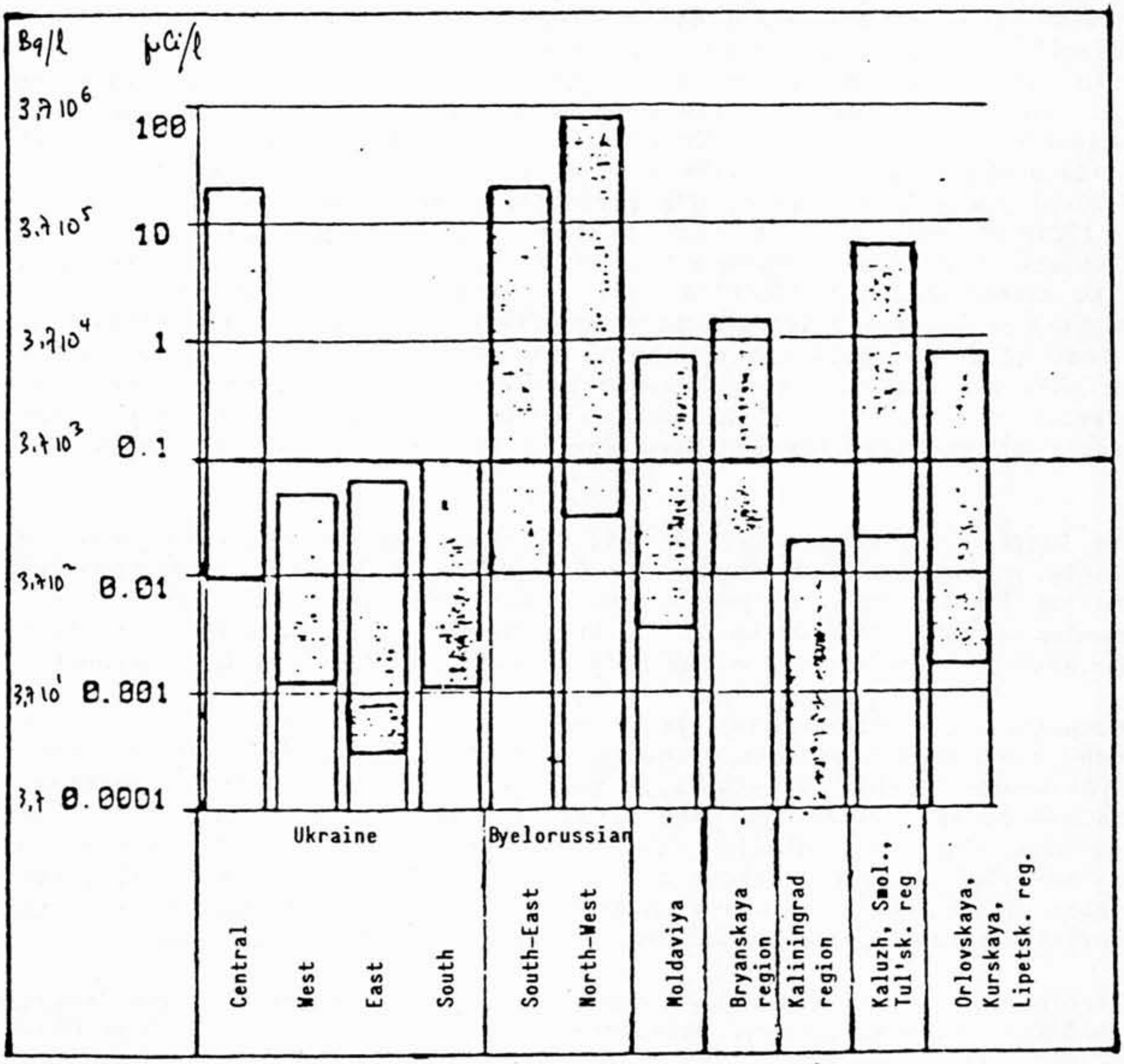
The comparison, based on the individual and collective dose estimates, between the risk of mortality as a result of exposure of the thyroid gland during a 30 year period after intake of iodine-131 and the risk of mortality from spontaneous cases of cancer of the thyroid gland during the same period (about 150 000 cases) showed that the increased mortality from iodine-131 is about 1% and hardly increases the mortality indices in the regions examined.

These estimates are based on the hypothesis of a non-threshold linear "dose-effect" relationship which is accepted in most countries. This hypothesis is based on theoretical representations of the carcinogenic mechanism, accumulated data on the dose-effect relationship in a region of high radioation doses and also the principle of "deciding in favour of man" i.e. deliberately ensuring his safety in a region of low radiation doses. It is significant that in the main ICRP publication on the problems of radiation safety (ICRP 26 para. 30) it is stated that: "The use of linear extrapolations from the frequency of effects observed at high doses may suffice to assess an upper limit of risk ... However, the more cautious such an assumption of linearity is, the more important it becomes to recognize that it may lead to an overestimate of the radiation risks ..." Thus the values given in this part of the report should be regarded as "upper" estimates of the radiation consequences for the population of the European part of the USSR as a result of the activity released during the accident at the Chernobyl' plant.

