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REVIEW OF THE RADIATION ACCIDENTS CONSEQUENCES IN THE FORMER USSR TERRITORY (BURNASYAN FMBC OF FMBA OF RUSSIA REGISTER DATA)

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Анализ медицинских последствий радиационных инцидентов на территории бывшего СССР (по материалам регистра ФМБЦ им. А.И.Бурназяна ФМБА России)

РЕФЕРАТ

В работе представлены обобщенные сведения по радиационным инцидентам на территории бывшего СССР, сопровождавшихся облучением людей с клинически значимыми последствиями.

За более чем 60-летний период (с 1949 г.) на территории бывшего СССР произошло, по крайней мере, 356 радиационных инцидентов, сопровождавшихся облучением людей с клинически значимыми последствиями у 765 пострадавших. Из этой когорты облученных диагноз острой лучевой болезни (ОЛБ), включая случаи, отягощенные местными лучевыми поражениями (МЛП), был установлен в 358 случаях. 407 пострадавших имели только местные лучевые поражения. В общей сложности в результате радиационного воздействия в первые 3–4 месяца после облучения погиб 71 человек.

Ключевые слова: *радиационный инцидент, медицинские последствия, острая лучевая болезнь, местные лучевые поражения, база данных*

ABSTRACT

The paper sums up the information on radiation incidents/accidents at the former USSR territory that related to the human exposure with significant clinical effects.

Within more than 60 years (since 1949), at least 356 such radiation incidents have happened at the former USSR territory, and there were 765 victims with clinically significant health effects. This exposed cohort includes 348 patients revealed acute radiation sickness (ARS) including cases aggravated by local radiation injuries (LRI). Isolated LRI were registered in 407 victims. Totally, 71cases of early (within first 3–4 months) radiation induced fatalities were observed.

Key words: *radiation accident, medical consequences, acute radiation sickness, local radiation injuries, database*

The Radiation Accident Register created in the A.I. Burnasyan FMBC of FMBA of Russia appears to be the basis for several our publications related to medical consequences of radiation incidents in the former USSR territory [1–4]. The published data on accidents' victims with acute radiation sickness (ARS) or the local radiation injuries (LRI) being analyzed in chronological sequence were of common character and presented simple enumeration of medical consequences. In to-day work we solved to expand the analysis and to give more detailed clinical characteristic of typical incidents inside separated groups of them.

The most important medical consequences were observed in the Chernobyl 1986 accident resulted into 30 early fatalities (two victims directly as a result of reactor explosion and 28 – as a result of irradiation). The ARS diagnosis was made to 134 victims (21 – very severe degree, 22 – severe, 50 – moderate and 41 – mild). The clinical course of ARS was aggravated with serious skin radiation burns in 54 cases. Clinical consequences of the Chernobyl accident have been described repeatedly in details, as an example, [5].

All other radiation accidents within the present publication are united in groups, and general characteristics and features of their medical consequences are analysed.

Accidents at x-ray devices and the charged particles' accelerators

We selected accidents with x-ray devices and charged particles accelerators in separate group (see Table). There were 31 accidents recorded in this group, which include 8 accidents in medical use of radiation and all other accidents took place at academic and research facilities. People injured in these accidents had only LRI of different severity and there was no mortal outcome. However, some of these cases led to the long disability and, therefore, continuous care (for 10–30 years) was essential. Only one accident with x-rays (in a period of 1962–2006) had several victims, as faulty x-ray therapy machine was used in cosmetic procedure. (Nizhny Novgorod, 2001). It's

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Table

Radiation accidents in the former USSR territory (according Burnasyan FMBC Register, 01/01/2013): Summarized data on radiation accidents with significant medical effects

