History of radiation and nuclear disasters in the former USSR

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Abstracts. The report describes the history of radiation and nuclear accidents in the former USSR. These accidents accompanied development of military and civilian use of nuclear energy. Some of them as testing of the first Soviet nuclear, Kyshtym radiation accident, radiation contamination of the Karachai lake and the Techa river, nuclear accidents at the Soviet submarine on August 10, 1985 in the Chazhma Bay (near Vladivostok) as well as nuclear accidents on April 26, 1986 at the Chernobyl NPP were of large scale causing significant radiological problems for many hundreds thousands of people. There were a number of important reasons of these and other accidents. The most important among them were time pressure by development of nuclear weapon, an absence of required financial and material means for adequate management of problems of nuclear and radiation safety, and inadequate understanding of harmful interaction of ionizing radiation on organism as well as a hypersecrecy by realization of projects of military and civilian use of nuclear energy in the former USSR.

Introduction.

The first nuclear reactor in the USSR reached the critical state on the 25 December 1946 [1] or 4 years later than reactor constructed by Enrico Fermi [2]. The first Soviet reactor was developed at the Laboratory N2 in Moscow (later I.V.Kurchatov Institute of Atomic Energy). This was a very important step in a realization of the Soviet military atomic program that began in September 1942. The Soviet intelligence service could receive in a previous year the secret information about the beginning of studies of the possibility to make a nuclear bomb in Great Britain and the USA [3]. As a result of an analysis of this information the Soviet government decided to begin similar activity in the USSR. On September 28, 1942 the Chairmen of the State's Council of Defense of the USSR I.V.Stalin signed the Decree N 2352, that had the title "On organization of the work on uranium" [3]. This decree ordered the Academy of Sciences of the USSR to set up a special laboratory for carrying out the necessary scientific work for development of nuclear weapon. The other decree of the State Council of Defense of the USSR appointed professor I.V.Kurchatov as a scientific supervisor of the Soviet uranium project and a head of a special laboratory named the Laboratory N2 of the Academy of Sciences of the USSR in February 1943 [3,4].

Construction of the reactor F-1 was accompanied by development of project of plutonium production on an industrial level. On March 23, 1946 the Government of the USSR issued a Prescription about construction of a special enterprise (Complex 817) for producing of fissionable materials for nuclear weapon as well as a city for employers of this enterprise [5]. The most important facilities of the Complex 817 were a plutonium-production reactor (Reactor "A"), a radiochemical facility (Facility "B") and a metallurgical facility (Facility "C"). The Complexs 817 and the city for its employers (the city Ozersk or

Chelyabinsk-40) had to be constructed in the South Ural (approximately 1200 km in east direction from Moscow) in the Chelyabinsk oblast (region) approximately 100 kilometers in northwest direction from the city Chelyabinsk and not far from the city Kyshtym .

The Complex 817 was renamed later as “Chelyabinsk 65” (“Chelyabinsk 40). Now it is known under the name Production Association “Mayak” or in short form as PO “Mayak” [6].

Up to the middle of 1949 the Complex 817 produced plutonium enough for development of the first nuclear device that was exploded at the Semipalatinsk Test Site on August 29, 1949 [1]. Its power was equal to 22 kiloton TNT [1,7].

The first Soviet nuclear device was made only 13 months after beginning of operation of the reactor “A” of the Complex 817. This was an outstanding achievement of the Soviet science and industry. However, this success was achieved by continuous disregard for environmental and public safety. Three specific radiation incidents that have their origin in the operation of Complex 817 or PO “Mayak” stand out even at present. They are: intentional dumping of radioactive wastes in the Techa river: an explosion at a radioactive waste storage in 1957 (Kystym accident); and a transfer of radioactive sediments from Lake Karachay in 1967 caused by a wind storm. These and other accident are described in more details in the present report.

Plutonium production reactor of the USSR

The first Soviet industrial reactor began its operation at the full power equal to 100 MW in June 22, 1948 [1]. It was constructed in Chelyabinsk oblast near the lake Kyzyl-Tash (Production Association “Mayak”). By construction of this reactor the Soviet specialists changed the arrangement of the active zone developed in the USA by construction of Hanford production reactors. They designed a vertical arrangement of the active core instead of the horizontal scheme used by American specialists. This was made in order to improve thermo-hydraulic parameters of the reactor.

The first Soviet production reactor was a heterogeneous thermal neutron channel-type reactor, in which graphite was used as the moderator and light water as the coolant. The reactor core took the shape of a vertical cylinder. The graphite stack consisted of blocks assembled into columns. They had axial openings into which the fuel channels were inserted. The total number of fuel channels was 1,200 [1]. The channels were made from aluminum. The aluminum alloy was also as a cladding material for fuel elements. The natural metallic uranium was used as a fuel. The water for cooling of the active core was taken from deep horizons of the lake Kyzyl-Tash [1]. It was then purified at a special chemical factory and led to the topic of the active zone. After passing of it, the water was brought back to the lake Kyzyl-Tash. As can be seen from here, the open cycle of cooling was used in case of the first plutonium reactor. The project plutonium output of this reactor was established as 36 kg for 1949 [1]. Plutonium that was produced by this industrial reactor was used for construction of the first Soviet atomic device [1,5,7]. In 1950 the second production reactor of the same type was constructed at the Production Association “Mayak” [8]. Later a number of other plutonium production reactors were constructed at the Production Association “Mayak” and at other weaponry facilities.

Table 1 presents information about plutonium production reactors constructed in the USSR. It can be seen from this table that tree different types of plutonium production reactors were used in the USSR: channel type reactors with natural uranium, graphite as a moderator, light water as a coolant; reactor of vessel type with enriched uranium and light water as moderator and coolant and heavy water reactor of vessel type. However, the main role in production of weapon-grade plutonium played in the USSR channel type reactor with graphite as moderator. Three generation of plutonium production reactors of such type were developed in the USSR. Reactors A and AI-IR constructed at the Production Association "Mayak" belonged to the first generation of plutonium production reactors. Their beginning power was 100 MW thermal. After reconstruction it was increased up to 900 MW thermal [9].

Reactors of the second generation, for example Reactor-AB, that was putted into operation at the Production Association "Mayak" in 1950, was simply a further improvement of the Reactor A. It had higher power and was safer in operation than reactors of the first generation. However reactors of the second generation had also an open cycle. This means that water after passing the active core was pumped out directly into a water reservoir.

The first channel reactor for plutonium production of the third generation was constructed at the Siberian Chemical Combine [10]. This was the reactor EI-2. By designing of this reactor a closed circuit of the active core cooling was provided. The thermal energy generated in the active core were transferred from the first circuit to the non radioactive water of the second circuit for generation of water steam. This allowed using thermal power generated in the active core for generation of the electricity. Development of this scheme required increase of water's pressure in the first circuit above atmospheric pressure specific for channel reactors of the first and second generations. The thermal power of channel reactors of the third generation were increased up to 2,000 MW [11]. They produced annually 500 kilograms of weapon-grade plutonium.

Table 1. Plutonium production reactors of the USSR [8]

Facility, Location	Reactor	Type of reactor	Reactor generation	Year		
				Start	Shut down	Reconstruction
PO «Mayak», Ozersk (Chelyabinsk-65)	A	UGCh	I	1948	1987	1963
	AI-IR	UGCh	I	1951	1987	-
	AB-1	UGCh	II	1950	1989	1973
	AB-2	UGCh	II	1951	1990	1972
	AB-3	UGCh	II	1952	1991	1975
	OV-180	HWV	I	1951	1966	-
	OV-190	HWV	I	1955	1965	1962
	OV-190M	HWV	I	1966	1986	-
	«Ruslan»	WWR	I	1979	-	-
	«Lyudmila»	UGCh	II	1987	-	-
Sibirian Chemical Combine (CChC), Seversk (Tomsk-7)	I-1	UGCh	I	1955	1989	1979
	EI-2	UGChT	III	1957	1990	1967, 1980
	OK-140	UGChT	III	1961	1992	1967
	OK-204	UGChT	III	1963	-	1967
	OK-205	UGChT	III	1965	-	1969
Mining and Chemical Combine (MChC) Яру (г.Красноярск-26)	OK-120	UGCh	II	1958	1992	-
	OK-135	UGChT	III	1962	1992	1969
	OK-206	UGChT	III	1964	-	1970

Notices: UGCh – uranium channel reactor with graphite as moderator; HWV – heavy water reactor of vessel type; UGChT – two purposes uranium channel reactor with graphite as moderator уран-графитовый; WWR – water-water reactor.

