(5) Effects of Radiation Accidents in South Urals

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In 1948 a weapon-grade plutonium separation combine for the USSR's first atomic bomb was put on line near the city of Chelyabinsk. Technological flaws and lack of expertise in radioactive waste management led to radioactive contamination of vast territories and radiation exposure of large population in the Urals. Among the people exposed to increased doses of irradiation due to the activities of the enterprise, currently called Mayak Production Association, the following population groups should be distinguished:

1. Population exposed to radiation due to discharges of radioactive waste into the river Techa
2. Population irradiated due to the explosion of a tank with radioactive waste in 1957
3. Population irradiated as a result of a downwind transfer of radionuclides from the shoreline of the lake Karachay, an open depot of liquid waste in 1967

Medical follow-up in three population groups and analysis of the health effects have been carried on for over 30 years by the Urals Research Centre for Radiation Medicine.

As can be seen from Fig. 1 the discharges of radioactive waste into the river Techa were made in 1949-1956. The thermochemical explosion of a waste tank occurred in September, 1957, and in spring of 1967 the territory adjacent to the lake Karachay, an open depot of radioactive waste, was contaminated. As a result of evaporation of the lake water caused by an unusually hot spring and summer of 1967 about 600 Ci of radioactivity were blown with dust by the wind from the drying lake shores and dispersed over the nearby territory. The so-called New Trace was formed.

Certain steps were taken to protect the population from the impacts of radiation incidents (resettlement of the population, sanitary alienation of contaminated lands, enactment of special sanitary protection regulations, etc) It should, however, be stressed that a delay in the implementation of these measures diminished their effectiveness considerably. As a result, a proportion of the Techa-River population and the 1957-Trace population received radiation doses conducive to health affections.

Fig. 3 shows the distribution of the accumulated doses in RBM for the population exposed on the Techa. It can be seen that about 8% (over 2 thousand people) of the Techa population received doses in excess of 1.0 Gy. The highest doses were received by the residents of the village of Metlino. The mean effective doses was estimated to be 1.7 Sv and the upper bound of individual doses amounted to 5 0 Sv The population of the riverside communities was exposed to both external and internal irradiation.

The doses of internal exposure depended on the content of radionuclides in water and the fact whether the residents used well water or river water.

As a result of radiation incidents of 1949-1956 and 1957 post-irradiation effects were noted in a proportion of the exposed population with highest doses

It was impossible to accurately determine early exposure effects from waste discharges into the Techa because regular medical examinations of the irradiated people were initiated from 2 to 4 years after the beginning of the exposure. However, in 940 residents of the Techa riverside villages chronic radiation sickness (CRS) was diagnosed in the early period of radiation exposure.

The diagnosis of CRS was based on the occurrence of the combination of the following sings (V.F. Ivanov, N.A Vyalova).

- hematologic syndrome (leukopenia, granulocytopenia, thrombocytopenia);
- neurological disturbances (asthenia, vegetative dysfunction, microorganic CNS affections),

- ostealgia;
- immunity changes (non-specific immunity inhibition, autoallergy);
- cardio-vascular syndrome (hypotonia, tachycardia).

It is evident that CRS has not a single specific symptom.

The exposures resulting from radiation events of 1957 and 1967 did not cause any cases of radiation disease.

Immunity disorders persisted for 30 years and longer after the beginning of the exposure. As was demonstrated by the retrospective studies of clinical manifestations of immune insufficiency in the exposed individuals and those who fell ill with cancer, immunity changes could play a significant role in the development of radiation-induced cancers.

Long-term health effects were registered only among the residents of the villages located in the upper and middle reaches of the Techa (within 150 km of the discharge site). They received the highest exposure doses

An increased incidence of leukemia was noted in this population in the period from the 5th to 20th years of the exposure. The maximum incidence of leukemia was observed from the 15th through the 19th years after the beginning of exposure.

Increased incidence of leukemia was accounted for acute leukemia and chronic granulosytic leukemia

The absolute leukemia risk value was estimated to be from 0.48 to 1.1 per 10^4 person- year-gray which is 3-5 times lower than the respective values obtained in Hiroshima and Nagasaki. This feature can obviously be attributed to essential differences in the nature of exposure (acute and chronic).