In addition to iodine-131, it will be necessary during this year and particularly in the following years, to pay attention to other radionuclides contaminating locally produced food products and water supplies. The possible contamination levels of foodstuffs in the short-term and in the long-term should be examined separately for the main nuclides and types of food products.

Ruthenium-106, ~~caesium~~ cerium-144 and other rare-earth nuclides make up a significant contribution only to products susceptible to surface contamination (green vegetables, other vegetables, and to a lesser extent - berries, mushrooms and honey), since they are hardly not assimilated from the soil by plants or from plants by animals. The biological significance of this group of radio- nuclides in such products does not exceed 10-20%. Subsequently, the contribution of rare-earth elements to the contamination of foodstuffs will be reduced significantly everywhere and will not have any practical value.

Caesium-137 and caesium-134 are the main biologically significant radio- nuclides which (excluding strontium-90) since the middle of June have been the main contaminants of meat, milk, vegetables and other products. Until now they have been incorporated into vegetable and animal products from the air. Incorporation from the soil has practically no significance. The grain and potato harvest in the autumn of 1986 will probably be relatively clean - not much caesium will already have been incorporated from the air and



<u>Fig. 7.2.7.</u> Concentration of ^{131}I in cows' milk (in µCi/L)

incorporation from the soil will not yet have played a role. The contamination of products by caesium in the next few years will be significantly different for the air around the Chernobyl' plant where the type of soil is different. Since caesium is incorporated from the Poles'ye soil which is poor humus, into plants at a rate which 10 or even 100 times greater than from other types of soil, the caesium-137 content in food in the Poles'ye region is likely to be relatively persistent and high in the next few years. In other regions, in particular in the north of Byelorussia, in the west of the RSFSR, in the south, north, east and west of the Ukraine, there are reasons to expect a sharp fall, of 10 or more times in the caesium concentration in food products.

The preliminary purely rough estimates of the contamination of food products by caesium isotopes are as follows. For a density of caesium-137 radioactive fallout on the surface of the earth of 1 Ci/km^2 and consumption by the population of locally produced food products, the doses of individual whole body exposure resulting from peroral intake of activity in the Ukrainian and Byelorussian regions of Poles'ye are (taking into account the additional exposure of the organism from Cs-134) 0.7, 0.34 and 3.3 rems for the first, second and 70 years respectively. In this case the collective doses, taking into account agricultural production for 1 km^2 in these regions of the Ukrainian SSR and Byelorussian SSR for the same periods are 120, 58 and 570 man.rems. For the rest of the country, with significantly lower coefficients for caesium transfer from the soil into agricultural products, the corresponding collective doses for the population are 120, 36 and 170 man.rems. If we consider that the total quantity of caesium-137 which was released into the atmosphere and settled on the earth's surface after the Chernobyl' accident is estimated at $1.0 \cdot 10^6$ Ci (see Sections 4 and 5) and taking into account the fact that about 10% of the caesium isotopes released fell over the Ukrainian and Byelorussian Poles'ye area, the collective dose for the population for a period of 70 years after the accident is $2.1 \cdot 10^8$ man.rems. This may lead to an increase in the cancer mortality rate not exceeding 0.4% of the natural mortality rate from malignant neoplasms. When the actual coefficients for the transfer of caesium isotopes to the food chain have been clarified for the specific soil conditions of the contaminated regions, it may be possible to make corrections to these estimates which would to reduce them.

With regard to the strontium-90 content in foodstuffs, the data so far obtained have been only isolated and not sufficient to make any corrections to the estimates. With time, it is possible that this nuclide will be of basic significance together with caesium-137. On the whole, the strontium-90 content in food products from the 1987 harvest will obviously be considerably reduced. In the Poles'ye soil region, the reduction in the role of strontium-90 by comparison with caesium-137 will be more significant.

30%

However, it will be possible to forecast the levels of the strontium-90 content in food in the next few years only after a fuller study of the strontium-90 content in the soils of the contaminated areas of the USFSR, the Ukrainian SSR and Byelorussian SSR.

Thus, an accurate evaluation of the dose burdens for the population resulting from the consumption of locally produced food products contaminated with caesium-137 and strontium-90 will be possible only after the actual transfer coefficients of radionuclides along the food chains have been established for these regions. This work being carried out by the country's various scientific subdivisions will enable recommendations to be made regarding the optimum methods of agricultural management in the zone of radioactive contamination in terms of the formation of dose burdens for the population.

7.3. Organization of medical examinations of the population from the regions around the Chernobyl' plant

Following the accident, 84 000 people including 18 350 children were evacuated from the town of Pripyat' and the Chernobyl' region. In addition there was a further evacuation from populated areas in the Kievskaya and Zhitomirskaya regions.

In order to provide medical care for those evacuated during the first few days after the accident, 450 brigades made up of doctors, nurses, assistants and health physicists were mobilized and provided with ambulances. In all (taking into account rotations related to the radiation conditions) 1240 doctors, 920 nurses, 360 doctors' assistants and 2720 assistants with secondary school education, 720 students from medical institutes of higher education and also a large group of members of Scientific Research Institutes.