Channel reactors of the third generation were two-purposes reactors. They were developed for production of weapon-grade plutonium and electricity. They became prototypes of the first Soviet power nuclear plant putted into operation in June 1954 in Obninsk. This NPP had the electrical power only 5,000 kWt [12]. Later channel power reactors of high power (from 1,000 to 1,500 Mw) were developed and constructed in the USSR. This is so-called RBMK reactors.

Parallel to the development of the plutonium bomb great efforts were made in the USSR for development of uranium bomb. Two different processes were studied for enrichment of uranium: gaseous diffusion process of uranium isotopes separation and electromagnetic separation process [13]. The experimental study of these processes began in 1946. It was carried simultaneously with construction of the industrial plants for separation of uranium isotopes began. The plant for the industrial gaseous diffusion process was erected near to the Ural city Nevjansk. The industrial plant for the electromagnetic processes of the uranium isotopes enrichment was constructed near to the Ural's city Verkhnyaya Tura.

Weaponry facilities of the USSR

The Production Association "Mayak" (PA "Mayak") was one of three facilities for weapons-grade fissile materials erected in the USSR.

On March 23, 1946 the Government of the USSR adopted decision about construction of a special enterprise (Complex 817) for production of fissionable materials for nuclear weapon as well as a city for employers of this enterprise [5].

The Central Direction of Industrial Construction Direction of the Peoples Commissariat of Internal Affairs of the USSR (NKVD) was appointed to construct the Complex 817 and the city Chelyabinsk-40 [5]. Later the NKVD was renamed as the Ministry of State Security of the USSR (Russian abbreviation MGB), that later was renamed as the Ministry of Internal Affairs of the USSR (Russian abbreviation MVD),

Approximately 45,000 thousand of construct builders and installers as well as many thousands of prisoners were involved in realization of this secret project [5].

A big area (approximately 100 km^2) including the industrial site of Complex 817 and the city Ozersk located 10 kilometers from Complex 817 was fully isolated from surrounding world in order to prevent any information leakage that could expose character of the project. This was achieved by installing a special borderland and cordons of soldiers. The NKVD internal troops fulfilled this task [14]. The convoy troops of the NKVD were used as a security guard of prisoners that worked by erecting of different objects of the Complex 817. Divisions of firemen of the NKVD were responsible for the fire security. Divisions of militia were responsible for public security in restricted zone. The life of employers of the Complex 817 and inhabitants of the city Ozersk was under full control of the NKVD. Nobody from military or civilian personal could leave the restricted area without a special permission. A very stringent pass control was established since beginning of the Complex 817 construction. It excluded fully an entry of any outsiders to this restricted zone. At the same time members of military stuff or civilian persons could leave the restricted area only in case of official necessity [15]. The restricted area was not shown on any open geographical map or plan as it not existed at all.

The Kystym accident characterizes stringency of security regulations applied in the restricted area of the Complex 817 (PO Mayak). Solders and officers of the MVD participated at the mitigation of direct consequences of the Kyshtym accident. However, even not all deputies of the Minister of MVD of the USSR were informed about this accident [16]. Only a very limit number of the highest authorities of the USSR knew about the Kystym accident. It was unknown for party functionaries and States authorities of the highest rank [17]. For example, the majority members of the Central Committee of the Communist Party of the Soviet Union did not receive any information about it [18]. No information was also given to executives of the military-industrial establishment of the USSR as well as administration of biggest enterprises of this establishment [16].

Also very stringent security regulations were in force in case of two other Soviet facilities for production of fissile materials. Construction of them began a couple years after the Second World War. Decree about erecting the Siberian Chemical Combine (Complex 816) was adopted by the Soviet Government on March 26, 1949 (Decree № 1252-443) [19]. This facility had to product weapon-grade plutonium and high enriched uranium for military use. It was erected in the Tomsk oblast not far from the city Tomsk. The city for employers of this facility was constructed approximately 15 kilometers in north direction from the city Tomsk [20]. It primary names was Tomsk-7, now the city Seversk.

Here one example of the regime regulations in the Siberian Chemical Combine. In accordance with regulations adopted on April 2, 1957 the entry to the city Tomsk-7 was forbidden for persons that worked outside of the USSR as well as citizen of Estonia, Latvia, Lithuania, Belarus and west regions of Ukraine [21]. Many other categories of Soviet citizen were also forbidden to entry the restricted area of the Siberian Chemical Combine.

The third Soviet weaponry facility, Mining and Chemical Combine, was constructed in the Krasnoyarsk oblast. Start of its construction began in 1950 on the basis of the Decree of the Central Committee of Kommunist Party and the Council of ministers of the USSR № 326/302ss/op from February 26, 1950 [22].

This enterprise was constructed at the right bank of the Enisei River 60 kilometers downstream from the city Krasnoyarsk. It was constructed 200 meters underground in rocks in order to protect the enterprise from attacks from air. The total volume of underground rooms of the combine reached 7 million of cubic meters or 3.5 times large than the volume of the pyramid of Cheops [23]. 70 thousand of prisoners and 135 thousand of military construction builders worked 6 years long by construction of the Krasnoyarsk Mining and Chemical Combine [23]. It was erected only for production of weapon-grade plutonium and produced before crush of the USSR 45 tons of it.

Radiological problems of nuclear weaponry tests in the Smipalatinsks polygon.

Significant radiological problems in the former USSR were caused by conducting of nuclear weaponry testing. There were two test sites in the USSR: the Semipalatinst Test Site (STS) and the Novaya Zemlya Test Site (NZTS) [24]. The NZTS is situated in the island Novaya Zemlya in the northern part of Russia that has very low density population. The Semipalatinsk Test Site lies in north-east part of Kazakhstan with also quite low density population [25]. The STS includes the east part of the Karaganda oblast (region) of Kazakhstan and the south part of the Pavlodar oblast of the Russian Federation. The first test of the Soviet nuclear device was conducted in the Semipalatinsk Test Site. This occurred on August 29, 1949 at 7: a.m. [2]. Its power achieved 22 kilotons. The second testing follows on September 24, 1951 [26]. This time a atomic bomb was dropped from an airplane. The first Soviet thermonuclear test was also carried out in the Semipalatinsk Test Site. This happened on August 12, 1953 [26]. The power of the first thermonuclear device achieved 400 kilotons. Later hydrogen bombs of the megaton class were also exploded at the STS. Bombs of this class were tested since 1957 only in the Nowaya Zemlya Test Site [25].

456 nuclear tests were conducted in the Semipalatinsk Test Site between 1949 and 1989 including 116 atmospheric nuclear and thermonuclear explosions (26 of them near the ground) [24,27].

The test of the first nuclear device of the USSR carried out on August 29, 1949 caused the most serious radiological problems. This device was installed on a metallic tower at the altitude 33 m [25]. By its explosion the fireball touched the ground. This caused formation of radioactive particles from soil and debris of the metallic tower and other constructions. They were carried downwind together with products of fission. The wind velocity at test time was 40-50 km/h [28]. Therefore within 2 hours radioactive clouds reached densely populated areas inside a 100-km from the hypocenter. According to report [28] exposure dose rates at some places exceeded the background by millions of times.

Table 2. Exposure characteristics of populations affected by nuclear tests performed in the Semipalatinsk Test Site [29].