A statistically significant increase in long-term general and cancer mortality was observed at mean effective doses 1.4 and 0.52 Sv

An increased contribution to cancer mortality structure was made by cancer of the esophagus, cervix and corpus uteri, colon and rectum.

As a result of increased mortality rates a decrease in mean life span was noted in a proportion of the population.

The most significant life span shortening was noted over the first 5 years of radiation exposure and it made up 4.5-6.5 years. In the early period life span shortening was accounted for increased mortality of children under 4 years from infectious diseases mainly of respiratory organs and adults over 60 from cardio-vascular diseases. The latter phenomenon can hardly be explained by radiation exposure. More likely it could be attributed to the situation-related distress following the radiation incident.

As a result of discharges of radioactive wastes into the river Techa the equivalent doses to gonads of exposed persons made up 160 mSv, on the average. Over 80% of the people received doses to soft tissues below 120 mSv, and in 20% the dose varied from 120 to 1260 mSv

It should be pointed out that equivalent doses to the gonads were built up mainly from external gamma-irradiation within the first six years of the exposure, the maximum irradiation rate amounting to 400 mSv/yr (mean value: 60 mSv/yr).

The incidence of spontaneous abortions, stillbirths and ectopic pregnancies in exposed women did not actually differ from the comparison group.

Birth and fertility rates were indicative of a normal reproductive function in the exposed individuals.

In the individuals exposed in utero an increased mortality rate not only from infectious diseases but from congenital developmental defects was noted over the first five years after the beginning of the exposure while no increase in mortality from congenital developmental defects was noted among the offspring of the first generation.

The prevalence of mental retardation among the those exposed in utero accounted for 2.2% and did not practically differ from the respective value for controls.

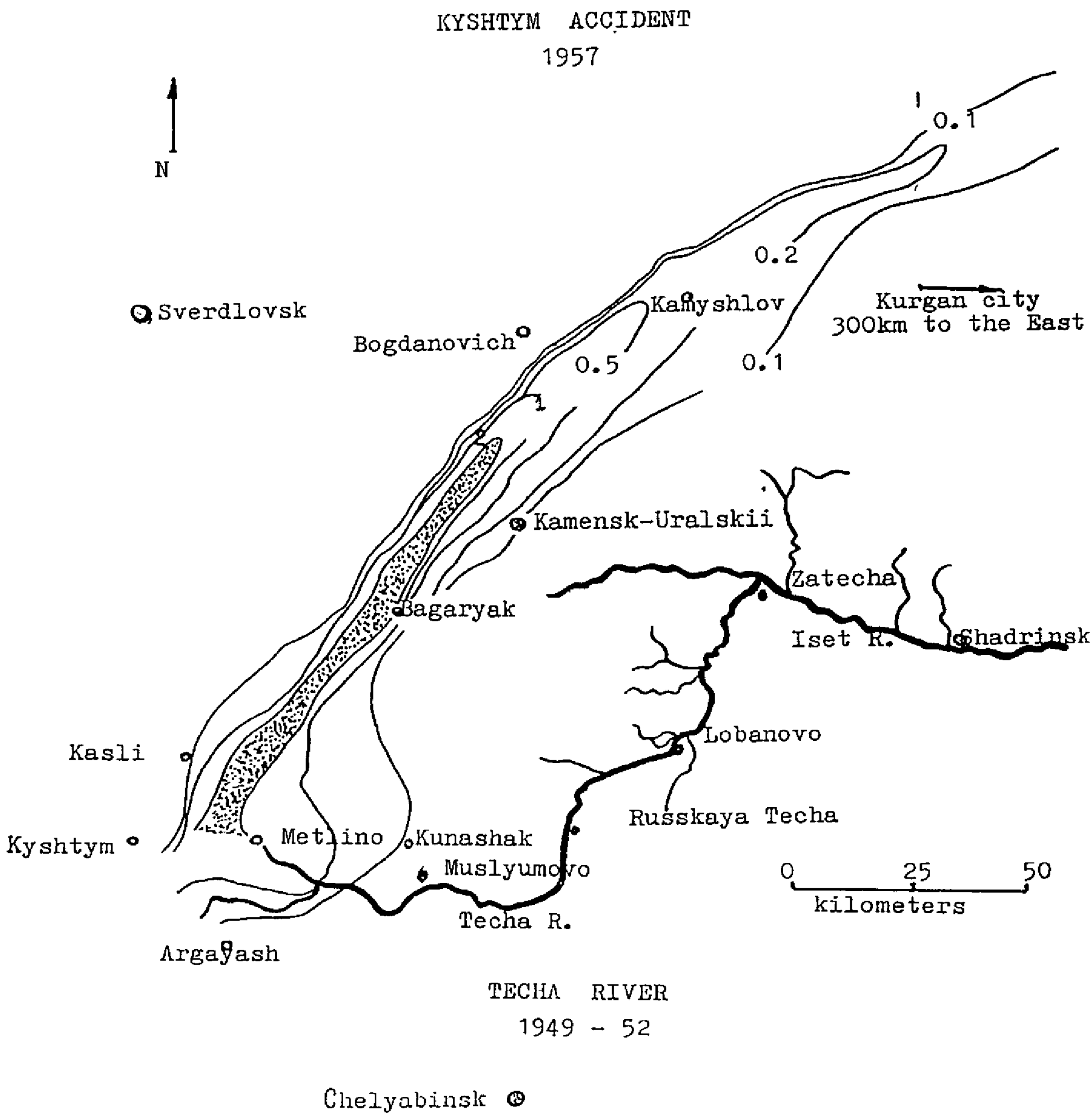
The incidence of Down`s syndrome was estimated to be lower among the offspring of the people exposed on the Techa as compared to that among the offspring of the residents of the nearby non-exposed villages.

