資料 2-11

旧ソ連核実験場セミパラチンスク近郊の被曝線量再構築と健康影響調査

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Late effects of exposure to ionizing radiation

— Studies of the resident population in the Semipalatinsk area —

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FOREWARD

Approximately half a century has passed after the first atomic bomb was exploded at the Semipalatinsk nuclear test site in the former USSR. After this explosion, several hundreds other explosions of the atmospheric and underground types were made, including the most powerful and dangerous explosions of hydrogen bombs. Several hundred thousand people in the Kazakhstan Republic and Russian Federation were exposed to various doses of ionizing radiation. Three generations of the exposed are now available for epidemiological and clinical studies. Even now, thousands of exposed people are battling diseases caused by radiation.

Our knowledge of late effects of radiation exposure derive from different sources,including studies of A-bomb survivors in Hiroshima and Nagasaki, studies of the exposed in nuclear plant accidents (in particular, the disaster at the Chernobyl nuclear facility in 1986), studies of the radiation-exposed in nuclear tests made in various parts of the world (for example, investigation of Marshall islanders), studies of people who received iatrogenic exposure, including diagnostic radiological examinations and some kinds of radiological treatment, and finally, studies of nuclear power plant workers and miners. Numerous comprehensive reports have been published concerning the late effects of radiation on the human body, including an excellent book "Genbaku Hoshasen no Jintai Eikyou 1992" (Effects of A-bomb Radiation on the Human Body"). However, any other additional sources of information on late effects of radiation exposure are of some interest. This report was made in order to fill in blanks in the information concerning of people exposed in the Semipalatinsk area in hundreds of nuclear tests. It may be of particular interest because of the peculiarities of the population under study. These peculiarities include cultural, social and diet differences, especially lack of vitamins and proteins in the diet of those exposed in the Semipalatinsk area.

The authors of this report well understand that some of their published data will seem very unusual to a reader acquainted with western scientific medical literature. Some of our investigations depart much from the usual epidemiological and clinical standarts. However, we hope that the reader will realise the limited capacity of scientists who have lived and worked for decades in the former USSR, a country cut off by the "iron curtain" from western scientific medical literature. We hope that our reader will be benevolent; for we have only the data that we have. We also hope that this report will be useful in increasing the realization of the harmful effects of radiation exposure on human health.

Chapter 1 Dosimetry

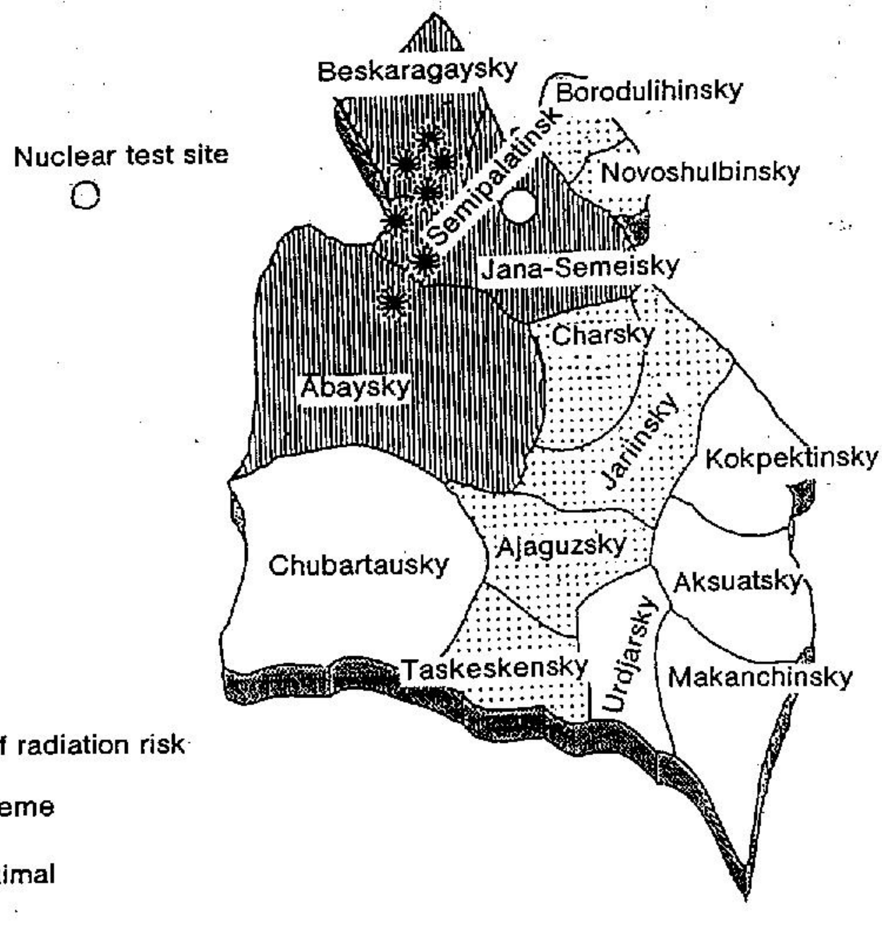
1. Studies of radioactivity produced by nuclear tests at the Semipalatinsk nuclear test site

The brief historic review

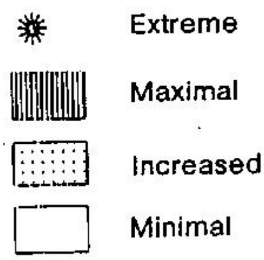
In 1949, on the left bank of the Irtish River, 150 kilometers away from Semipalatinsk, construction of a nuclear test site was completed. And over the whole period that tests were made (from 1949 to 1989) control of radiation doses was exercised by the USSR Defense Department. There were no alternative control by another department or institution.

In 1957, by the order of the Health Minister of the former USSR, a special medical institution of the secret type, "Dispensary N4" was opened. In order to hide from the population the real aims of this institution, which were investigation of the health of the residents living near the nuclear test site and measurement of radiation exposure doses, it was named "Antibrucellosis Dispensary". But during the whole period, that this Dispensary was in existence, from 1957 to 1991, not a single patient with real brucellosis, a sort of special infectious disease, was treated at this institution. Until 1991 the staff of the Dispensary was too inexperienced to achieve the goal of radiation dosimetry; during almost 20 years, the staff of the Dispensary (who conducted medical investigations of the exposed population) used in their work the parameters of only two atmospheric explosions, made in 1949 and 1953, calculated according to the methodology of the Defense Department.