Exposed settlements	Nuclear test leading to main exposure	Average cumulative dose estimate, 1949 - 1960 (mSv)	Number of person in cohort	Person-years at risk
Cheremushki	August 29, 1949	1,746	538	14,740
Dolon	August 29, 1949	1,590	941	27,670
Kanonerka	August 29, 1949	718	1,239	22,310
Mostik	August 29, 1949	448	485	37,080
Kainar	September 24, 1951	451	718	81,410
Karaul	August 12, 1953	455	2,836	15,350
Kaskabulak	August 12, 1953	225	515	16,910
Kundyzdy	August 12, 1953	233	613	13,490
Sarzhal	August 12, 1953	665	1,013	28,710
Znamenka	August 24, 1956	302	913	26,590
Combined		634	9,850	284,260

The radioactive fallout affected territories located up to a distance of 2,000 km from the hypocenter of explosion. About 500, 000 people lived in these territories. They all received quite high doses of irradiation because no countermeasures of radiation protection were undertaken at this test. Significant radiological problems arose also after nuclear tests carried out at the Semipalatinsk region on September 24, 1951 (atomic bomb), on August 12, 1953 (thermonuclear test) and on August 24, 1956 (atomic bomb).

Table 2 (Table 2 from the report [29]) presents mean external doses of the whole body irradiation of inhabitants of the most affected by these tests settlements of Kazakhstan. The main contribution to irradiation of them as well as inhabitants other contaminated settlements gave shot-living gamma- and beta-irradiators. They were received during quite long time beginning from the time of test (about 1 year).

Table 3. Doses of the whole body irradiation of most affected populations received in the first day after explosions of the first Soviet nuclear device.

Exposed settlements	Nuclear test leading to main exposure	Average dose in the first day (mSv)	Dose of critical group irradiation in the first day(mSv)
Cheremushki	August 29, 1949	698	2095 - 3492
Dolon	August 29, 1949	636	1908 - 3180
Kanonerka	August 29, 1949	287	862 - 1436
Mostik	August 29, 1949	179	538 - 896

According to assessment [28] approximately 40% of doses shown in Table 2 formed during the first day after explosions. Using this finding as well as data presented in the third column of Table 2 allows to assess doses of the whole body irradiation received by inhabitants of contaminated settlements in the first day after test. Such data evaluated in this report for inhabitants of settlements Cheremushki, Dolon, Kanonerka, Mostik are presented in the third column of Table 3.

It is well known that some members of irradiated group accumulate doses that are 3-5 times higher that the mean dose of this group. Such high irradiated persons form so-called critical group. The fourth column of Table 3 presents assessment of doses of the whole body irradiation received by members of critical groups of inhabitants of settlements Cheremushki, Dolon, Kanonerka, Mostik accumulated in the first day after explosion of the first Soviet nuclear device. They were evaluated simply by multiplying of data given in the third column of Table 2 with factors 3 and 5.

As can be seen from the fourth column of Table 3, doses of the whole body irradiation of members of critical groups are in the range of doses that causes acute radiation syndrome [30]. This means that at least members of critical groups in settlements Cheremushki, Dolon, Kanonerka, Mostik had to experience acute radiation disease as a result of the first atomic test in the USSR.

There are data that allows assuming that manifestation of acute radiation disease could be possible not only in mentioned settlements of Kazakhstan but also in other settlements of this country as well as in some settlements of Altay Region (Russian Federation). Now it is known that radioactive clouds formed by explosion of the first Soviet nuclear device reached also this region. According to report [31], the mean dose of the whole body irradiation of inhabitants of the Uglovsky district of the Altay Region caused by the first Soviet nuclear exploding reached 800 mSv. The main contribution to total irradiation of inhabitants of the Uglovsky district as in case of irradiation of inhabitants of affected populations of Kazakhstan gave shot-living gamma- and beta-irradiators.

The collective equivalent dose of the whole body irradiation of the Uglovsky district population irradiation is estimated as $16{,}5 \cdot 10^3$ чел·Зв [31]. However radioactive substances deposited also in three other districts of the Altay Region with the population 200,000 people. The collective equivalent dose of the whole body irradiation in affected people of the Altay Region is assessed equal to approximately $28 \cdot 10^3$ PSv and the mean dose of irradiation equal to 142 mSv. 90% of the irradiation dose in affected population of the Altay Region was received in the first year.

The very high doss of acute and sub-acute irradiation of people in Kazakhstan as well as in the Russian Federation (Altay Region) could cause also so-called chronic acute disease among irradiated people. According to Soviet specialists [32] it develops if annual irradiation doses are about 100 mSv annually and the total accumulated dose of the whole body irradiation exceeds 700 mGy.

However there is no any documentation that can give reliable evidence indicating manifestation of acute and chronic radiation diseases among populations of Kazakhstan and the Altay region of the Russian Federation affected as a result of nuclear tests at the Semipalatinsk Test Site. Detailed study of radiological problems of nuclear explosions at the STS began only at the end of eighties. These studies demonstrated reliable data about manifestation of different cancers among affected populations (leukemia, lung, stomach, female breast cancers etc) [33]. In accordance with findings of the last report the excess relative risk per sievert for all solid cancers combined was 1.77/Sv. This is by some factors higher than excessive relative risk of cancers established for atomic bomb survivors. The last finding indicates that radiation risk of chronic irradiation is higher than radiation risk observed for acute irradiation (atomic bomb survivors).

Techa River radiation problems.

Reprocessing on the industrial scale of uranium irradiated in the first plutonium production reactor of the PA "Mayak" (Reactor A) began in March 1949 [5].Because of the absence of reliable technology for reprocessing and storing of radioactive wastes liquid radioactive effluents of reprocessing were piped directly into the near Techa River [34]. Approximately 76 million cubic meters of liquid radioactive wastes with total activity of β-emitters approximately 3 MCi ($\sim10^{17}$ Bq) came as a result of this practice into the river Techa in 1949-1956. This was a mixture of the radionuclides ^{89}Sr, ^{90}Sr, ^{137}Cs, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru and isotopes of rare-earth elements. Isotopes ^{90}Sr and ^{137}Cs determined about 25% of the total activity of this mixture. About 95% of the waste was discharged into river from March 1950 to November 1951 [35].

The Techa River is a medium-size river that flows from a small lake located near the Production Association "Mayak" [35]. Its length is about 240 km. It flows through rural areas of Chelyabinsk and Kurgan oblasts before merging with the Iset River that is a tribute of the Tobol River a tribute of the Enisey River. 41 rural settlements were located along its riverside. Inhabitants of these settlements were not informed about discharge of radioactive wastes in the river and kept the normal habit of life. They used water from the Techa Rive as drinking water, they cultivated their contaminated pieces of land and used contaminated flood lands as a pasture for their cattle etc. This caused an exposition to external γ-radiation and internal irradiation from consumption of locally produced food and river water. The skeleton and bone marrow were critical organs of irradiation [34].

In 1951 or 2 years after beginning of radioactive wastes discharge into river medical examinations of the health status of residents of settlements located along riverside of the Techa River started [34]. Visiting teams of specialists from the Biophysics Institute of the USSR Ministry of Health Care and from Medical-Sanitary Department carried out the exams. These visits were not able to perform regular examination and treatment of affected persons. Therefore special dispensaries No 1 and No 2 were organized in Chelyabinsk and the city Shadrinsk of the Kurgan oblast [34].

Medical examinations demonstrated that a fraction of inhabitants of settlements located in the Techa River riverside had changes in their hemopoietic, immune and other systems. These findings led to diagnosis of chronic radiation sickness (CRS) and other radiation-induced reactions. According to archive data [36] 935 cases of chronic radiation sickness were diagnosed primarily among of residents of affected settlements located along riverside of the Techa River. This number was decreased after more detailed examinations to 66 cases [34].

There were a number of reasons for overestimation of the incidence in chronic radiation sickness among residents of settlements affected as a result of the discharge of radioactive wastes into the Techa River [34]. Firstly, doctors did not know doses of irradiation. Secondly, residents of affected settlements did not know anything about reasons of their illness and regular aminations of their health status. Thirdly, there was no correct understanding of possible health effects of combined chronic irradiation (external and internal irradiation).