Long-term follow-up of the progeny of the first and second generation of the exposed population failed to detect any changes in their health status.

Thus, due to the three radiation incidents that occurred in the Urals region over 400 thousand people were exposed to elevated radiation levels. The exposures resulted in the development of early and late radiation effects in a proportion of the population.

SHALAGINOV

Fig. 1



The main characteristics of radiation situations in the Southern Urals

Parameters	the Techa	1957 accident	events of 1967
Activity released, Ci	$3 \cdot 10^6$	$2 \cdot 10^7$	$6 \cdot 10^2$
Path of contamination	aqueous	aerial	aerial
Radionuclide composition of the release, %	Sr-89+ Sr-90:21 Cs-137:12 Zr-95+ Nb-95:14 Ru-103+ Ru-106:26 Rare earth elements:27	Sr-90: 5 Zr-95+ Nb-95: 25 Ru-106: 4 Ce-144: 66	Sr-90: 34 Cs-137: 48 Ce-144: 18
Numbers of people exposed to elevated radiation doses (thousand),	~124	~272	~42
including those with dose >5 mSv/yr	28.1	~20.0	none
Area with Sr-90 contamination density ≥0.1 Ci/km^2 (thousand km^2)	flood lands of r. Techa & Iset ~1.0	23.0	2.7
Area of quarantined land ($\cdot 10^{-2}$ thousand km^2)	8	106	none
Maxim. values of equiv. dose to RBM* (Sv)	3.0-4.0	0.9	0.003
Numbers of resettled population, thousand	7.5	11	none