Figure 1. Semipalatinsk region



Picture I. Zones of radiation risk



On February 12, 1989 the last underground nuclear explosion was made at the Semipalatinsk nuclear test site. One day after the explosion, in Chagan village, about 100 km away from the nuclear test site, an abrupt increase of radiation level was confirmed. The level was 150-200 times higher than the usual background level. This situation was not unique for high military officials. The cause was leakage of inert radioactive gases, xenon and krypton, from a crack. A radioactive cloud of these gases mixed with air after some hours came to the populated areas of Jana-Semeisky district and Beskaragaisky district (figure 1), and the dose equivalent of the population just from this explosion ranged from 0.03 to 0.05 mSv. How dangerous was it? The natural radiation dose per year is considered to be about 1 mSv (Hoshi M., 1993), so the population received, just from a single explosion, addition of 3 to 5% to their annual dose.

The nuclear explosion was the last one at the Semipalatinsk nuclear test site. It was the last case of radiation exposure of the population living around this area. From the historical point of view, it was this explosion, that gave rise to the struggle for prohibition of nuclear explosions at the nuclear test site near Semipalatinsk.

In 1992, by the insistance of the government of the Kazakhstan Republic, the Defense Department of the former USSR prepared a special report on the radiation exposure doses of the populations of 4 regions of the Kazakhstan Republic. The parameters were calculated based on previously secret technical data for 97 atmospheric and 26 on-the-ground nuclear explosions. The above mentioned report gave the doses of external and internal irradiation and also their totals for the population of 711 areas in Semipalatinsk, Pavlodar, Karaganda and East Kazakhstan regions of the Kazakhstan Republic. It must be note that in this report the exposure doses are much higher than the officially reported doses, given previously to the USSR government as a top secret document (1962).

The experience of exposure to ionizing radiation of the population, living around the Semipalatinsk nuclear test site is unique. The 87 atmospheric, 26 on the ground, and 346 underground nuclear explosions, officially reported (the exact number is unknown to date), were the cause of considerable exposure and contamination of the soil with radioactive substances of vast territories of the Kazakhstan Republic, including its Semipalatinsk, East-Kazakhstan, Pavlodar and Karaganda regions, and the Altaisky region of the Russian Federation. Approximately one million people were exposed to repeated acute and chronic irradiation with various ionizing radiation doses.

.1. Period of atmospheric and on-the-ground explosions (1949-1963)

On August 29, 1949, 7^{00} a.m. the first atomic bomb explosion in the USSR was made at the Semipalatinsk nuclear test site. The altitude of explosion was 38 meters above the ground (military experts said "on the table"), and the energy released was equivalent to 20 kilotons of TNT. Wind velocity was 45-50 kilometers per hour. Two hours after the explosion a huge radioactive cloud came to the large populated areas of Budene, Dolon, Tcheremushki, Mostik, Malaya Vladimirovka, Bolshaya Vladimirovka, Kanonerka and others. The distance from the hypocenter to these populated areas was 70-120 kilometers. The doses of irradiation on the ground in some populated areas because of radioactive fallout were millions of times higher, than the natural level, because of radioactive fallout. The maximal doses of gamma-rays on the ground in Tcheremushki and Dolon villages were more than 200 roentgen because of the fallout. The data on external gamma ray doses in the populated areas of Dolon, Tcheremushki and Mostlk are shown in the table 1. 1.

able 1. 1. The dynamics of formation of doses of external irradiation in populated areas of Dolon, Cheremushki, Mostik (after atomic bomb explosion in 1949)

	Time after beginning of exposure (days)					Total accumulated dose
	1	7	30	90	365	
the open (cGy)	81	130	160	170	190	200
or population (cSv)	60	96	120	130	140	160

Significant values of exposure are evident. The population received 64% of the dose during the first week after e explosion, 85% of the dose during the first three months. The level of radioactivity from the fallout 3.5 years ter the explosion was higher than the background level.

The data on internal radiation exposure of the residents of the same populated areas from intake of the radionuclides from this explosion with food and water are shown in the table 1. 2.

Table 1. 2. Internal irradiation doses from intake of radioactive substances with food and water (cSv)

(after atomic bomb explosion in 1949)

Time after irradiation (days)	7	30	90	365	50 years
Thyroid gland	62	110*	130*	130*	130*
Digestive tract	7	8	11	13	13

Note: * - Tissue doses to children's thyroid are 5-10 times greater because of higher milk consumption

It is evident that due to the radioactive fallout and intake of radionuclides the thyroid glands of the population were exposed to significant doses, mainly from radioactive iodine. The doses to the digestive tract and the skeleton were significantly less. However, using a screening coefficient of 0.6 the tissue doses were found to be about 240 cGy to the bone marrow, 100 cGy to the digestive tract, and 300 cGy to the thyroid gland.

The extremely harmful effects of this explosion to the residents of the area are attributable to two factors. First, the explosion was made practically on the ground, "on the table," and, as a result, a huge radioactive cloud formed. Second, the explosion was made at 7^{00} a.m., when almost all adults of agricultural region were out harvesting their crops, and when the cloud came to the villages at 9 a.m., they had no shielding, with only open fields around them.

The yield and danger of the radioactive cloud were so high that even 6 cities and 26 districts in the Altaisky region of Russian Federation situated 500-1000 kilometers from the nuclear test site, were exposed. The radioactive track of this explosion (1949) was the reason for forming two zones of radiation exposure risk: zone A, with a dose equivalent of the exposed population ranging from 35 to 100 cSv, and zone B with a dose equivalent less than 35 cSv. These zones are in the Altaisky district of Russian Federation, several hundred kilometers away from the Semipalatinsk nuclear test site.

There are also documents giving evidence of the occurrence of acute radiation sickness in some exposed people. In the Beskaragaisky district radiation skin burns were reported among the residents exposed when radioactive cloud came over their areas.

Four years after the first atomic bomb explosion on August 12, 1953, the first hydrogen bomb was exploded in USSR. The altitude of explosion was 1 kilometre, the yield of the bomb was 470 kilotons, and the wind velocity was 80-85 kilometres per hour.