Establishing of different health effects was the reason for resettlement of residents of high contaminated settlements to clean areas of the Chelyabinsk and Kurgan oblasts. This action was undertaken after 1956 when people received quite significant doses of external and internal irradiation. Approximately 10,200 persons including children were resettled to clean areas of the Chelyabinsk and Kurgan oblasts.

As can be seen from Table 4 this were mostly residents of rural settlements of the Chelyabinsk oblast located in a head of Techa rive. They received the highest external and internal doses of bone tissue and bone marrow.

Table 4. Techa riverside settlements, distances and the number of inhabitants [3]

Village of first exposure	Distance from release point	Evacuated[a]	1950 population[b]
Chelyabinsk oblast			
Metlino	7	Yes	961
Techa-Brod	18	Yes	77
Asanovo	33	Yes	787
Maloye Taskino	41	Yes	114
Gerasimovka	43	Yes	268
GRP	45	Yes	49
Nadyrov Most	48	Yes	155
Nadyrovo	50	Yes	149
Ibragimovo	54	Yes	136
Isayevo	60	Yes	366
Farm of Trust nj.42	70	Yes	379
Muslyumovo station	71	No	432
Muslyumovo	78	No	1,958
Kurmanovo	88	Yes	914
Karpino	96	Yes	169
Zamanikha	100	Yes	299
Vetroduika	105	Yes	134
Brodokalmak	109	No	3,095
Osolodka	125	Yes	330
Panovo	128	Yes	103
Cherepanovo	137	Yes	181
Russkaya Techa	138	No	1,170

Baklanovo	140	Yes	396
Nizhnepetropavlovskoye	148	No	766
Chelaybinskaya oblast total			13,388
Kurgan oblast			
Beloyarka-2	155	Yes	319
Lobanovo	163	No	578
Anchugovo	174	No	1,010
Verkhnaya Techa	176	No	869
Skilyagino	183	No	426
Bugayevo	186	No	1,028
Dubasovskoye	190	Yes	650
Biserovo	202	No	457
Shutikhinskoye	203	No	1,081
Progress	207	Yes	186
Pershino	212	No	1,016
Klyuchevskoye	223	No	1,226
Markovo	230	No	134
Ganino	234	No	1,039
Kurgan oblast total			10,101
Chelyabinsk and Kurgan oblasts together			23,489

[a] Indicates whether residents of the village were moved to another location as a result of the radioactive contamination.

[b] Population estimates taken from 1950 official estimates.

This can be seen from Table 5 that contains results of an assessment of irradiation doses of bone tissue and bone marrow accumulated during first 25 years after beginning of radioactive wastes discharge into the Techa river.

Table 5. Doses of bone marrow and bone tissue accumulated during 25 years by resients of settlements along the riverside of the Techa accident [37]

Settlement	Distance from "PA Mayak", km	Status, evacuated	Population, persons	Bone Marrow (mSv)	Bone tissue (mSv)
Chelyabinsk oblast					
Metlino	7	Yes	1242	1640	2260
Techa-Brod	18	Yes	75	1270	1480
Asanovo	33	Yes	898	1270	1900
Maloye Taskino	41	Yes	147	1100	1680
Gerasimovka	43	Yes	357	980	1630
Geologorazvedka	45	Yes	238	750	1220
Nadyrov Most	48	Yes	240	700	1180
Nadyrovo	50	Yes	184	950	1800
Ibragimovo	54	Yes	184	950	1800
Isayevo	60	Yes	434	590	1190
Farm of Trust №42	64	Yes	487	630	410
Muslumovo	78	No	3,230	610	1430
Kurmnovo	88	Yes	1,046	380	880
Karpino	96	Yes	195	480	1150
Zamanikha	100	Yes	338	360	850
Vetroduika	105	Yes	163	440	1060
Brodokalmak	109	No	4102	140	310

Osolodka	125	Yes	362	340	830
Panovo	128	Yes	129	380	910
Cherepanovo	137	Yes	222	250	590
Russkaya Techa	138	No	1472	220	530
Baklanovo	141	Yes	480	75	170
Nizhnepetropavlovskoye	148	No	919	280	680
Kurgan oblast					
Beloyarka-2	155		386	310	750
Lobanovo	163		626	220	530
Anchugovo	170		1093	260	630
Verkhnaya Techa	176		979	290	700
Skilyagino	180		492	400	900
Bugayevo	186		1074	250	600
Dubasovskoye	200		703	160	370
Biserovo	202		465	260	630
Shutikhinskoye	203		1109	80	180
Progress	207		205	170	400
Pershino	212		1143	150	340
Ganino +Markovo	215		220	120	290
Klyuchevskoye	223		1309	80	170
Zatecha	237		1135	170	400

Data of Table 5 show that even people in settlements located about 200 kilometers from the head of the Techa River accumulated doses of the bone marrow and bone tissue in hundreds of millisievert. This demonstrates that significant amount of radioactive substances released in the Techa river at its head were transferred up to the Iset River located 200 kilometers from the PA "Mayak". This transfer meant that radioactive substances could be transferred through rivers Iset, Tobol and Enisei up to the Arctic Ocean increasing possibility to discover the place of the Soviet plutonium production facility. In order to prevent such possibility release of radioactive wastes of the PO "Mayak" was practically stopped in November 1951.

Very high irradiation doses of the bone marrow and bone tissue received residents of the settlement Muslumovo that was not resettled. Examination performed in this settlement in 1993 demonstrated that exposure dose rates in some areas with lengths about 100 meters were 6-7 microsievert per hour [37]. Areas with the enhanced exposure dose rates were also found in personal subsidiary plots of residents of this settlement. It was established that radioactive contamination of personal subsidiary plots was caused by using of dung of the cattle that grazed on flood lands of the Techa River. It was found that dung emitted γ-radiation at the exposure dose rates about 0.5 – 3 microsievert per hour [37].

Last time a number of reports with results of radioepidemiological studies of the mortality from cancers among residents of settlement located in the riverside of the Techa River were published [34,38,39]. These studies were performed for the cohort of evacuated and remined residents of settlements located in the riverside of the Techa River. The mean dose of the whole body irradiation of this cohort was assessed equal to 0,31 Gy [34]. According to the report [34] 46 fatal solid cancers and 31 fatal cases of leukemia (excluding chronic lymphoid leukemia) occurred in the cohort containing 29,873 persons up to the end of 1999. Similar results were observed also in reports [38, 39].

Studies of the cohort of residents of settlement located in the riverside of the Techa River [34,38] allowed to establish very important data in respect of chronic irradiation of normal population with low doses and low dose rates. It was established that no threshold exists for carcinogenic impact of such kind of irradiation. It was also found that excessive relative risks of mortality from solid cancers and leukemia in members of the cohort of residents of settlements located in the riverside of the Techa River are by approximately 2 times higher than by atomic bomb survivors. This means that coefficient of radiation risks observed for atomic bomb survivors can not be transferred for chronic irradiation of normal population.

It is clear that data on numbers of additional fatal solid cancers and leukemias presented here do not express all possible health effects caused by release of radioactive wastes into the Techa River in 1949-1956. One needs to remember that the cohort studied in reports [34,38] comprises only residents of settlements located in the riverside of the Techa River. However, the total number of persons that were affected through release of radioactive wastes is much higher. It is approximately 142 thousands [40]. This number includes also residents of settlements that located near to settlements of located in the riverside of the Techa River. It is also necessary to remember that detailed studies of health effects of this release began practically at the end of the USSR existence. This means that a lot of data important for assessment of the impact of radioactive wastes on health was lost. This does not allow to describe full picture of health effects in population suffered from release of radioactive wastes into the Techa River.