* RBM - red bone marrow

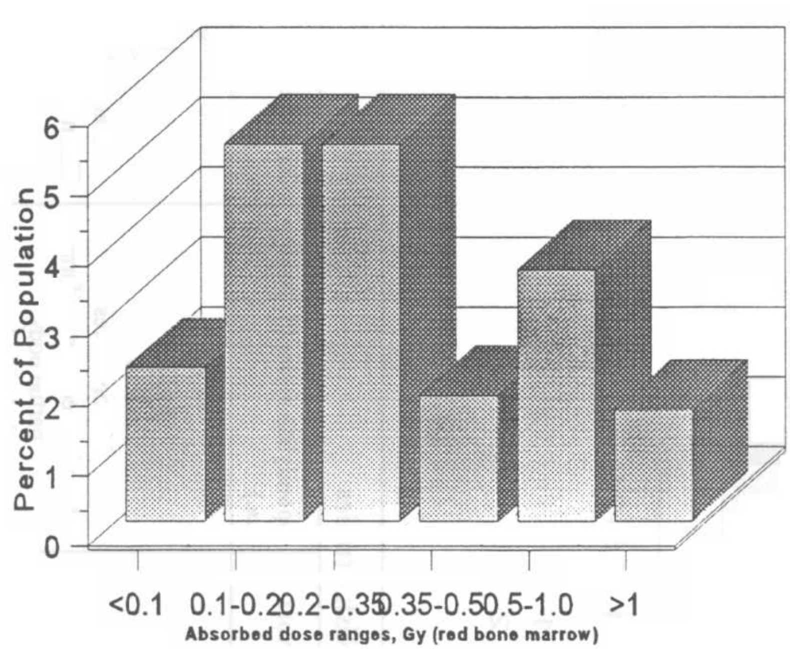
EARLY HEALTH EFFECTS OF POPULATION IRRADIATION IN THE SOUTHERN URALS

River Techa	the 1957 accident	the events of 1967
I. Chronic radiation sickness II. Radiation reactions. - hematologic syndrome (leukopenia, granulocytopenia, thrombocytopenia) - neurologic syndrome (asthenia, vegetative dystonia, organic microsymptomatology) - ostealgic syndrome - immunologic deficiency syndrome III. Increase in childhood morbidity and mortality caused by infections (mainly of respiratory organs)	Radiation reactions. - haematologic syndrome (leukopenia, granulocytopenia, thrombocytopenia) - neurological syndrome (asthenia, vegetative dystonia)	None was noted

Incidence of clinical manifestations of immune deficiency in exposed patients with tumour and comparison group

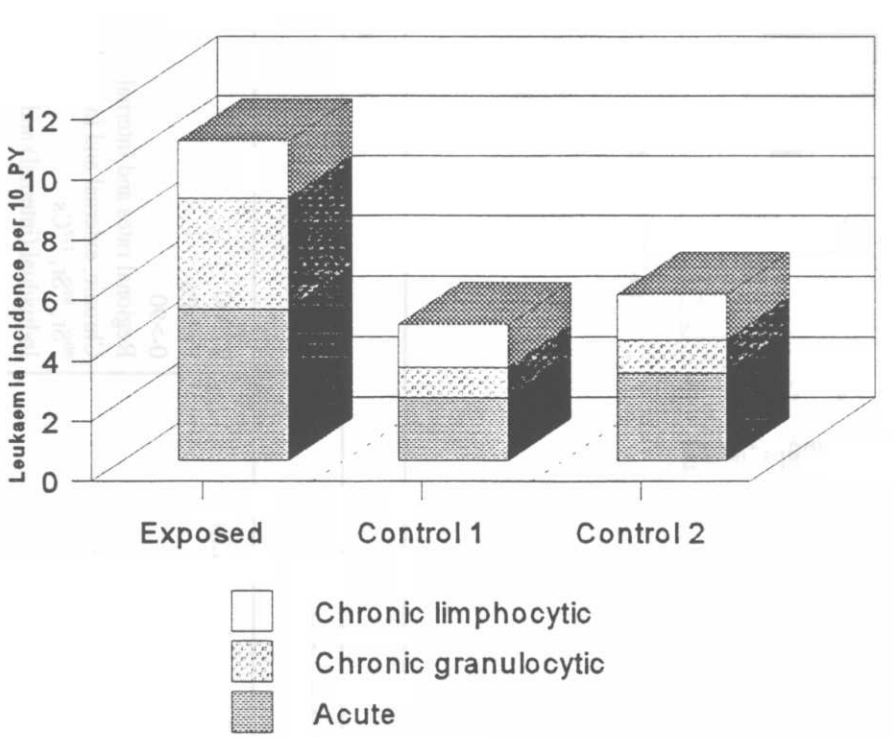
Key syndrome	Disease	Study group		Comparison group	
		persons	%	persons	%
Infectious	Chronic pneumonia	49	13.9	282	3.8
	Chronic obstructive bronchitis	18	5.1	12	0.2
	Pulmonary tuberculosis	19	5.4	94	1.3
	Osteomyelitis	3	0 9	13	0.2
Autoimmune	Chronic hepatitis	19	5.4	205	2.7