Taking into account the enormous danger of future hydrogen bomb explosion to all living creatures, the government and the headquarters of the nuclear test site took some measures for radiation safety. Most important among them was the evacuation of the population from the supposed areas of radioactive fallout to the so called "safe zones". For three days, the populations of small and large villages were evacuated from a "corridor" 120 kilometers wide, extending from the hypocenter of explosion in the direction of the supposed movement of the radioactive cloud southeasterly to Karaul village, the centre of Abaisky district. But the "experiment" was not conducted, as it was supposed to be. The wind velocity in reality was 2 times higher, than it was supposed to be (40-45 kilometres per hour), and the direction of the wind also was not what it was supposed to be. Three hours after the explosion a huge radioactive cloud came over those villages and populated areas that were not expected to be contaminated, and also over Karaul village, to which the population had been evacuated. The official data shows that the population was not evacuated when the radioactive cloud appeared over Karaul village, to which the population had been evacuated. As the result, 191 people were exposed to huge dose of radiation.

All areas of Abaisky, Jana-Semeisky, Abralinsky and some Tchubartausky districts in the Semipalatinsk region were contaminated by the radioactive fallout. At the time of evacuation of the population (9 - 19 days after the explosion), the rate of gamma irradiation in Sarjal, Kainar, and Karaul villages, Kizil-Tu and some other populated areas was 40-60 milliroentgen per hour. The total doses of external radiation exposure were calculated taking into account this data. They are shown in the table 1.3.

Table 1. 3. The dynamics of dose formation (external X-ray exposure) for the residents of some populated areas in Abaisky district

(after H-bomb explosion in 1953)

	Time after beginning of irradiation (days)					Total accumulated dose
	1	7	30	90	365	
In the open (cGy)	1	8	23	43	54	
For population (cSv)	1	6	17	32	40	42

The main part of the dose of external radiation exposure to the population of some populated areas in Abaiski district was received during one year. Considering the case of the evacuated population after the said H-bomb explosion, they were exposed to 2% of the future total radiation exposure dose on the first day, 15% in the first week, and 41% in the first month.

The doses of internal radiation exposure are shown at the table 1.4. As is evident from the presented data, the irradiation of internal organs and bone tissues of the population, evacuated to "safe" zones was less than that of those who were not evacuated, especially in comparison with the explosion of the first A-bomb in 1949. Taking external irradiation and shielding coefficient (0,6) into consideration, the tissue doses were equal: 215 cSv to bone marrow, 150 cSv to the digestive organs, and 130 cSv to the thyroid gland.

Table 1. 4. Tissue doses from incorporated radioactive substances (ingested with food and water) of the population of some populated areas (cSv)

(after H-bomb explosion in 1953)

	Time after beginning of irradiation (days)				50 years
	7	30	90	365	
Skeleton	0.1	1	1	1	1
Thyroid gland	2	13	18	18*	18*
Digestive tract	1	3	5	7	7

Note: * - Tissue doses to children's thyroid gland are 5-10 times greater because of higher milk consumption

It must be emphasized that only a part of the population of the Abaisky district was evacuated. Residents of other districts were not evacuated. Both the explosion, made in 1949 and that made in 1953, were conducted in the late summer, crop-harvesting season, when almost the entire adult population of rural areas worked in the fields from early morning, just after the dawn, to late evening. The conclusion is that the external radiation exposure doses were almost equal to the doses in the open.

Unfortunately, we have no data on the radiation exposure doses of the population from the atomic bomb explosion of 1951.

Hundreds of other explosions were made after 1953. Therefore, the population of the Semipalatinsk region were exposed to excessive doses of ionizing radiation during the whole period of testing at the Semipalatinsk nuclear test site (1949-1989 years). The data on the total radiation exposure doses for this period and later (from 1949 to 1992) are shown in the table 1. 5.

Because of nuclear testings all the areas of the Semipalatinsk region were contaminated by radioactive substances. The minimal dose on the ground was 500 milliroentgen. The highest dose of radiation exposure in the populated area of Tailan was as high as 1000 Roentgen!

Officially reported doses in the open and calculated doses from the fallout show that they constitute a significant dose equivalent for the population in the Semipalatinsk area.

Absence of alternative (besides military experts) control of some parameters of radiation exposure and some antihuman laws, which permitted an annual dose to the population of up to 50 cSv, were the reasons of not carrying out any measures for the protection of the population from exposure to ionizing radiation.

Table 1. 5. Data on external, internal and total radiation doses of the population at the Semipalatinsk nuclear test site (list of populated areas) for the whole period of nuclear explosions

(from 1949 to 1992)

Name of populated area	The doses, cSv		
	External	Internal	Total
	SEMIPALATINSK REGION		
	Abaisky district		
1. Akbar	8.44	12.0	20.44
2. Akbulak	8.9	16.0	24.9
3. Aktogai	66.7	96.0	162.7
4. Eshkislgen	11.5	21.0	32.5
5. Jaima	22.8	32.0	54.8
6. Zagotskot	50.2	73.0	123.2
7. Zulkarash	39.5	55.0	94.5
8. Kainar	27.1	41.0	68.1
9. Karakorik	232.4	270.0	502.4
10. Karaul	35.7	52.0	87.8
11. Sarjal	116.3	130.0	246.3
12. Nurlan	12.6	18.0	30.6
13. Oljabai	16.0	23.0	39.0
14. Ashisu	5.5	9.4	14.9
	Beskaragaisky district		
1. Bodene	167.9	180.0	347.9
2. Dolon	217.4	230.0	447.4
3. Jana-Kush	95.3	96.0	191.3
4. Kanonerka	84.0	95.0	179.0
5. Kara-Togai	10.8	38.5	49.3
6. Kizil-Kuduk	55.1	82.0	137.1
7. Solprom	115.7	125.0	240.7
8. Chagan	54.1	58.0	112.1
9. Cheremushki & Mostik	115.2	110.0	225.2
10. Malaya Vladimirovka	11.1	14.1	25.2
	Aksuatsky district		
1. Aksuat	6.9	24.0	30.9
2. Bazarka	5.0	17.0	22.0
3. Egindibulak	6.2	20.0	26.2
4. Jdanova collective farm	7.2	25.0	32.2
5. Kokjira	7.6	26.0	33.6
6. Koktyubek	6.3	22.0	28.3
7. Kiziljuldiz	6.6	23.0	29.6
8. Serektas	7.5	26.0	33.5
9. Chapai	5.6	19.0	24.6
10. Shetbogas	6.9	22.0	28.9
11. Shibindi	5.6	19.0	24.6
	Ayaguzsky district		