After personnel decontamination all those evacuated were examined by doctors and compulsory dosimetric monitoring and laboratory blood tests was carried out. Where necessary, the examination was repeated.

All those evacuated from the 30-kilometre zone who showed any irregularities in their health requiring further examination were hospitalized in special sections set up at central regional hospitals.

In order to provide medical care for workers involved in eliminating the consequences of the accident, a polyclinic with four 24-hour first-aid brigades was set up in Chernobyl' based on the central regional hospital.

Special attention was given to the examination of children from the 30-kilometre zone and also to selected children living in populated areas close to the 30-kilometre zone (a total of about 100 000 children were examined).

7.4. Long-term programmes for the medical and biological monitoring of the population and personnel

Long-term programmes are being established for the medical and biological monitoring of the population and personnel.

The measures taken to provide medical care for those who have been exposed to radiation resulting from the accident at the Chernobyl' plant include: the establishment of a register of all those exposed to radiation; the grouping of those exposed in order to determine the volume of medical care required; measures to organize and provide the necessary volume of medical care.

The purpose of the register is to study the possible consequences of the radiation effects on all those who were exposed and to ensure purposeful medical surveillance appropriate to the expected effect resulting from the range of doses involved.

The effects of low dose total external exposure will be analysed in terms of the stochastic effects (incidence of infectious diseases, incidence of and deaths from malignant tumours, birth-rate, state of health of children who are born), and the neuro-psychological aspects of the reaction to the situation.

A special study will be made of the functioning of the thyroid gland and over extended periods the frequency of development of adinomas and malignant neoplasms.

The whole study will be based on the dynamic characteristics of the background level of the above parameters in the regions where those examined originally lived and also in the places of evacuation. The volume of examinations will be determined on the basis of international and national recommendations regarding the possible biological effects (UNSCEAR, ICRP and others).

The criteria used in examining the general state of health of those involved will be based on the data from therapeutical examinations and the detailed clinical blood analyses. All women will be examined by a gynaecologist and the children by a paediatrist who will provide data on their physical development in accordance with Soviet regulations. In dose ranges presenting even minimal risk of dysfunction of the thyroid gland this examination will be complemented by special dynamic observation of the endocrinology of the thyroid gland using hormones - thyroxine, triiodothyroxine, thyroid stimulating hormone and others.

The increased frequency of the risk of mortality from cancer as a result of the radiation effects (from fractions of a percent to several percent) can be estimated only if data are available for a very large population.

In view of this, the register will include all those who were residing or staying in the area, the organized groups involved in dealing with the accident and its consequences, their children and grandchildren and also those evacuated from the contaminated regions.

The register consists of registration and dosimetric charts for each of those examined.

The registration chart includes the following information: surname, forenames, passport details (passport series and number or birth certificate, date of issue of the document) date of birth, place of birth, sex, nationality, place of residence, whereabouts during the period of the radiation action, duration of the action, anamnestic information about the state of health, pregnancy at the beginning of the action (period in weeks) and occurring after the beginning of the action, data about the child, cause of death (adults, children, babies) measures taken (hospitalization, iodine prophylactic treatment).

The dosimetric chart records the sanitary characteristics of the region and the degree of radiation effect on the individual (contamination of clothing, shoes, skin before and after decontamination in μR/hour).

The chart includes data on the iodine-131 content of the thyroid gland which is a dosimetric parameter for clincial investigation of those being examined and also data on personal dosimetry (measurement of biosubstrates using whole-body counters and other instruments).

Local health authorities are completing the registration and dosimetric charts. The completed charts are sent to the Ministry of Health of the Republic concerned and to the Ministry of Health of the USSR. Apart from the registration charts, all the infomation is entered in a registration journal which is kept at the place of examination.

The grouping of people who were exposed (or who may have been exposed) as a result of the accident at the Chernobyl' plant on 26 April 1986 requiring appropriate medical care is based on the principle of differentiation in terms of the whole-body dose and the dose to the thyroid gland. All the dose gradients are given for adults and these doses should be reduced by a factor 10, for children up to the age of three and for pregnant women.

The frequency of examinations is based on the results of the first examination and the estimate of dose level. The prophylactic treatment and protection measures are taken into account (iodine prophylactic treatment, evacuation, limitation of intake of radioactive substances through the respiratory and the alimentary tracts).

The above examinations are in addition to the medical surveillance provided for the whole Soviet population.

The programme envisages increasing the number of experts in various professional disciplines. An estimate is being made of the time spent, the technical equipment, the algorithm and software support and the computer work involved in carrying out these measures. The clincial data will be interpreted in the light of material on the dynamics of the environmental contamination, characteristics of the isotopic composition and the iodine prophylactic treatment administered. It is planned to set up simulation models and survey prognoses of the expected variants of late stochastic consequences (oncological effects, genetic influences) for the next 30 years and for a lifetime (50 years).

A collection and accumulation of information about the oncological and genetic aspects of morbidity among the population maybe established to be used in the event of a similar accident situation.

The prepared programmes take account of the experience of other countries (the Three Mile Island programme; the IAEA meeting in Yugoslavia and so on).