Kystym radiation accident

At the beginning of fifties special storage for radioactive wastes originated from reprocessing of irradiated uranium was erected at the PA Mayak. It consisted a number of tanks made from stainless steel and installed in concrete canyons embedded partly in the ground [41]. They were located about 2 kilometers from the radiochemical plant (Plant “B”). The volume of each tank was 300 cubic meters. Each tank had a water cooling system placed on the internal wall. Construction of cooling systems did not allow their repair. The cooling system of one tank was out of operation in 1956 due to corrosion of metallic tubes caused by an impact of mixture of radioactive salts. Specialists of radiochemical plant assessed the possible consequences of a complete failure the defect cooling system. According to performed assessments such failure could not influence a safe storage of radioactive wastes. Considering these conclusions nothing was made during a year after establishing of problems with the cooling system. It turned out later that these conclusions were incorrect. The failure of the cooling system caused expulsion of water, warming and concentration of highly explosive nitrates and acetates containing in the tank. An occasional spark from defective control equipment initiated chemical reactions between these components. This caused a powerful detonation and destruction of a tank. The energy of explosion was assessed later equal to 5 – 10 tons of trinitrotolulol (TNT) [42]. This accident occurred at 16:30 on September 29, 1957.

Approximately 20 Millions Curie of radioactive substances was there in the tank before explosion. Approximately 18 Millions Curie (90%) fell on the territory of radioactive wastes storages and other objects of the industrial are [43]. Approximately 2 Millions Curie (10%) formed a radioactive cloud that moved in north-east direction from the place of accident because of strong wind from south-west direction. It reached the altitude of 1 kilometer. Falling of radioactive substances by passing of radioactive cloud contaminated some territories of Chelyabinsk, Serdlovsk and Tyumen oblasts of the Russian Federation.

Table 6 gives information about composition of radioactive substances released to the environment as a result of explosion [43]. It can be seen from it that short-living radioisotopes ^{144}Ce, ^{144}Pr,

^{95}Zr and ^{95}Nb made the main contribution to the initial activity of released radioactive substances. They fully determined radiation situation in a first year after accident. However, the long-term radioactive situation in contaminated areas was determined by isotope ^{90}Sr that gave together with isotope ^{90}Y only 5.4% of the initial activity. Therefore the isotope ^{90}Sr was chosen as a quantitative indicator of radioactive contamination. It was found that approximately 15,000 km^2 were contaminated with this isotope to the level higher than 3.7 kBq/m^2 (0.1 Ci/km^2). Approximately 1000 km^2 had the level of contamination with $^{90}Sr \geq 2$ Ci/km^2 (74 kBq/m^2).

Table 6. Composition of radionuclides in damaged tank of the PA "Kystym" [43].

Radionuclide	Half-life	Irradiation type	Specific contribution to priamarytotal activity, in %
^{89}Sr	51 day	β, γ	Traces
$^{90}Sr + ^{90}Y$	28.6 years	β	5.4
$^{95}Zr + ^{95}Nb$	65 days	β, γ	24.9
$^{106}Ru + ^{106}Rh$	1 year	β, γ	3.7
^{137}Cs	30 years	β, γ	0.036
$^{144}Ce + ^{144}Pr$	284 days	β, γ	66
^{147}Pm	2.6 years	β, γ	Traces
^{155}Eu	5 years	β, γ	Traces
$^{239,240}Pu$		α	Traces

The level of contamination decreased monotonically in direction of the radioactive cloud passing and had quite sharp boarders in a crosscut axes [43]. The maximal total contamination reached 15,000 Ci/km^2 and maximal contamination with the isotope ^{90}Sr was approximately 4,000 Ci/km^2. The contaminated area had a form of a strip that crossed Chelyabinsk, Sverdlovsk and Tyumen oblasts of Russia that went through rural areas of these oblasts of Russia. This strip, "Kyshtym footprint", received the official name of "East Urals Radioactive Trace" (EURT) [43]. 217 settlements with approximately 272 thousands of residents were located at the time of explosion in the area with the isotope ^{90}Sr 3.7 kBq/m^2 and higher [44].

Because the Kystym accident was the topic secret of the USSR it was unknown even for high party functionaries and for high rank of the Soviet State authorities [45]. Nothing was also known in West. The first information about the Kystym accident appeared in West only in 1974 when the Soviet dissident biologist Zhores Medvedev published at the end of fifties his article about a radiological accident in the South Ural [46]. Zhores Medvedev did not known exactly when it happened and what the reason of it was. He had drawn his conclusions about the accident on the basis of an analysis of some published articles in the open Soviet scientific literature about incidence of ionizing radiation on animals and plants in the Ural Region. According him a radiological accident occurred in the Kystym area at the end of 1957 or at the beginning of 1958 with release of approximately 50 MCi ($1.85 \cdot 10^{18}$ Bq) radioactive substances.

Report of Zhores Medvedev [46] caused a number of different of hypotheses on origin of the accident including very exotic. For example, it was proposed that Soviets dropped an atomic bomb with equivalent of 22 TNT in order to examine the strengths of radiochemical plant and its infrastructure [47].

Controversial debates in Western about the Kyshtym are described in details in the book of Rosalie Bertell [48].

Correct information about this accident became available only after crush of the USSR. It is known today that this accident occurred at 4:25 p:m on September 29, 1957 and that it was caused by explosion of radioactive waste in a defect storage [43,49].

The power of explosion was so high that the upper cover, a heavy concrete plate, was thrown off in the distance of 200 meters. In a building located in 200 meters from the waste‘s tank not only all windows but even one wall made from bricks were damaged. Windows of all buildings in a radius of more than 1,500 meters were also crushed. Eyewitnesses of explosions told later that a column of smoke and dust formed over the damaged waste‘s tank. It shimmered with red and orange light that was similar to the aurora borealis [50].

The radioactive cloud contaminated different buildings of industrial area, military quarters, fire department, location of military construction builders and the prisoner's camp [50].

According to [49], the commander on-duty ordered all officers and solders to go to quarters, to occlude all destroyed windows using all available materials and wet floors in quarters. A dark radioactive cloud overhung the location of troops soon after the military staff reached its quarters. It became very dark. Outside of quarters big flakes began to drop from the cloud. Smaller particles were dropping also on the next day. Specialists in dosimetry appeared soon in the location of the military stuff. After measurement of exposures doses they told to commanders that all people had to be evacuated immediately from contaminated quarters to clean areas of the restricted zone. However, the commanders could not undertake this action without permission from Moscow. It came at the beginning of night of September 30, or 8 hours after the accident. The evacuation of the military stuff began at 2 in the night. The trucks that even had no tents were used for evacuation. Some solders and officers had to walk because there was no place enough in trucks. After evacuation all solders and officers undertaken the sanitization and received clean clothing. However nobody understood how to perform the sanitization. Therefore all solders and officers simply washed themselves some during some hours with hot water. That such method could not assure required decontamination of hair and skin.

Significant deposition of radioactive substances was registered also in location of the prisoner camp where there were 1,100 prisoners and 80 persons of the guard [51]. The head of guard was informed about radiological situation only at 2 in the night of September 30. All prisoners together with their guard were evacuated in the period from 4 to 8 in the morning to clean area. After evacuation they had sanitization that lasted 3 days.

General Ptashkin, the Division Commander of Internal Troops of the MVD that guarded the restricted area informed in a secret report to Moscow, that as a result of the explosion a fraction of industrial area and area of military quarters were significantly contaminated. It reported that exposure dose rates achieved in some places 5,000 – 6,000 microroentgens per second [52]. This was approximately 1 million times higher than the exposure rate of background irradiation.

Many rural settlements outside of the restricted area were contaminated to high levels of radiation too. Therefore, authorities in Moscow decided to evacuate residents of the most contaminated settlements such as Berdyants, Saltykovo, Galikaevo and Russkaya Karabolka (Kasli district, Chelyabinsk oblast) [53]. Practical realization of this decision began 7-10 days after the accident when inhabitants of contaminated settlements received quite high doses of irradiation. Measurements performed in the rural settlement Berdyants before evacuation demonstrated that exposure dose rates were about 40-50 microroentgens per second close to stomach of children [54]. Anserine droppings emitted radiation with the exposure rate about 50-70 microroentgens per second.

Later another contaminated settlements were evacuated too, so the full number of evacuated settlements reached 23 [43]. All residents of contaminated settlements were evacuated or resettled to near districts of the Chelyabinsk oblasts. This was made on the cost of the State.

The evacuation and resettlement of affected residents were performed in 5 steps. Table 7 shows number of evacuated or resettled persons and other relevant data.