1. Biesimas	14.1	44.0	58.1
2. Enkerei	17.6	38.0	55.6
3. Issari	10.5	33.0	43.5
4. Kairakti	13.4	42.0	55.4
5. Karasu	6.8	16.0	22.8
6. Sartarka	13.9	44.0	57.9
7. Topar	6.3	14.0	20.3
8. Chubartas	8.7	28.0	36.7
	Borodulihinski district		
1. Korosteli	102.2	140.0	242.2
2. Baitanat	4.6	6.1	10.7
3. Meshanka	40.8	50.0	90.8
4. Stepanovka	25.3	37.0	62.3
	Jarminsky district		
1. Erenkey	15.9	33.0	48.9
2. Ushbiik	12.8	28.0	40.8
	Jana-Semeisky district		
1. Znamenka	21.7	40.3	62.0
2. Sherbakovka	6.6	5.3	11.9
3. Tasbulak	4.3	5.1	9.4
4. Sartagai	2.8	12.8	15.6
5. Repinka	12.9	14.0	26.9
6. Musa	11.7	0.5	12.2
7. Kospak	4.1	5.1	9.2
8. Kuldai	13.2	13.9	27.1

EAST-KAZAKHSTAN REGION

	Glubokovsky district		
1. Belousovka	10.2	21.0	31.2
2. Gerasimovka	10.2	21.0	31.2
3. Kazachye	6.1	12.0	18.1
4. Novoyavlenka	10.2	21.0	31.2
5. Opitnoye Pole	10.1	21.0	31.1
6. Praporshikovo	10.2	21.0	31.2
7. Ukrainka	6.1	12.0	18.0
8. Ushanovo	3.5	7.7	11.2
	Zaisansky district		
1. Voroshilovo	2.3	9.1	11.4
2. Jambul	2.3	9.1	11.4
3. Dairovo	2.5	9.5	12.0
4. Jirishkesu	2.3	9.1	11.4
5. Karabulak	2.5	9.7	12.2
6. Karatal	2.3	8.9	11.2
7. Taskuduk	2.5	9.7	12.2
8. Satbai	2.9	11.0	13.9
9. Oktyabrskoye	2.6	8.6	11.2
	Tavrichesky district		

1 . Jantai	4.2	8.0	12.2
2 . Menovnoye	3.5	7.5	11.0
3 . Mitrofanovka	7.3	12.0	19.3
4 . Stepnoye	4.3	7.7	12.0
5 . Uzunbulak	3.1	6.0	9.1
		Tarbagataisky district	
1 . Akjar	3.4	13.0	16.4
2 . Bakai	3.5	12.0	15.5
3 . Sholakarda	5.2	19.0	24.2
4 . Sharga	3.9	14.0	17.9
5 . Sariolen	3.4	13.0	16.4
6 . Kizilkaiin	3.6	13.0	16.6

It is well known at present that the main aim of the Semipalatinsk nuclear test site staff was to investigate the early and late effects of radiation exposure in human beings, as radiation is believed to be one of the principal "defeat factors" in any "potential future nuclear war".

There are 3 different possibilities of radiation exposure of the resident population of the Semipalatinsk area due to the nuclear tests :

1 . Acute external gamma-ray exposure from radioactive clouds coming over the populated areas. Such a "model" was rare . This type of exposure took place only in some populated areas where luckily there was no radioactive fallout.
2 . Acute external gamma-ray exposure from radioactive clouds coming over the populated areas combined with fallout and subsequent chronic radiation exposure (internal type) from intake of radionuclides with food, water and inhaled air. This "model" was most often true for atmospheric nuclear explosions.
3 . Chronic internal irradiation due to intake of radionuclides with food and water. This model of irradiation was usual for those residents who entered the exposed populated areas after a period of atmospheric nuclear explosions (after 1963).

After 1963, 2 additional atmospheric explosions, actually were made, despite of official declaration of prohibition of atmospheric testing. In January 1965, a so-called "underground" nuclear explosion with soil excavation was made near the confluence of 2 rivers, the Ashisu and the Chagan. The aim of this explosion was to make a crater and embankment for an artificial lake, a so called "experimental artificial reservoir". After this explosion a powerful radioactive cloud formed. It's altitude was low. Because of this cloud, vast territories of the Jana-Semeisky and Beskaragaisky districts were exposed to additional radiation. The doses on the surfaces of the ground in the populated areas of Znamenka, Isa, Sarapan, Terestambali, and Delbegetei were as high as 20-30 Roentgen. The dose equivalent of the population due to this explosion was from 10 to 20 rem (cSv). Documents remaining revealed that thousands of domestic animals (horses, sheep, cattle) were exposed to excessive doses, epilated and died of acute radiation sickness after this explosion. Cattle, horses and sheep were kept at places 1.5 - 2 kilometers from the hypocentre deliberately - in order to study the acute effects of radiation exposure.

A huge radioactive cloud also formed due to an accident that occured at the time of the underground nuclear explosion in May,1974. The doses of radiation the population of some areas were exposed to after this explosion were 5 to 10 cSv, and the doses received in the open were more than 10 - 15 Roentgen.

Together, these data allow us distinguish 4 different zones of radiation exposure (so-called "radiation risk zones"). A description of these zones is given below:

1 . The zone of extreme radiation risk comprising 15 populated areas, where radiation doses in the open were more than 200 Roentgen and the dose equivalent was more than 100 cSv (502.4 cSv in Karakorik village, 447.4 cSv in Dolon village, 246.3 cSv in Sarjal, 242.2 cSv in Korosteli, 240.7 cSv in Solprom, 225.2 cSv in Tcheremushki and Mostik, 191.3 cSv in Jana-Kush, 179.0 cSv in Kanonerka, 162.7 cSv in Aktogai, 160.0 cSv in Isa, 150.0 cSv in

Sarapan, 137.0 cSv in Kizil-Kuduk, 123.2 cSv in Zagotskot, 112.1 cSv in Chagan).

2. The zone of maximal radiation risk comprising populated areas within the Abaisky, Abralinsky, Beskaragaisky and Jana-Semeisky districts of the Semipalatinsk region. The estimated dose equivalent of the population was 35 to 100 cSv (for example, 94.5 cSv in Zulkarash village of Abaisky district, 87.7 cSv in Karaul, 68.1 cSv in Kainar, 49.3 cSv in Kara-Togai village of Beskaragaisky district, 62.0 cSv in Znamenka village of Jana-Semeisky district).
3. The zone of increased radiation risk comprising the populated areas of 6 districts in the Semipalatinsk region (Tchubartausky, Novo-Shulbinsky, Borodulihinsky, Charsky, Jarminsky, Ayaguzsky) and Semipalatinsk city itself. The radiation doses of the population at these areas ranged from 7 to 34.9 cSv.
4. The zone of minimal radiation risk, comprising 5 most distant districts of the Semipalatinsk region (Makanchinsky, Urdjarsky, Taskeskensky, Kokpektinsky and Aksuatsky). The dose equivalent of the population of this radiation risk zone was less than to 6.9 cSv.