Accident classification	Number of accidents	Number of victims with significant clinical effects (ARS and LRI)							
		Total	Incliding with ARS (severity degree)*				ARS + LRI	LRI only	died
			I–IV	II–IV	III–IV	IV			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Accidents with radioisotope facilities and its sources (total)	94	171	51	27	11	6	34	120	16
Including: ^{60}Co	17	28	15	9	6	3	9	13	3
^{137}Cs	19	58	13	7	1	–	12	45	9
^{192}Ir	39	56	11	3	–	–	9	45	1
other sourses	19	29	12	8	4	3	3	17	3
2. x-ray units and accelerators (total)	43	52	–	–	–	–	–	52	–
Including: x-ray units	30	38	–	–	–	–	–	38	–
electron accelerators	10	11	–	–	–	–	–	11	–
proton accelerators	3	3	–	–	–	–	–	3	–
3. Reactor accidents and loss of control over the criticality of fissile material (without the Chernobyl accident, 1986)	33	82	73	39	25	13	31	9	13
Including: control over criticality loss	16	42	42	30	20	10	26	–	10
reactor accidents (other reasons)	17	40	31	9	5	3	5	9	3
4. LRI cases of «Mayak» Plant (1949–1956)	168**	168	–	–	–	–	–	168	–
5. Accident at the nuclear-powered submarines and accidents at nuclear tests	5	141	93	37	19	12	74	48	12
6. Other accidents (total)	12	17	7	3	2	2	3	10	2
TOTAL (without the Chernobyl accident, 1986)	355**	631	224	106	57	33	142	407	43
7. The Chernolbyl accident, 1986	1	134	134	93	43	21	54	–	28
TOTAL (1949–2011)	356**	765	358	199	100	54	196	407	71

* ARS degrees: I – mild, II – moderate, III – severe, IV – very severe ("II–IV" means "moderate and more")
** each case with LRI at the enterprises of Mayak Plant 1949–1956 seen as an isolated incident

important to know that only one accident happened out of Russian Federation borders – in Frunze University (Kirghiz SSR, 1967).

Thirteen incidents with 14 people involved were recorded at charged particle accelerators (in 1957–2005). Ten of these incidents happened at electron accelerators and three – at proton accelerators. Only in one accident two persons were irradiated at once (St.Petersburg, 1979), others reviled by one victim. Health effects of this type of accident in most cases were more serious than those at x-ray devices, and there was distinct relationship between the energy of radiation and the injury severity. All accidents happened in Russian Federation territory (except one – Ukraine, Kiev, 1977).

Accidents at industrial gamma facilities and with other gamma-radionuclide sources

This group of accidents with gamma radiation sources is the largest one and can be divided into several subunits. The first one includes accidents happened at industrial radiological facilities where powerful gamma source used, as an example, for sterilization of medical products. Sealed 4.0–20 PBq and more activity ^{60}Co-sources are used. There were 6 accidents registered here. The whole-body irradiation resulted in development of ARS, complicated with severe LRI in three cases was observed. Victims of two most serious accidents (St.Petersburg, 1980 and Nesvizh – Belarus, 1997) were exposed to whole body dose ≥ 15 Gy. They developed intestinal syndrome of ARS and died on the day10th and 111th, relatively. The difference in time of death can be explained with significant progress in ARS treatment within the past two decades. In other four accidents 5 people were involved: two of them were irradiated to whole body relatively homogeneously (bone marrow syndrome), other victims were exposed with non-homogeneous absorbed dose distribution, and bone marrow syndrome of ARS was combined with severe LRI. In all cases of this group the cause of accident was flagrant violation of safety rules.

The second subunit is the most numerous – it includes 52 accidents with ^{60}Co, ^{137}Cs and ^{192}Ir radioactive sources, mostly used in radiography. There 62 victims in total, and only LRI took place in all cases.

The third sub-group consists of 42 accidents with gamma-sources, which had not been controlled, i.e. "lost" sources, and accidents when ionizing radiation source was used in criminal purpose or in purpose of suicide. (See the part "Other accidents"). In all these accidents non-homogeneous irradiation took place with ARS and LRI

(31 accidents) or only LRI (58 accidents). There were 14 lethal cases registered in this group.

It is a good reason to repeat once more the conclusion of our article [6], that accidents with "lost" sources are of particular dangerous, because the victims in most cases were persons from population, including children (!), and health effects in most of victims were more serious than those in personnel exposed, for example, in accidents with radiography devices. One of the reasons of the serious health effects in accidents with "lost" sources links with too late hospitalization. People who found the source do not have an idea about the nature of the object, its danger and unable to understand relationship of that with the disease appearing.

Significant radiation exposure was observed in three accidents (7 victims) with "lost" sources used in medicine. And it is important to mention that there was disrepair of transportation equipment in two these cases. One of these accidents is described hereinafter.