Fig. 3 Techa River



M.O. Degteva, et al. 1992

Techa River



M.M. Kossenko, et al, 1991

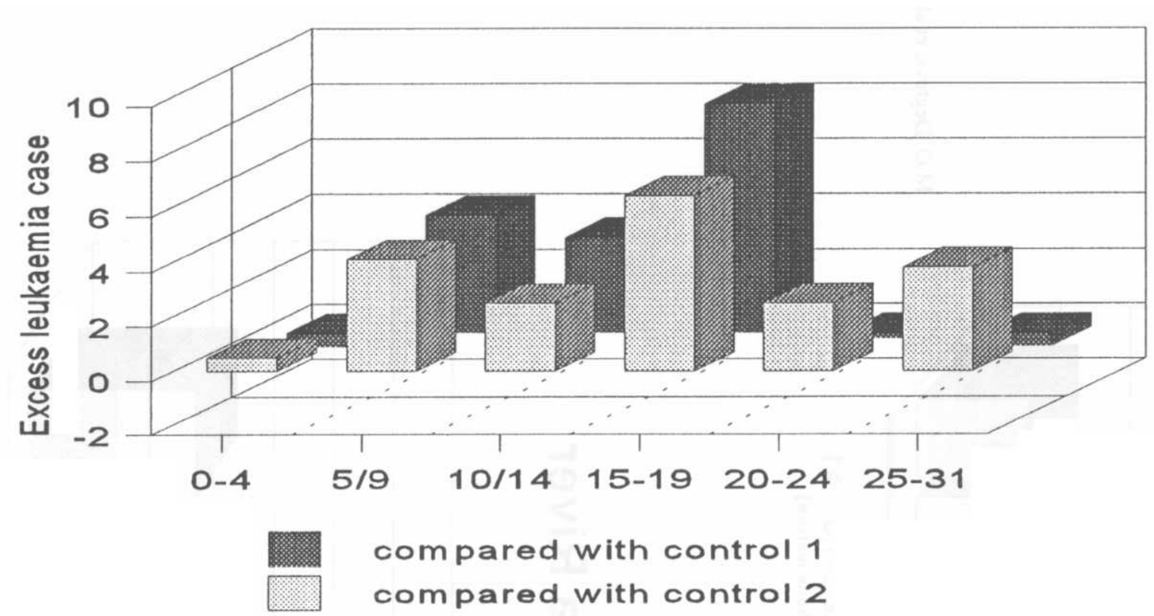


Table 4
Kossenko, et al., 1991

Comparison of the Leukaemia Risk Studies

Main characteristics	Techa river study	Atomic bomb survivors (Y. Shimizu e.a.)	Spondylitis series (S. Darby e.a.)	Cervical cancer series (J. Boice e.a.)
Size of exposed population	27800	42000	14000	83000
Sex composition	F=56%	F=59%	F=17%	F=100%
Age at irradiation, yr	0->90	0 - >90	>15	<30 - >70
Type of control	Regional rates and internal	Internal (34000)	National rates	National rates and internal
Type of irradiation	Chronic, external and internal included ^{90}Sr, ^{89}Sr, ^{137}Cs	Instantaneous whole-body	Fractionated, non-uniform partial body	Chronic, fractionated, parital body
Type of dosimetry	Individual (internal) and mean doses of a village (external)	Individual (DS86)	Individual	Mean dose of a sample
Dose distribution:				
mean dose, Gy	0.40	0.24	1.9	Extremely uneven
range of individual doses, Gy	0 - 30	0.01 - 6.0	0 - 8.06	
Person-years at risk	422000	1134000	184000	623800
Absolute risk per 10^4 PYGy	0.48 - 1.10	2.94 (2.43-3.49)	2.02	0.61