To be sure, the distinguishing of these zones is conventional. It is difficult to set any clear territorial borders for specific doses of external or internal radiation exposure. The "behavior" of radionuclides within the radioactive cloud is unknown as well as why radioactive fallout occured in territories very far from the hypocenter of nuclear tests, for example, 1000 kilometres away in Altaisky region of the Russian Federation, after the A-bomb explosion of 1949.

1.2. Period of underground nuclear tests (1963-1989)

One of the main peculiarities of radiation exposure of the resident population of the Semipalatinsk area was that there were 2 possible sources of exposure:

1. Radioactive fallout on the ground, accumulated in the period when atmospheric explosions were made.
2. Radioactive clouds coming after occurrence of some accidents during underground nuclear explosions. According to official statements of experts of the former USSR Defence Department, 346 underground nuclear explosions were made at the Semipalatinsk nuclear test site from 1963 to 1989. It was reported, that after 30% (or about 100-125 of those explosions) the radioactive inert gases xenon and krypton came out into the open and formed radioactive clouds. In a number of cases currents of gas mixed with air reached some populated areas of the Semipalatinsk region and Semipalatinsk city.

In 1963 control was exercised over the parameters for radioactive fallout in Semipalatinsk city and some other districts of the Semipalatinsk region. In 1967 and later, the concentrations of radioactive substances and their isotope spectra in the air were estimated. For the determination of the concentrations of radioactive substances in "near-the-surface" air, the method of filtration through the tissue FPP-15 was used. Air was filtered using an air-capturing device with a volume-velocity of current $6\text{-}8 \cdot 10^4$ litres per hour. Radioactive substancies were collected with the use of a horizontal case open on one side, which had two baths with a surface 0.3 m^2 each.

In the period from 1966 to 1981, 15 instances of contamination of the air by iodine isotopes were noticed. All resulted from the coming of radioactive clouds over the Semipalatinsk region. We consider that 11 cases were attributable to radioactive clouds after the atomic bomb explosions at the Semipalatinsk nuclear test site and that 4 others - the were due to nuclear explosions in the USA and China.

Some examples of appearance of radioactive gases in Semipalatinsk city are given below.

April, 1972

The concentration of the fallout was 10 times higher than the natural level - 31.5 microCurie/km^2 against 3.5 microCurie/km^2. The appearance of isotopes Zn95, Nb95, and Ru103 was registered.

April, 1974

An increase of radioactivity up to 1 micro Curie/km^2 was registered, whereas the radioactivity from the natural everyday fallout was 0.2-0.4 microCurie/km^2.

April, 1978

The total concentration of radioactive substances and the density of the fallout increased 1.5-4 times above the background level.

So-called "underground" explosions led not only to the appearance of "fresh" fission products in the air, but also to increased concentrations of some other isotopes, such as Zn95, Ru103, and Ce141, above the usual level.

A retrospective estimate of the radiation circumstances in the Semipalatinsk region (1965-1989) would not be complete without calculating the contribution of the parameters of the radioactive cloud to the dose equivalent of the population from the underground nuclear explosions conducted with soil excavation.

At the beginning of the 1960s "The programm for industrial use of underground nuclear explosions in the National Economy" was elaborated and worked out in the USSR. In the same period an analogous programm under the title "Plausher" was elaborated and worked out in the USA. A number of underground nuclear explosions with consequent soil excavation was made in both countries for these programms until 1970. The data on the yield and other parameters of this explosions are shown in the table 1.6.

Table 1.6. Some parameters of underground nuclear explosions with soil excavation

Country	Title of explosion	Date of explosion	Capacity (kilotonnes)	Depth of explosion (metres per 1 kt)	Size of a crater Radius m	Depth m	Altitude of a cloud km	Part of the radioactive substancies behind the embarkment (%)
USA	Jungl-1	1.29.1951	1.2	4.9	40.0	16.0	2.0	40
	Tunom-Ess	3.23.1955	1.2	19.5	44.5	27.4	2.4	35
	Neptun	10.14.1958	0.15	53.5	0.5	10.7	1.2	0.3-0.5
	Dni-Boy	03.05.1962	0.42	50.0	33.5	19.3	0.3	7.7
	Sedan	07.06.1962	100.0	50.0	183.0	97.0	4.0	7.3
USSR	1004	01.15.1965	224.0	41.0	205.0	100.0	4.5	21.5
	1003	10.08.1965	?	47.0	53.5	31.0	0.3	4.5
	Telkem-1	October, 1968	?	51.0	35.0	21.0	0.3	?

Besides these explosions simultaneous explosions of 5 line-situated cartridges of small yield were made in 1968 in the USA under the project "Buggy". The aim of these explosions (or "experiments") was to investigate the possibility of constructing the channels by excavating soil by nuclear explosion. A similar experiment was also carried out in the USSR in 1968 under the title "Telkem-2". All of these explosions were of the so-called "experimental" type. Reportedly, the population of the USA was not exposed to ionizing radiation from these explosions. But in the USSR the explosions were made near populated areas, of the Beskaragaiski district of the Semipalatinsk region. From the point of view of radiation safety the principal danger of underground nuclear explosions with soil excavation is the possibility of radiation exposure due to: 1. formation of radioactive clouds and their coming to populated areas, and 2. contamination of the environment by radioactive substances and their consequent intake.

Therefore, the levels of contamination and the doses of exposure depend on the amount of radioactive substances released into the atmosphere.

Whether the amount of radiation exposure is significant or not, depends on the parameters of the cloud. The "cloud" dose could be the principal dose constituting the total dose, if the altitude of the cloud is not high. According to K.I.Gordin (1967), the dose of radiation exposure from the cloud can be calculated by the following formula:

$$D\ cloud/D\ fall = 1.08e^{(2-4.7\ lghn)}\ (K+7.6)\,10^{2}$$

where hn — the altitude of the cloud (km)

R — the distance from the hypocentre (km)

Calculations made according to this formula showed that if the altitude of the cloud was less than 3 km, the principal part to the dose would derive from the cloud itself. But if the altitude was more than 3 km, the principal part of the dose formation would derive from the radioactive fallout.