In general, there were 171 victims in 103 accidents with radionuclide sources; 51 of them revealed ARS, and 34 had ARS combined with LRI; 120 victims had only LRI. Seventeen victims died of ARS. The structure of accidents by relation to the nuclide involved is following: ^{60}Co-source (energy of γ-radiation 1.1–1.3 MeV) – 17 accidents, ^{137}Cs-source (energy of γ- radiation 0.662 MeV) – 19 accidents, ^{192}Ir-sources (maximum energy of γ- radiation 0.618 MeV) – 39 accidents. However, the severity of radiation damage did not always depend on energy of radiation; mostly it depended on the source activity, and precise condition of irradiation in each particular case.

Some of listed accidents must be described in more detail, as they had several victims and the cause was malfunction of the equipment or inappropriate source storage. Among these is the accident with ^{60}Co-source (Sverdlovsk, 1975), where the cause of the accident was shipping container malfunction; the source transported for burial fell out unnoticed of the container to the car body. Three people were irradiated; the whole body dose of one of them was about 7 Gy. He was hospitalized on the day 14th since the accident and died of ARS on the day 35th in spite of very active therapy.

Accident with high-energy ^{137}Cs-source in troop unit (former Azerbaijan SSR, 1982) had drastic consequences too. Cause of the accident was inappropriate storage of "spent" source: the source was found in raincoat that was wearied by several people. As a result 18 people were irradiated, and had non-homogeneous distribution of absorbed dose. Five people died of very severe LRI (local dosage ≥ 700 Gy), combined in one victim with high extent of ARS disease and in other four cases with middle and mildew bone marrow syndrome. Thirteen victims had LRI of hands (one victim had LRI of hand and thigh). There was no death among these LRI patients, however, in three of them LRI was the cause of stable disability.

Two of nineteen accidents with ^{137}Cs-source in 1967–1997 happened in Ukrainian SSR, (Kramatorsk, 1982 and Kharkov, 1983). One of these accidents listed above – Azerbaijan SSR, 1982, and after break up of Soviet Union – in Tallinn (Estonia, 1994) and in Tbilisi (Georgia, 1997). Other 14 accidents had happened in Russia.

Accident in Kramatorsk (1982) is quite different from all other accidents. High-energy ^{137}Cs-source had been inserted in construction bloc of dwelling; therefore dwellers had been irradiated for long time. There was not registered ARS diagnosis as the radiation wasn't acute, but total dosage was intense and 2 victims died in one family; the cause of death was tumorous disease, which in such case is related to chronic radiation exposure.

Another case with an "orphan" ^{137}Cs-source had happened in Tallinn. The source was found at the scrap site by a boy and brought to dwelling. It was established that 4 people were irradiated and developed ARS combined with LRI. One of the victims died because of very late ARS diagnosis. In the Georgian 1997 accident 9 soldiers were irradiated, some of them revealed multiple LRI, none died. These two accidents described in details in IAEA publications.

Accident of criminal character in Moscow (1993) had the lethal1 outcome, as far as; ARS wasn't diagnosed in proper time and has not been treated properly. Another accident with prolonged (about 5–6 months) irradiation related to criminal activity happened in Moscow (1995). The victim had developed chronic radiation disease from external non-uniform gamma irradiation (summary whole body dose about 8–10 Gy) with malignant transformation. He died 2 years after.

Also there were other 3 accidents related to criminal usage of radiation source. Two people in Lipetsk (1974) were exposed with stolen by them source. They had extent ARS of middle severity, combined with LRI in one patient; both of them were treated successfully. In Norilsk (1985) a ^{192}Ir source was found built in the chair used by several people; there was no lethal outcome, but as a result of localized exposure of buttock spermatogenesis disorder were registered in three victims. In Bratsk (1991) there was no lethal outcome as well, however, one case of mild severity ASR resulted from irradiation with stolen and destroyed source (^{137}Cs) was observed.

Among the accidents with "lost" gamma-sources there are two that should be mentioned separately, as soon as, children appeared to be victims. The first one had happened in Yuzhno-Sakhalinsk (1980); 10-years old boy was exposed to radiation, absorbed dose estimated to fingers (source in hand) was 20–30 Gy and to two spots on abdomen area (source in pockets): ≥30 Gy. Patient

died of moderate degree ARS combined with severe LRI. The second one – in Krasnodar region (1982); of 8-years old girl was exposed and moderate severity LRI of hand and foot developed, and surgical operation appeared to be necessary for treatment.