M.M. Kossenko et al., 1983

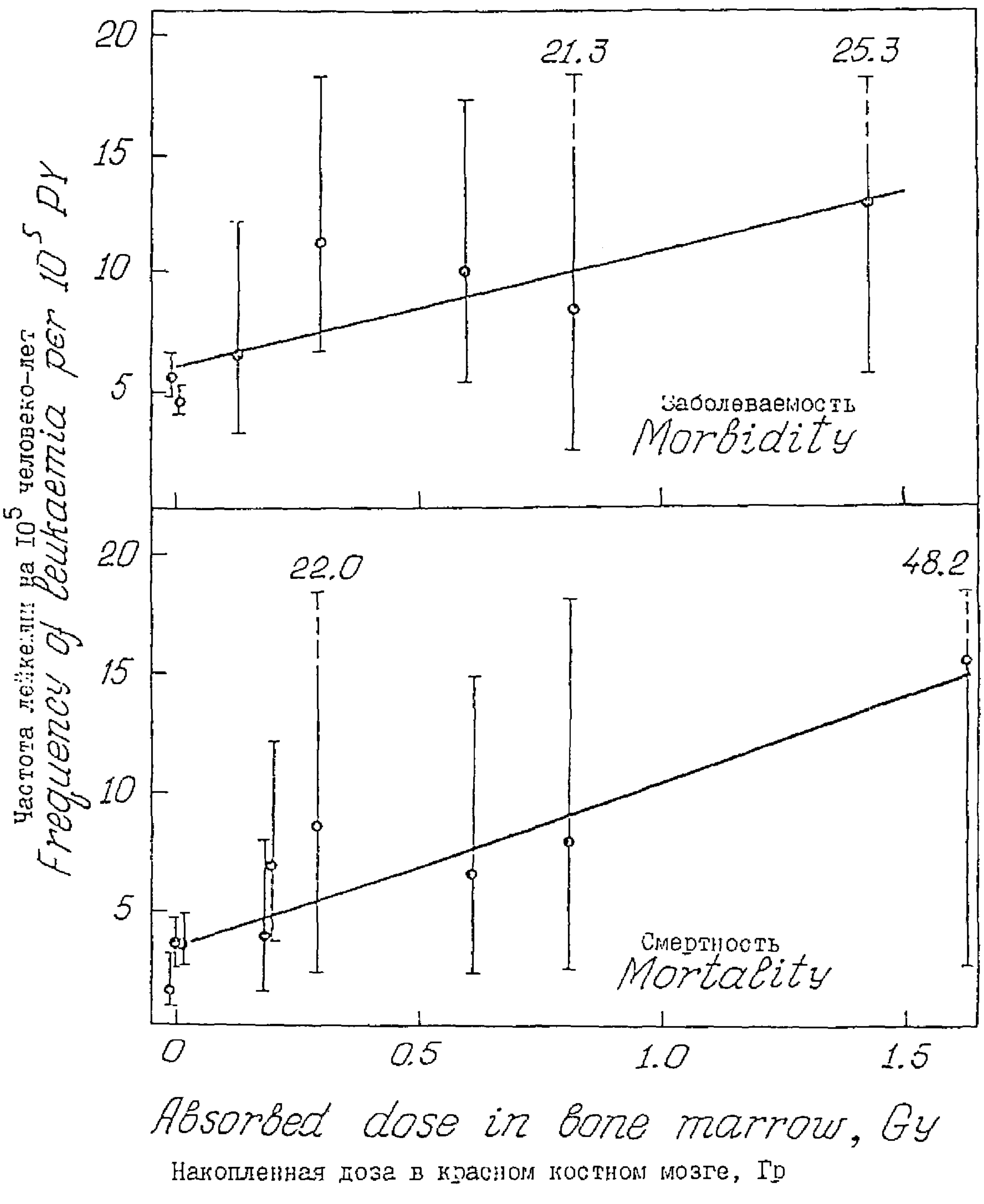


TABLE 5

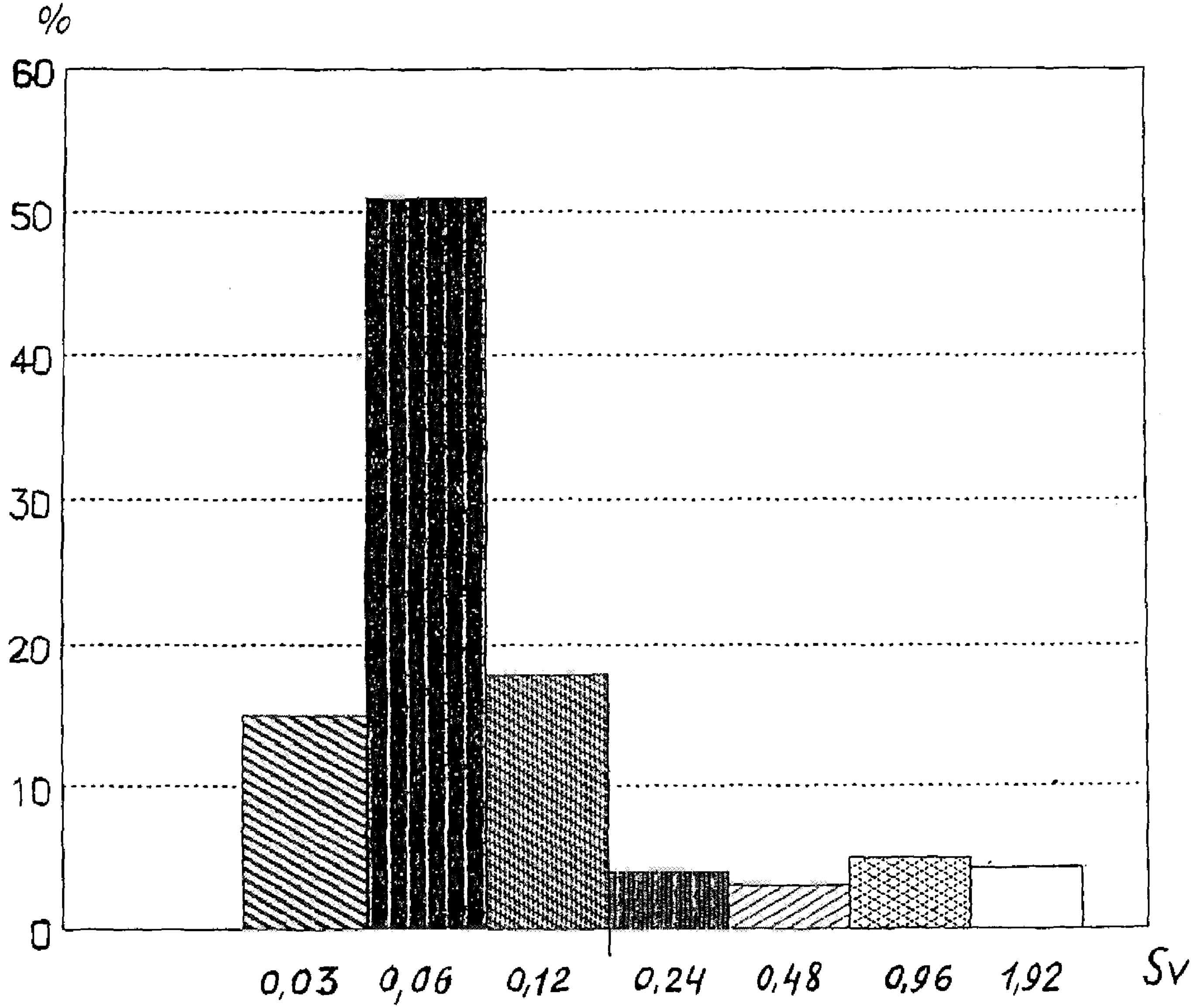
Kossenko M.M., Degteva M.O.

MORTALITY RATE AMONG IRRADIATED RESIDENTS

Group examined	Mean EED, Sv	Total Mortality x 10^{-3}	Mortality from Cancer		
			Number of Deaths	Mortality 10^{-5}	95% Confidence Intervals
1	52	11.5[a]	84	165.9[a]	132.2 - 205.4
	24	10.1	79	127.7	101.0 - 158.9
Control	-	9.8	425	114.1	103.4 - 125.5
2	140	14.0[a]	35	267.9[a]	186.5 - 372.4
	11	12.1	76	215.6	169.9 - 270.6
	7.5	12.0	274	210.8	[illegible]
Control	-	11.3	1437	177.2	168.3 - 186.5
3	7.4	13.3	226	172.1	150.1 - 196.2
Control	-	13.4	1501	160.0	152.9 - 169.4

a - in this variant, statistically significant differences from the control were found.

Distribution of doses to gonads, %



A.N. Komarova et al., 1993

Incidence of spontaneous abortions, ectopic pregnancies and stillbirths

Group	Pregnancies	Pregnancies without medical abortions	Mean age (yrs)	Spontaneous abortions		Ectopic pregnancies		Stillbirths	
				abs	%	abs	%	abs	%
Exposed	4033	2498	28.3	105	4.2 (3.42-5.11)	26	1.04 (0.68-1.53)	85	3.40 (2.72-4.20)
Control	1882	1485	27.8	48	3.2 (2.36-4.24)	8	0.54 (0.23-1.06)	41	2.76 (1.98-3.74)