It was determined that the basic source of internal irradiation of the population after underground explosions with soil excavation depended on the parameters of air contamination by highly toxic and easily biologically accessible radionuclides (Sr-89,I-131, I-133, I-135,Ba-140, Mo-99, Ag-111, Ru-106, Te-132 and others). The principal period of dose formation is the period of track formation. During this period, the concentration of radioactive substances in the air could be 10000 times higher than after track formation.

Underground nuclear tests are therefore quite dangerous for all living things, including human beings. If made near populated areas, the population would be in real danger of radiation exposure from low-spreading radioactive clouds and inhaled air contaminated with highly toxic radionuclides.

In 1987, the contamination density of Cs-137 in the Semipalatinsk region was 0.006 to 0.11 Ci per km^2. The rate of exposure to gamma-ray dose in air was 4.8 10^{-7} 2.14 milliroentgen per second or 0.0324 roentgen per year. Under this circumstances, the rate of absorbed dose in air was 0.028 cGy per year. The relationship of the rate of absorbed dose in air to the exposure dose was 0.028/0.0324 = 0.864. The rate of absorbed dose in air (if contamination density of Cs-137 was 1 Ci/km^2) would be 3.76 microrad per hour. In this case, the rate of exposure would be 4.35 microroentgen per hour. Using this coefficient, the rate of exposure to gamma-ray dose from Cs-137 contamination was calculated to be from 0.027 to 0.50 microroentgen per hour. Therefore, the additional dose contributed by Cs-137 to the background radiation dose from natural sources was no more then 3.3%.

The internal irradiation dose was estimated from the data on the specific activities of Sr-90 and Cs-137 in the diet of the residents of the Semipalatinsk region (tables 1.8 - 1.12), and the data on the average annual consumption of main food products in the diet of Semipalatinsk region residents (table 1.7).

Table 1. 7. Average annual consumption of meat and milk of the population of radiation risk zones (per day) for the period from 1981 to 1990

	Meat (kg)	Milk (l)	Bread (kg)	Water (l)
Adults	0.28	0.3	0.4	2.2
Children	0.14	0.6	0.2	0.9

Table 1. 8. Average radioactivity of Sr^{90} and Cs^{137} in beef (picocurie/kg)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}	3.4	4.5	7.4	8.1	11.1	11.1	12.4	12.6	13.1	13.4
Cs^{137}	13.8	17.5	10.9	4.9	4.0	52.8	30.0	12.5	16.5	14.3

Table 1. 9. Average radioactivity of Sr^{90} and Cs^{137} in milk (picocurie/kg)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}	11.2	8.9	5.8	12.7	11.4	8.4	13.8	13.4	16.2	15.1
Cs^{137}	5.7	5.2	4.1	2.1	1.5	105.0	13.9	6.8	11.3	12.1

Table 1. 10. Average radioactivity of Sr^{90} in cattle bones (picicurie/kg)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}	1189	622	459	611	981	2351	3081	3432	3531	3472

Table 1. 11. Average radioactivity of Sr^{90} and Cs^{137} in bread (picocurie/kg)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}	6.2	5.9	5.1	2.2	2.5	2.3	1.7	1.8	2.1	2.2
Cs^{137}	5.2	5.1	3.8	2.9	1.1	1.5	3.9	2.8	3.9	3.1

Table 1. 12.Average radioactivity of Sr^{90} in water (picocurie/kg)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}	—	—	—	—	0.65	0.57	0.59	0.65	0.53	0.56

Using all these data, we calculated the median annual intake of Sr-9O and Cs-137 of the population of the Semipalatinsk region (table 1.13) and of the population of the maximal radiation risk zone (table 1.14).

Table 1. 13. The median annual intake (with diet) of Sr^{90} and Cs^{137} of the population of Semipalatinsk region (nanocurie)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sr^{90}										
Adults	2.94	2.81	2.44	2.44	2.31	4.01	2.30	2.57	3.21	2.57
Children	2.39	1.98	1.79	1.90	2.53	2.57	1.71	1.96	1.84	1.51
Cs^{137}										
Adults	3.69	1.98	1.51	1.24	0.75	45.2*	20.2*	9.52	4.3	5.6
Children	3.59	1.52	1.21	1.10	0.72	53.3*	29.22*	2.9	17.3	14.5

Note: the increased levels in 1986-1987 could be explained by the fallout after the Chernobyl accident

Table 1. 14. The median annual intake of Sr^{90} with diet of the population of exposed area (nanocurie)

Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Adults	3.91*	2.98*	2.53*	3.37*	4.03	5.90	7.44	6.10	6.43	6.51
Children	3.80*	2.95*	2.22*	3.77*	3.84	4.78	5.94	3.72	5.81	3.92

* - without water

It was calculated, that the year equivalent dose of the bone marrow would be 3 cSv, if the intake of Sr-90 through the digestive tract is 0.32 microCurie per year, and that if the intake of Cs-137 through the digestive tract is 12 millicurie per year, the year equivalent dose of the whole body would be 0.5 cSv (Committee on ...., 1980).

Using these data, the year equivalent doses of the populations of the severely exposed districts (Abaisky, Abralinsky, Jana-Semeisky and Beskaragaisky) and the whole Semipalatinsk region were calculated from the intake of Sr-90 and Cs-137 with the diet (table 1.15).

The level of Sr-90 in the bone tissues of children would be 5 times higher than in the adult bone tissues even if the intake of radionuclides is equal. In this case, the dose equivalent of the children would also be 5 times higher (table 1.15).