The total number of all residents evacuated or resettled in 5 phases was 10,800. The highest doses of irradiation received residents of settlements Berdyants, Saltykovo, Galikaevo and Russkaya Karabolka. The mean arithmetic effective dose of their irradiation was 52 rem (520 mSv). This value was estimated on the basis of the mean external dose, 17 rem, and the mean dose of stomach irradiation equal to approximately 160 rem.

Table 7. Dynamic of evacuation and doses of irradiation received before evacuation [43].

Evacuated groups and number of evacuated persons, thousands	Average density of ^{90}Sr deposition, Ci/km^2	Time of evacuation after accident, days	Average dose received before evacuation	
			External dose, rem	Effective equivalent dose, rem
I; 0.60	500	7 - 10	17	52
II; 0.28	65	250	14	44
III; 2.0	18	250	3.9	12
IV; 4.2	8.9	330	1.9	5.6
V; 3.1	3.3	670	0.68	2.3

Only residents of settlements with the level of contamination by the isotope $^{90}Sr \geq 2$ Ci/km^2 (74 kBq/m^2) were evacuated or resettled as a result of the Kystym accident [43]. The mean contamination level of remaining settlements where about 270,000 residents lived was approximately 1 Ci/km^2 (37 kBq/m^2) with ^{90}Sr. Despite of quite high irradiation doses of evacuated and resettled residents no reliable evidences of such radiation-induced health effects as cancer were observed among them during 30 years after accident [43]. The possible reasons of such finding could be quite low collective doses of irradiation and quite low follow-up. For example, the collective effective dose of the whole body irradiation of evacuated and resettled residents is only approximately 980 PSv. This value was estimated on the basis of data presented in Table 7. It is quite small in order to established statistical significant health effect of irradiation.

According to the report [43] only decrease of leucocytes in peripheral blood, decrease0f the number of platelets as well as functional neurological disturbances. The most possible reason of such results of medical examinations can be late and not adequate observation of affected people.

Evacuation of residents of high contaminated settlements was performed by troops of the Ministry of Internal Affairs of the USSR. It was forbidden to explain the real reason of evacuation. It was forbidden even using the word “radiation”. The people in settlements foreseen for evacuation were said that it was *dirty* in their settlements [55]. They did not want to leave their houses, their asset and graves of their parents. In order to avoid evacuation they have undertaken a general cleaning of their houses. They asked authorities to see that their houses were very clean and therefore there were no necessity for evacuation.

All persons that were involved into performing of evacuation and mitigation of direct consequences of the accident or that knew about accident were enforced to sign a special document that required keeping the secrecy about the accident and its consequences. A very serious punishment expected those persons that did not fulfilled this requirement.

This policy of the hypercecrecy became later a serious handicap for many people affected by the accident. Many of them became ill as a result of significant irradiation. However they were not allowed to tell their doctors the reasons of their illness. This made impossible for doctors to establish correct diagnose and apply correct treatment of illness [56]. Such policy caused loosing of very important data about health effects of ionizing radiation and makes impossible correct estimation of health effects in all groups affected by the Kyshtym accident.

Deputy Head of the Department of Special Troops of the MVD General-Leutnant G.I.Aleinikov prepared a special report on the Minister of the Interior of the USSR about reasons and consequences of the Kystym accident [57]. He sugested to carry out a full analysis of the accident and made a number of proposals regarding the necessity activity in affected areas. He suggested also making familiar all other divisions of the MVD with experience accumulated by direct mitigation of the Kystym consequences.

Unfortunately last proposal of General-Leutnant was no accepted by authorities and all experience accumulated in Kystym was newer used in the USSR. According to the General-Leutnant (in resignation) of the MVD of the USSR N.I.Demidov [58] by mitigation of the Chernobyl accident were made practical the same errors as in Kystym. And this aggravated significantly its consequences.

Karachai Lake radioactive contamination

The Karachai Lake located near to the radiochemical plant (Plant “B”) of the Production Association “Mayak”. This lake was used since autumn of 1951 for storage of liquid radioactive effluents. The total activity of radioactive wastes loaded into this lake is assessed equal to approximately 120 Millions Curie [59].

The water level in the Karachai Lake decreased very significantly in 1962-1967 outcropping the lake shore contaminated with radioactive substances. The wind storm that happened in 1967 caused significant transfer of radioactive substances and contamination of the environment. Approximately 0.6 Millions Curie were transferred from Karachai Lake on this way [60]. This caused a significant contamination of 63 rural settlements located on the territory of 2,700 km^2 with 41.5 thousands of inhabitants. Some of these settlements were contaminated in 1957 as a result of the Kyshtym radiation accident.

In order to prevent the further transfer of radioactive sediments it was decided at the end of nineties to lay hollow concrete blocks on the opened bottom of the Karachai Lake. This decision was realized some years ago. However it did not solve problems of the Karachai Lake. Very serious problem of radioactive wastes loaded into the Karachai Lake causes penetration of radioactive substances into a subsurface waterbearing formation. Assessment show that about 4 Millions cubic meters of radioactive substances already penetrated up to the depth 100 m [59]. They migrated slowly into direction of the

Chelyabinsk city water intake. Therefore a very serious problems has to expect in the future in respect of water supply of this city.

Nuclear accident in the Chazhma Bay.

A serious accident occurred on 10 August 1985 at a Soviet submarine K-431 by fuel reloading [61]. The submarine belonged to the first generation of Soviets atomic boats. Such submarines were supplied with 2 identical pressurized water reactors that had the power 70 MW and used enriched uranium (21% of ^{235}U) [62]. Their design was similar to design of western pressurized nuclear reactors (PWRs).

The submarine was moored at the pier of shipyard in the Chazhma Bay (not far from the city Vladivostok). It was discovered by finishing of a fuel reloading that the gasket of the cover of the port side's reactor was untight. By elimination of this defect a compensation grid was withdrawn out the active core. This initiated a chain reaction on prompt neutrons and powerful explosion that damaged the reactor. One fuel assembly was thrown out the active core. Its metallic construction dropped into VI partition of submarine near the cover of the reactor of starboard.

Witness of the accident observed rich flash of white color up to 6 meters in the height. It was followed by orange-grey fume that was rising up to 20 meters in the height. Immediately after explosion a fire began in the VI partition. 4 hours were required for its suppression. Explosion damaged also strong hull of the submarine. There were other serious damages of the submarine.

The active core at the moment of explosion contained only a fresh fuel. This was a reason that released radioactive substances were mostly short-living radionuclides with negligible contribution of such isotopes as ^{90}Sr and ^{137}Cs [63]. The total activity of released radioactive nuclides was only about 5 millions Ci. Decay of short-living radionuclides caused a rapid decrease of the activity of radioactive substances discharged to the environment. Assessment carried out in the report [63] showed that it fell up to approximately 0.8 Ci to days after the accident.

The significant fraction of fission products and dispersed particles as well as substances formed by the fire fell around the submarine in the area with the radius 50-100 meters. The exposure dose rate in this area was about 250-500 milliroentgens per hour 7.5 hours after the accident [64].

Another fraction of released radioactive substances deposited in some kilometers from peer in an empty area. Thus, only stuff members of fleet as well as fireman suppressed the fire developed at the submarine were affected of this accident.

Immediately after explosions naval specialists and specialists of the enterprise that served submarines organized dosimetric measurements, localization of high contamination and liquidation of direct consequences of the accident [64]. Military personnel as well as personnel of the enterprise that was not involved in this activity were evacuated from the zone of accident. Different other countermeasures were also undertaken. This was made in order to decrease a number of persons that could be irradiated as a result of the accident.

Approximately 2,000 persons were involved in liquidation of direct consequences of it [64]. The mean dose of the whole body irradiation of this group was about 5 rem. Approximately 290 persons from this group received higher doses of irradiation. The symptoms and signs of acute radiation diseases were registered by 39 persons. However, acute radiation diseases developed only by 10 persons. 10 persons (8 officers and 2 other persons from military personnel) died from injuries gotten during the explosion. These data show that the accident in the Chazhma Bay caused quite serious health effects.