The loss of the ^{192}Ir source in Gorky (1984) led to 8 LRI cases. Four of them had low extent of ARS, combined with LRI, other victims had only LRI, and none died. The same situation in Kharkov (1990) led to one case of ARS with LRI, no lethal outcome. There was one ^{192}Ir accident of criminal character with LRI case registered in Far Eastern district (1976).

As it was mentioned above, there were 39 incidents with ^{192}Ir-sources used for gamma-defectoscopy (1969–2007); most of them (27) were linked with abnormal situation during working procedure. Among these there were accidents in Frunze (Kirghiz SSR, 1979), at Ignalinskaya NPP (Lithuanian SSR, 1985), Tashkent (Uzbek SSR, 1988) and in Kharkov (Ukrainian SSR, 1990). Two accidents took place in Kazakhstan after break up of Soviet Union (Aksai, 1992 and Aktyubinsk, 2007). Other accidents happened in Russia.

Different sources accidents

Different radionuclide sources are widespread in all sphere of human activity. In the Register 19 accidents with other, non-listed above, sources can be found. There were 29 victims of these accidents with 12 ARS cases and 3 lethal outcomes.

Three accidents at Mayak Plant (1952, 1953 and 1963) were connected with radioactive water leakage; there were 5 ARS victims with 2 lethal outcomes. An accident in Sarov, 1954 characterized with ^{210}Po intake; two people were suffered of internal exposure, one of them developed ARS and died.

Similar accident at the same institute happened in 1968: there were 2 internally exposed people without serious consequences. There was no more lethal case in accidents analyzed in this part. Two accidents with ^{124}Sb source were registered in Arsamas-16, 1955 and in Moscow, 1984. In both cases there was by one not severe exposed victim.

Two accidents with ^{90}Sr+^{90}Y sources took place in Moscow (1984) – one victim, and in Lia – Georgia (2001) – three victims with LRI of different severity; one of Lia accident victim died 2 years later and did not therefore included in statistic of ARS lethality. An accident with ^{104}Rh – source was registered at radiochemical plant in town Seversk (1974) resulted into LRI in one person. An accident of criminal character happened in Riga, Latvian SSR, 1988; a nurse of ontological clinic stole the ^{252}Cf and kept it in the pocket for several hours; surgical operation was necessary for the thigh's LRI treatment.

There is no entire information on the accident at gamma instillation in Moscow, 1969: it is known that exposed person had LRI only.

Accidents at nuclear reactors and criticality accidents

Chernobyl NPP accident, as the most important from the medical consequences point of view, has been already mentioned above. So, in this part of our analysis the information on other 33 nuclear accidents will be presented.

In the document [7] the review of more than 30 criticality accidents had been made by the group of US and Russian scientists and could be regarded as the most significant analysis of the problem. Nevertheless, medical effects of these accidents presented very scanty.

It is necessary to underline that accidents with self-sustained chain reaction (SCR) appeared to be first in the line of ARS study and description and it was shown, for example, that the most severe cases of ARS in man with the very early (within first 49–120 h) lethal outcomes had been observed in criticality accidents only [8, 9].

There are seventeen SCR accidents registered on the former USSR and Russia territory. There were three accidents for the period 1953–1958 years at Mayak Plant (town Osersk) when 12 people in general were overexposed and ARS developed combined with LRI in half of cases; 5 of these patients died at acute stage of disease, including 4 deaths of cardiovascular toxemic and gastrointestinal radiation syndromes. Also three accidents took place in Obninsk (1954, 1962, 1977). One accident had happened in Ukrainian SSR.

Two criticality accidents had occurred in Tomsk-7 (now – Seversk) in 1963 and 1978. There were 4 victims suffered with ARS; all survived.

Four accidents took place in Moscow, at Kurchatov Institute (1953, 1961 and 1971 twice); there were 15 victims. In all cases ARS was observed, with severe LRI complications in 9 patients. Two victims of last 1971 accident – died of cardiovascular (the dose about 50 Gy) and gastrointestinal radiation syndromes (the dose about 20 Gy) on the 4th and 13th days, correspondently.

There were three patients with ARS resulted from 2 accidents happened in Sarov in 1963 and 1977; one of them died 52 hours since exposure.

One more registered criticality accident (Chelyabinsk-70 or Sungul, 1968) had been resulted into high dose irradiation of two workers. Very severe ARS developed in both cases; one patients died on the 3rd day of cardiovascular syndrome and another – on the 55th day of bone marrow syndrome.