Table 1. 15. Doses equivalent of skeleton of the population of the Semipalatinsk region and exposed zones (extreme and maximal risk) from intake of Sr^{90} and Cs^{137} with diet

Years	Dose rate, millirem/year			
	Exposed districts		Semipalatinsk region (whole)	
	Adults	Children	Adults	Children
		Sr^{90}		
1981	36.66	178.2	27.56	112.2
1982	27.94	138.3	26.34	92.8
1983	23.72	104.1	22.88	83.9
1984	31.59	176.7	22.88	89.1
1985	37.78	180.0	21.66	71.7
1986	55.31	224.1	37.59	120.5
1987	69.75	278.5	21.56	80.2

1988	57.19	174.4		24.09	91.9
			Cs^{137}		
1981	0.15	0.15			
1982	0.083	0.063			
1983	0.063	0.05			
1984	0.052	0.045			
1985	0.031	0.03			
1986	1.88*	2.22*			
1987	0.83*	1.21*			
1988	0.15	0.12			
1989	0.84	0.12			
1990	0.32	0.10			

Note: * - the increased levels in 1986-1987 could be explained by the fallout after Chernobyl accident

In table 1.16 the specific activity of Sr-90 in the bone tissues of urban and rural populations of the Semipalatinsk region is shown. One kilogramm of bone tissues contains 160 g of calcium. So, in order to obtain data on the concentration of Sr-90 in bone tissues, we must divide the specific activity of Sr-90 in the bone tissues by 160. The data are shown in "Sr units" (table 1.16).

Table 1. 16. Sr^{90} in bone tissues of urban and rural population of the Semipalatinsk region

Sr^{90} activity in the bones (skeletal tissues) of population				
Years	Urban		Rural	
	Picocurie/1kg bones	Sr-unit	Picocurie/1kg bones	Sr-unit
1981	159	0.99	76	0.48
1982	97	0.60	54	0.34
1983	157	0.98	168	1.05
1984	295	1.84	156	1.00
1985	183	1.21	144	0.98
1986	176	0.96	132	0.76
1987	221	1.31	138	0.75
1988	243	1.63	158	1.32
1989	295	1.84	299	1.91
1990	183	0.60	172	0.82

Table 1. 17. The activity of Sr^{90} in extracted teeth of Semipalatinsk city residents

Years	Activity in children		Activity in adults			
	5-13 years		14-20 years		>20 years	
	pCi/kg	Sr units	pCi/kg	Sr units	pCi/kg	Sr units
1983	1065	7.6	1038	7.4	714	5.1
1984	214	1.5	267	1.9	—	—
1985	185	1.3	175	1.2	160	1.1
1986	270	1.9	—	—	149	1.06
1987	228	1.6	227	1.6	191	1.35
1988	216	1.5	—	—	117	0.84
1989	234	1.7	234	1.6	182	1.31

The specific activity of Sr-90 in the extracted teeth of Semipalatinsk city residents is shown in the table 1.17. One kilogramm of teeth contains 282 g of calcium; thus, the coefficient for calculation of the activity of Sr-90 in bone tissues from teeth is 0.5. Using these parameters, the average dose equivalent of the bone tissues of the Semipalatinsk region residents were calculated. It was established that if the concentration of Sr-90 in the bone tissues is 2 milliCurie, the average annual dose equivalent would be 30 cSv. The usual amount of calcium in the bone tissues of a standard man is 1000 g. So, the dose to bone tissues can be calculated as being 30 cSv per year if the concentration of Sr-90 in the bone tissues is $2 \cdot 10^6$ picocurie/skeleton 10^3g (calcium/skeleton) and equal to $2 \cdot 10^3$ strontium units (Sr/u). Accordingly, 1 Sr/u can be a dose equivalent of 15 millirem per year. All of these calculations were used to gain the data shown in table 1.17. And, a decreasing tendency of median annual dose equivalent of the bone tissues (and, accordingly, of the bone marrows) was evident in the observed population after 1983.

The median annual external exposure doses were measured using the dosimeters IFKU and IKS in 16 populated areas of maximal radiation risk (Figure 1). The data for the period from 1981 to 1988 are shown in table 1.18. Exposure year doses after substractioning the natural (background) radiation dose (the median figure for this zone is 0.12 roentgen per year) are shown. The results of direct measurements (table 1.19) show that the exposure doses from the fallout were not so high - 0.008-0.015 microroentgen per hour = 1051 milliroentgen per year.

Table 1. 18. Average dose equivalent of bone tissues of the population of Semipalatinsk city (based on analyse of samples from extracted teeth, millirem/year)

Years	Age groups (years)		
	5-13	14-20	>20
1983	114.0	111.0	76.5
1984	22.5	28.5	—
1985	19.5	18.0	16.5
1986	28.5	—	15.9
1987	24.0	24.0	20.3
1988	22.5	—	12.5

Table 1. 19. Exposure year doses of γ-ray irradiation in populated areas of control zone, after subtraction of background dose

Populated area	Dose of γ-ray irradiation (Roentgen) by year							
	1981	1982	1983	1984	1985	1986	1987	1988
1. Semiyarka	0.08	0.08	0.00	0.00	0.00	0.14	0.38	0.03
2. Grachi	0.05	0.05	0.00	0.27	0.00	0.07	0.25	0.02
3. Cheremushki	0.18	0.18	0.00	0.09	0.00	0.24	0.30	0.06
4. Mostik	0.11	0.11	0.00	0.00	0.00	0.22	0.34	0.03
5. Dolon	0.11	0.11	0.00	0.23	0.00	0.25	0.37	0.04
6. Belokamenka	0.08	0.08	0.00	0.07	0.00	0.10	0.15	0.05
7. Gluhovka	ND	ND	0.00	0.00	0.00	0.06	0.44	0.03
8. Beisen	ND	ND	ND	0.00	0.00	0.12	0.37	0.04
9. Sarapan	ND	ND	ND	0.05	0.00	0.21	0.37	0.03
10. Chinji	0.18	0.18	0.00	0.19	0.00	0.43	0.17	0.03
11. Gostinitsa	0.15	0.15	0.085	0.45	0.36	0.25	1.00	0.08
12. Sarjal	0.18	0.18	0.00	0.21	0.00	0.26	0.42	0.05
13. Jarik	ND	ND	0.00	ND	0.00	0.02	0.02	0.05
14. Bolshaya Vladimirovka	ND	ND	0.00	0.21	0.00	0.17	0.12	0.03

15. Kanonerka	ND	ND	0.00	0.27	0.00	0.01	ND	0.04
16. Semipalatinsk	0.085	0.085	0.00	0.00	0.00	0.13	0.04	0.03

Note: ND - no data

Therefore, the main sources of exposure were the radioactive clouds coming over the populated areas. The influence of the "old radioactive tracks" was not so important in determining the total dose.

During the period of nuclear bomb explosions , the short-living radionuclides, i.e. Zr-95, Ru-103, Nb-95, Ru-106, Po-106, Ce-141, Ce-144 and others, were detected in the fallout (table 1.20) and vegetations (table 1.21).