The primary reason of the Chazhma Bay accident was inserting of an additional positive reactivity to the active core. This caused a development of an uncontrolled chain reaction. It means that it had a character of a nuclear explosion. It demonstrated that a water-pressurized reactor can explode like a small nuclear bomb after inserting of a positive reactivity into active core.

The accident in The Chazhma Bay was some kind of a general repetition of similar accident of a large scale. Careful analysis of this accident could be very important for Soviet specialist in the field of nuclear safety. Unfortunately, the information about the accident in the Chazma was kept in the USSR like some topic secret. Ten months later the Chernobyl accident occurred. Its primary physical reason was also the inserting of a positive reactivity into active core [65].

Chernobyl accident

The Chernobyl NPP accident has become the most severe technical accident in the history of humankind. It took place on April 26, 1986, during an electromechanical experiment. The aim of the experiment was a determination of the amount of electrical energy produced by the electrical generator in the process of an idle turbine rundown. The program of the experiment did not take into account a number of important physical and thermal-hydraulic features of the reactor and the whole reactor unit. This caused some wrong operations of the personal and as a result the total destruction of the active core of the forth unit of the Chernobyl NPP as well as considerable damage of the third unit of the plant [65]. The witnesses of the Chernobyl NPP accident claim that destruction of the Chernobyl reactor occurred as a result at least of two consecutive explosions. Specialists believe that the first explosion was caused by an explosion-like formation of vapour in the active core of reactor. This caused complete displacement of water from reactor and nuclear explosion in the drained active core [66]. The power of this second explosion is estimated to be approximately 0,28 kilotons TNT [67], which is in 50 times less than the power of the atomic bomb dropped on Hiroshima.

The damage of the Chernobyl reactor caused the release of a huge amount of radioactive substances into the environment. They spread far beyond the borders of the nuclear plant [68, 69]. These substances where deposited in many countries of the northern hemisphere including Japan [70], causing considerable radioactive ecological problems. However, Belarus suffered most severely from the Chernobyl NPP accident than any other country of the world. Such conclusion can be drawn by comparing densities of the isotope ^{137}Cs deposition in the different countries of the world. This isotope was chosen after the Chernobyl NPP accident as a quantitative indicator of radioactive contamination. According to data [68], the maximal contamination with ^{137}Cs beyond the borders of the former USSR has not exceeded 185 kBq/m^2 (5 Ci/km^2). In Belarus the maximal density of ^{137}Cs fallout reached 59,200 kBq/m^2 (1600 Ci/km^2) [71] or about 300 times more than maximum contamination beyond the former USSR.

Approximately 23% of the total amount of the isotope ^{137}Cs deposited on the territory of Belarus [69,72]. Assessment carried out in the report [73] show that doses of the whole body irradiation reached in some rural settlements 300 mSv. The maximal doses of the whole body irradiation could reach in Belarus 1,500 mSv. Similar results were established by authors [74]. Doses of the thyroid gland irradiation in

Belarus were one order in magnitude higher than doses of the whole body irradiation. In some cases they exceeded 50 Gy [75]. Similar irradiation arisen also in affected regions of Ukraine and Russia [72].

As a result of an extensive irradiation additional thyroid cancers in children and adults [76-85], leukemias in children and adults [86-91], stomach cancers [92], lung cancers [93], female breast cancers [94, 95] as well as nonmelanoma skin cancers [96] manifested in Belarus after the Chernobyl accident. Statistical reliable data indicating manifestation of radiation-induced stomach, colon, lung, thyroid and urinary bladder cancers in the Belarusian liquidators as well as of all malignant neoplasms combined together have been established [97,98].

An increase in the incidence **of** thyroid cancers was also established in children of Ukraine and Russia affected at the Chernobyl accident [99, 100]. In case of Russian liquidators radiation-induced thyroid cancers and leukemias as well as cancers of digestive and other systems were also found [101-103].

It was established in reports [84, 90-95, 98, 102] that radiation risks of the incidence in malignant neoplasms manifested in affected regions of the former USSR as a result of the Chernobyl accident are higher by some factors than radiation risks established for atomic bomb survivors.

Additional to malignant neoplasms a significant increase in the incidence in general somatic disease was established in affected populations of Belarus, Ukraine and Russia as well as in liquidators of these countries [104-111]. Data of the Belarusian, Ukrainian and Russian specialists about link between the incidence in general somatic diseases correspond qualitatively with findings observed by survived inhabitants of Hiroshima and Nagasaki for which higher incidence in cerebrovascular and other somatic diseases in comparison with no irradiated Japanese population was [112-115]. It was found that radiation-induced general somatic diseases in case of atomic bomb survivors gave the similar contribution to the additional mortality as radiation-induced cancers.

An assessment of the incidence in radiation-induced malignant neoplasms in Belarus was performed for the period 1986 – 2056 in report [116] based on the analysis of medical data registered in Belarus. Published data of the Belarusian Cancer Registry were used for the assessment. It was estimated that approximately 28,300 solid cancers other than thyroid cancers, about 31,400 thyroid cancers as well as approximately 2,800 additional leukemias can be expected in Belarus in 1986-2056 as a result of the Chernobyl accident. According to performed assessment the excessive absolute risk, EAR, of radiation-induced solid cancers averaged for 1986-2056 will be about 230 cases per 10,000 PYSv. This value is in a qualitative agreement with the value of EAR established for the incidence in radiation-induced solid cancers in the cohort of atomic bomb survivors in 1958-1998 (52 cases per 10,000PYSv) [117]. A qualitative assessment of excessive absolute risk of the incidence in thyroid cancers and in leukemias was carried out in the report [116]. Estimated values are also higher by some factors than radiation risks of thyroid cancers and leukemias established for atomic bomb survivors.

An assessment of additional incidence in cancers in affected European countries that can be expected in the period 1956-2056 as a result of the Chernobyl accident was performed in the report [118]. It was carried out by indirect transition of radiation risks estimated for Belarus. The estimated results are presented in Table 8.

Table 8. Predicted numbers of excess cases, 1986-2056, in European countries after the Chernobyl accident.[118].

Cancers and countries	Excess cases		Relative risk		Share, in %
	Cases	90%CI	RR	90%CI of RR	%
Thyroid cancers					
Belarus	31,400	15,400÷47,500	2.625	1.797÷3.460	33.9
Belarus, Russia and Ukraine	65,800	31,800÷99,900	1.151	1.073÷1.230	71.1
Other countries of Europe	26,800	11,500÷42,200	1.019	1.008÷1.030	28.9
All countries	92,600	44,000÷141,200	1.050	1.024÷1.077	100
Solid cancers other than thyroid and non-melanoma skin cancers					
Belarus	28,300	11,800÷44,800	1.015	1.008÷1.023	21.7
Belarus, Russia and Ukraine	82,000	30,900÷133,100	1.002	1.001÷1.004	62.9
Other countries of Europe	48,400	4,300÷92,500	1.000	1.000÷1.001	37.1
All countries of Europe	130,400	42,900÷217,900	1.001	1.000÷1.001	100
Leukaemia					
Belarus	2,800	1,000÷4,600	1.047	1.017÷1.078	21.7
Belarus, Russia and Ukraine	8,100	2,400÷13,800	1.008	1.002÷1.014	62.8
Other countries of Europe	4,800	-870÷10,470	1.001	1.000÷1.003	37.2
All countries	12,900	2,800÷23,000	1.003	1.001÷1.005	100

It gives excess cancers estimated for Belarus, for Belarus, Russia and Ukraine combined together, for all other European countries combined together as well as for all European countries including Belarus, Russia and Ukraine combined together. The last column of Table 8 gives contribution of country or of group of countries to the total number of assessed malignant neoplasms that can manifest as a result of the Chernobyl accident.