In Kiev (Ukrainian SSR) one SCR-accident had happened at research reactor (1970), and one person was irradiated. He survived severe ARS with very severe LRI.

Other reactor accidents and LRI's incidents at "Mayak" Plant in period 1949 – 1956

This group of acncidents differs of all other in scanty information on circumstances and consequences of events. There are data on 9 accidents related to manipulation with fuel rods in which 25 workers had been irradiated, and all of them survived the ARS. During the same period 168 cases of LRI were observed, as it was found owing to medical archive data analysis, made by A.K. Guskova [10]. Detailed analysis of these cases appeared to be impossible.

Several accidents in operations with fuel rods took place in later period of time, as well. They are: Osersk, 1963; Obninsk, 1969; Novovoronezh NPP, 1969; Kurchatov Institute (Moscow); 1978, Sverdlovsk; 1979. In general there were 7 victims of these accidents, 4 of them with ARS, all patients survived.

There is no complete information about an accident in MSO-99 (1969) where two people were exposed during the work at reactor. It is known only that both developed ARS of mild severity and survived.

The last case in this list is the accident at "Krasnoye Sormovo" plant (1970). It was the sudden discharge of hot steam from reactor happened in the process of nuclear submarine's reconstruction. Five workers were overexposed. Three of them suffered with very severe ARS complicated with severe skin burn of 90 % of body, they died within a month. Two others survived ARS of moderate severity with skin born of hands.

It is necessary to note that the most number of nuclear accidents had happened before the end 1970, and only 2 accidents of this nature were observed in the later period (1993 and 1997).

Submarine accidents and out of control situations in the time of nuclear weapon testing

There is information on 55 accidents at submarines nuclear reactors and other navy ships happened during 1960–2000 [11].

The information on radiation accidents at submarines and other navy ships can be found in books [11, 12]. Particularly in [11] there is description of an accident on bay Chazhma (1985) and data on victims which was not known previously. It was an explosion with SCR and radioactive substances discharge in the time of submarine nuclear reactor recharging causing by safety rules violation. All ten workers dealing with recharging were killed by explosion. There were 7 more irradiated persons who suffered with ARS mild and moderate severity; they all survived.

Four other submarine accidents are described in [12]. Two of them K-119, 1961 and K-140, 1968 were related with SCR, and had been of most serious: they resulted into 12 lethal outcomes.

The first nuclear reactor counter was damaged in North Navy submarine K-19 accident in 1961, and following necessity for people to enter the reactor compartment despite high level radiation resulted in serious exposure.

As a consequence of that 54 people were exposed externally to gamma-beta radiation and internally contaminated with fission products. Diagnosis of ARS in combination with LRI was confirmed in 30 cases, 8 of these patients died, all other survived.

27.08.1968 submarine K-140 had being repaired at Severodvinsk dock. At the moment of spontaneous raising compensating (balancing) lattice non-predicted power upsurge of the reactor occurred. As a result, 68 people were irradiated. ARS diagnosis was confirmed in 44 patients, four of them died.

Relative to 1979 accident there is short information [12] about four survived ARS victims.

One more accident which was not described previously could be mentioned now. It was extraordinary situation at the time of air nuclear test in Semipalatinsk region 16.03.1956. The team of cinema-operators being engaged in the test filming accompanied with few military men had found their-self on the contaminated territory. The fact was clarified some later when clinical signs of radiation exposure appeared. There were eight victims exposed to gamma-beta radiation. They developed middle degree ARS accompanied with mild skin burns. All survived.

Summarized data on number of accidents and victims of submarine and situations with nuclear weapon tests can be found in Table.

Some other incidents

There are 12 accidents which could not be included into any group regarded above because of their particular features or incompleteness of information about. In general, 17 people were victims of these accidents, among them 7 cases of ARS, 3 with LRI complication; 2 people died. Other ten patients had LRI.

The great majority of patients – victims of accidents analyzed in this article had been treated in clinical department of the Institute of Biophysics, called now A.I.Burnasian FMBC of FMBA of Russia. Their case reports are saved in the clinical archives of FMBC, and the whole medical information in digital form related to each patient has been included into Human Acute Radiation Injuries Database [13]. It is unique information resource for human radiation pathology study and could be useful for physicians as a guide in diagnosis and treatment of acute radiation disease.

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