Table 1. 20. Radioactive fallout in Semipalatinsk in 1981-1984 (Bq/m^2 per month)

Years	Monthes												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
				Sr^{90}									
1981	0.37	0.148	0.37	1.48	2.59	1.85	1.11	0.259	0.37	0.037	x	x	8.584
1982	x	x	x	0.074	0.74	0.74	0.592	0.333	0.74	0.296	x	0.111	3.626
1983	x	x	x	0.37	0.37	0.74	1.11	0.74	0.74	0.37	0.7	0.96	6.1
1984	x	x	1.48	x	x	x	0.36	0.37	1.11	ND	ND	x	3.32
				He^{96}									
1981	27.75	9.25	33.85	49.8	66.41	21.46	48.0	x	x	x	x	x	256.53
1982	x	x	x	x	x	x	x	x	x	x	x	x	x
1983	x	x	x	x	x	x	x	x	x	x	x	x	x
1984	x	x	x	x	x	x	x	x	x	x	x	x	
				Ru^{103}									
1981	10.58	8.69	18.88	10.37	22.42	10.66	40.0	5.51	9.4	9.065	x	x	152.212
1982	4.847	1.332	1.739	6.845	16.243	6.919	10.471	7.585	3.7	11.322	3.441	2.331	76.775
1983	x	x	3.219	2.96	24.901	10.841	11.137	7.441	6.66	10.25	5.77	1.67	84.549
1984	2.48	x	0.85	5.0	7.62	19.57	31.67	7.29	2.81	3.55	3.16	x	84.00
				Ru^{106}									
1981	x	x	x	20.57	23.12	x	13.06	x	14.25	3.00	6.29	12.77	93.06
1982	x	x	x	x	x	x	x	x	x	x	x	x	x
1983	x	x	x	x	x	x	x	x	x	x	x	x	x
1984	x	x	x	x	x	x	x	x	x	x	x	x	x

Notes: x - below detection;

ND - no data

Table 1. 21. Radioactive pollution of vegetation in 1981-1984 (Bq/kg)

		Activity of radionuclides						
Populated areas	Sample	Sr^{90}	Cs^{137}	Zr^{95} & Nb^{95}	Ru^{103}	Ru^{106}	Ce^{141}	Pz^{144}
Sarjal	hay	10-13	4.7	x				
grass	1.5-17	5-22	158	17-140	16	16		
Beryozka	hay	2-22	5-16	8.6				
grass	1-17	2-11	13	38	48	9.7		
Obali	grass	2-16	6-16	101	7-51	18-26	ND	59
Zaveti Ilicha	grass	2-39	3-37	10-384	12-161	14-64	ND	31-77
Yubileinaya	grass	3-22	11-25	38-139	16-65	10-22	ND	79
Sarapan	grass	2-26	5-32	29-334	11-23	18-70	ND	27-73

Beisen	grass	3-12	2.2-2.3	15	62	14-22	ND	ND
Chinji	grass	3-17	3-12	308	15-99	23	128	ND
Belokamenka	grass	1.5-6.85	ND	23.8	ND	ND	ND	ND
Vladimirovka	grass	1-14	3-14	31-55	5-42	15-18	ND	19-36
Kanonerka	grass	1-21	ND	20-28	8-23	9-33	ND	35
Dolon	grass	2.6-10.4	4.63-5.4	ND	4.44	ND	ND	ND
Mostik	grass	2-16	7.4-12	3.1	6-10	ND	ND	75
Cheremushki	grass	1.5-2.2	ND	90	6-24	13-24	ND	82.5
Grachi	grass	2-18	3-7.4	33.8	3.7-23	9.55	ND	ND
Semiyarka	grass	2-14	5-12.6	16-88	7.8-16	13-25	127	37.6

Notes: x - below detection; ND - no data

In the period from 1981 to 1990, the maximal meaningful gamma-ray doses were detected in 1987. These data were confirmed by the more severe pollution of vegetation. In a majority of the populated areas, the exposure dose of gamma-rays was 0.43 roentgen. This dose corresponds to absorbed dose in air of 0.43 0.864=0.3456 cGy. Because of shielding by tissues, the absorbed dose in the human body is 70% of the absorbed dose in air, or 0.3456 0.7=0.242 cGy. The RBE coefficient for gamma-rays is 1.0, so the dose equivalent of the whole body (for a person who is in the open) was 0.242 cSv. The coefficient of decrease of dose is 2.5 in a city, and 1.5 in the rural area. So, in 1987 the dose equivalent in 1987 from external sources of gamma-ray exposure of an urban population was 0.242/2.5=0.968 cSv, and that of a rural population was 0.242/1.5=0.161 cSv.

How much was it? According to the generally accepted opinion, the level of exposure to ionizing radiation from natural sources is approximately 0.1 cSv (Gofman J.W.,1981; Hoshi M.,1993). So, the population living in Semipalatinsk city received a 97% addition to the background dose from just the external gamma-ray sources. Military experts usually use the coefficient 1.8 for calculation of the dose of internal radiation exposure (Gusev B.I.,1993). In this case, the internal radiation dose would be 97%·1.8=174.6% from background level, and the total additional to the background level dose would be 97% + 174.6%=271.6% for the Semipalatinsk-city residents.

For the rural population, the same calculation gives 161% as additional exposure from external sources, 290% as exposure from the internal sources, for a total - addition of 451% to the background exposure.

The dose to bone tissues derived mainly from external radiation exposure and also from internal irradiation by nuclides (mainly Sr-90) taken in with the diet. The critical group for bone tissue (namely, bone marrow) exposure was the population of children under 7 years of age. The total dose equivalent of the bone marrow of children in the period of underground nuclear explosions was approximately 453 millirem per year.

The dose to the bare skin surfaces derived from contact with beta-emitters from the air sedimented to the skin when radioactive air streams came. The dose equivalent of the skin of Semipalatinsk city residents in the study period (from 1981 to 1990) was 413 millirem per year.

Most of the exposure dose to the thyroid gland derived from consumption of milk contaminated by I-131. The "critical" group for such exposure were children younger than 5 years. The dose equivalent of the thyroid glands was estimated after the accident occurred in May 28,1973. The dose equivalent of the children population from this accident alone was 970 millirem.

Therefore the main sources of exposure to ionizing radiation during the period of underground nuclear tests were:

1. Sr-90 intake with the diet
2. radioactive gases leaking into the atmosphere due to accidents
3. so-called "old radioactive tracks".