As can be seen from data of this table 92,600 additional thyroid cancers (90% CI from 44,000 to 141,200 cases), 130,400 additional solid cancers other than thyroid and non-melanoma skin cancers (90% CI from 42,900 to 217, 900 cases) and 12,900 additional leukaemia cases (90% CI from 2,800 to 23,000 cases) are expected in all affected countries of Europe as a result of the Chernobyl accident during 1986-2056. Approximately two thirds of all excess cancers will occur in Belarus, Ukraine and Russia. Belarus alone will contribute approximately 34% of thyroid cancers and about 20% of all other excess solid cancers and leukaemia that can be expected in countries of Europe affected as a result of the Chernobyl accident.

Data presented in Table 8 show those health effects of the Chernobyl accident are more significant that is recognized by the International Radiation Community that rejects even possibility to establish statistical reliable manifestation of radiation-induced cancers caused by this accident. Data presented in Table show that such possibility exists at least for Belarus.

The accident at the Chernobyl NPP has affected all spheres of the man's activity in Belarus [119]. As a result of this accident 2,640 km2 of agricultural lands have been excluded from the agriculture turnover. 54 collective farms and sovkhoses have been liquidated, 9 processing industrial plants for the agroindustrial complex have been closed down. Arable lands and gross agricultural crop yield reduced sharply, the cattle stockhas decreased considerably.

Great damage has been incurred by the Chernobyl accident on the forestry of Belarus [119]. More than a quarter of the forest resources of Belarus - 17.3 thousand km2 of forest were subjected to radioactive contamination. In the middle of nineties the annual losse3s of wood resources exceeded 2 Millions of cubic meters.

22 layers of mineral and raw resources of building sand, sandy-gravel materials, clays, chalk and peat were brought out of use [119]. The territory of Pripyat oil and gas bearing field whose resources were evaluated in 52 millons tons of oil has been excluded from the geological exploration plans.

The accident at the Chernobyl NPP caused significant economical problems for Belarus, Ukraine and Russia. According to assessment [119], economical loses of Belarus in 1986-2015 caused by overcoming of the Chernobyl consequences will be 235 Billions of US dollars or equal to 32 annual budgets of Belarus in 1985. 81.6% of this sum or 171 Billion of US dollars will be connected with the support of production functioning and realization of protection measures [119].

Protective measures include resettlement of residents of high contaminated settlement (contamination level with the isotope ^{137}Cs higher than 555 kBq/m^2) and providing safe living conditions for population living in areas with the contamination level with the isotope ^{137}Cs less than 555 kBq/ m^2.

The accident at the Chernobyl NPP was simply devastating for Belarus. It caused the relocation of a large number of people in Belarus. According [120], 24,725 persons were evacuated from May to September 1986. During 1991-1998, another 110,000 persons were resettled from highly contaminated areas to clean territories of Belarus [120]. Evacuation and resettlement were performed with financial and material support of the Belarusian State. Additionally, up to the end of year 2000, approximately 200,000 persons moved from contaminated areas without any state's assistance [121]. On the whole, at least 335,000 persons in Belarus lost their place of living and their property. It is clear that such extensive evacuation and resettlement fully destroyed the social life of the most contaminated areas of Belarus and caused significant psychological tensions and stresses.

Similar problems and similar financial and material loses arisen as a result of the Chernobyl accident in Ukraine and the Russian Federation. According to assessments of the Ukrainian specialists performed in nineties of the last century summary loses of Ukraine in the period 1986-2015 will be 178.7

Billions of US dollars (on the state of currency rate for 1984) [122,123]. Approximately 116 thousands of residents of contaminated settlements of Ukraine were evacuated in 1986 days after the accident [122,123]. This number includes about 50 thousands of inhabitants of the city Pripiat that were evacuated on April 27, 1986. In 1990-1998 approximately 100 thousands of residents of high contaminated settlements of Ukraine were resettled to clean areas.

The economical loses of the Russian Federation in 1986-2015 were assessed to approximately 200 Billions of USA dollars [124]. 186 persons were evacuated during summer and autumn of 1986. Only very small area in the 30-km zone belonged to the Russian Federation. And this is a reason of a small number of evacuated persons in this country because only residents of 30-km zone were objects of evacuation. The 30-km zone is a kind of orbicular area around the Chernobyl NPP. Its radius is approximately 30 kilometers.

Information presented here shows summary loses of Belarus, Ukraine and the Russian Federation as a result of the Chernobyl accident will be about 600 Billions of US dollars in 30 first years. This accident caused evacuation and resettlement of many thousands of persons and devastated big territories that were affected as a result of the Chernobyl accident. I was the reason of significant social-psychological tensions and stresses. All these consequences made the accident at the Chernobyl NPP the most sever technical accident in the modern history of humankind.

Discussion and conclusions

This report does not pretend to give the full picture of nuclear and radiation accidents as well as radiation situations in the former USSR. It gives only description of some large radiation accidents and situations such as Semipalatinsk polygon, radiation situation of the Techa River, Kyshtym radiation accident, radiation contamination of the Karachai Lake, nuclear accidents at the Soviet submarine on August 10, 1985 in the Chazhma Bay (near Vladivostok) as well as nuclear accidents on April 26, 1986 at the Chernobyl NPP. These accidents caused irradiation of many hundreds of thousands of persons, destroying of normal life on big territories of the former Soviet Union, significant economical loses significant social-psychological and medical consequences. However, there were much more other radiation accidents in the former USSR that occurred at nuclear power plants with channel graphite reactors and pressurized water reactors, at weaponry facilities and mining enreprises as well as at other enterprises of the nuclear industry [126]. The Soviet policy of hypersecrecy was the reason that all these accident and situation were unknown not only for western specialists but also for the Soviet citizen and specialists. This caused additional aggravations of accidental situations and unnecessary suffering of many people.

Many of these accidents have their historical roots in realization of the Soviet military project in the field of nuclear energy. It required an allocation of huge financial and material means at the time when the whole European part of the territory was in ruins as a result of the German aggression. Development of the nuclear weapon at such conditions aggravated immensely the life conditions of Soviet people. However, the Soviet leaders were oppressed to concentrate all economic means for construction of nuclear weapon because they knew that a number of plans of nuclear attacks on the USSR were developed in Washington. Possessing of own nuclear weapon reduced the threat of such attacks. Existence of this threat influenced fully the Soviet nuclear project. All efforts of Soviet specialist were directed only on receiving of fissionable materials and construction of nuclear weapon. Problems of possible harmful influence of radiation on specialists and workers involved in realization of these tasks as well as possible irradiation of general public did not play an important role in the USSR. And this caused a number of large accidents with significant irradiation of many hundreds thousands of people in the USSR. Some of these accidents were discussed in the present report.

The USSR could solve the problem of nuclear weapon development in very short time despite very big economical, material and civilian causalities during the Second World War. The first nuclear device was exploded at the Semipalatinsk Test Site on August 29, 1949. This was a very significant achievement of Soviet science and industry. However, the practice of hypersecrecy installed in the first years of development of the Soviet military roots became a normal practice of all activity in the field of nuclear energy in the former USSR including the field of peaceful use of it. This made impossible the transfer of experience accumulated by mitigation of radiation accident that occurred at different enterprises and nuclear power plant.

The accident at the Chernobyl NPP gives telling information of negative influence of the regime of hypersecrecy adopted in the former USSR on safety of nuclear objects. In 1975 an accident of the Chernobyl type accident happened at the Unit No1 of the Leningrad NPP [65]. As a result of this accident some technological channels were damaged and a big amount of radioactivity was released to the environment. This accident happened as a result of an inserting of positive reactivity in some adjacent technological channels. Critical analysis of this accident by specialists in reactor safety could be very useful for abolishing the most negative features of the RBMK reactor. It could be very useful for operating personal of nuclear power plants with such reactors. However all information about this accident was classified and therefore not inaccessible.

A lot of important information about effectiveness of different countermeasures in case of large radiation accidents was accumulated at the Kystym accident. However this important information was fully inaccessible for Soviet specialists in mitigation of radiation accidents. And as a result of this policy many errors suffered by mitigation of consequences of the Kystym accident were repeated after the accident at the Chernobyl NPP. The hypersecrecy and totalitarian system of the former USSR are more important reasons that have been turned big areas of its territory in the main polluted areas on our planet.

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