Table 5

Cause-related mortality for progeny of irradiated population

Causes of death	Number of cases for 10^{+3} births			
	Group 1 (parental gonadal dose 0.011 Sv)	Control 1	Group 2 (parental gonadal dose 0.045 Sv)	Control 2
Neoplasms	0.0	0.07 (1)	0.5 (1)	0.14 (4)
Congenital abnormalities	2.3 (8)	1.3 (19)	1.0 (2)	1.1 (30)
Perinatal mortality	5.3 (15)	4.5 (66)	6.3 (13)	4.1 (113)
Inadequately diagnozed conditions	9.9 (28)	5.0 (73)	1.5 (3)	2.5 (69)

Note: the number of death causes is given in brackets

(6) Estonia Radiation Accident: Investigation of Source, Accidental Circumstances, Dose Assessment and Early Biological Effects

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Introduction

In November 24, 1994 the government authorities of the Estonian Republic have requested the Federal Department of Medical, Biological and Emergency Problems at the Ministry of Health and Medical Industry of Russia to invite the staff members of SRC-IBP to provide "emergency assistance in victims of radiation accident happened with powerful radiation source in Estonian Republic". The authors of present report have arrived to Tallinn in November 25, 1995 and started the patient observations, accident circumstances clarification, victims dose assessments, diagnosis formulation, and issuing the recommendations for patient treatment. We would like indicate the high professional level of Estonian physicians and specialists, whose cooperation gave the opportunity to get some success for solving above problems.

The radiation accident describing in this report is similar to the Goyania radiation accident (Brasilia, 1987) from the viewpoint of its origin (the collection of scrap metal for following selling), although, fortunately, the activities of radiation sources of the describing accident were hundred times lower and no source destruction (and following radioactive contamination) happened. The comparatively small number of people involved in this accident (6 persons) also represents the significant difference, however, one of these persons represents fatal case.

1. Source description and accident circumstances

1.1 Source description

According to information given by Estonian colleagues, the source was described as rectangular metal assembly (200x420x40 mm) with five cylinder channels, two of which have contained two radioactive metal cylinders ("pencils") of 35-40 m length and 1.5-2.0 mm diameter (There is a version that one "pencil" (hereinafter referred to as "Source 2") had 150 mm length) The total mass of the above assembly, which is possibly represents the part of radiation sterilization source assembly, was approximately 7 kg. The metal used for manufacturing of assembly and sources is unknown. No referral inventory marks or trademarks were found. Dose rate at the surface of the assembly exceeded 200 cGy/h (the upper limit of measurement of available dose meters). The assembly had a part of fixing accessory representing the metal hook. According to dose rate measurements at different distances from the source, the calculated dose rate at the source surface (1 cm distance) was 2000 - 3000 Gy/h According to the attenuation of radiation emitted by source situated in standard lead container, it is possible to conclude that the radiation source (Source 1) contained Cs-137.

All measurements of dose rates given the substantiation for consequent dose assessments of local exposure and whole body exposure were done by DP-5 dose rate meter.

One of the sources (Source 2) was thrown back to the Depository after a short-term contact with victim hands, the other source (Source 1) was deposited to the same Depository immediately after the revealing (November 18, 1994).

The activity of Cs-137 source (Source 1) was calculated to be equal to 3.33 TBq (90 Cu)

1.2 Accident circumstances

According to data collected by Estonian specialists and authors if present report, the accident occurred due to the extraction of the Source 1 from the low-level Radioactive Waste Depository situated near the town of Kiisa (40 km from Tallinn). The source was taken in October 21, 1994 by the RIH, the resident of Kiisa. The date of the source extraction was established indirectly through the statements of other persons, because RIH died before the date, when the accident was revealed.

Persons involved in the accident are:

RIH - went down to the Depository, extracted and handed assembly and Source 1, carried the Source 1 to the House 1 and House 2 (residence of RIH), stayed in House 1 within 6 hours at the distance of 3 m from Source 1, lived in House 2, where the Source 1 was found;

RAH - took the assembly from RIH, handed the Source 1 and threw it back to the Depository, walk together with RIH from the Depository to the House 1 (the residence of RAH and IVH), stayed in House 1 within 6 hours at the distance of 3 m from Source 1;

IVH - took the non-radioactive subjects from RIH, walk together with RIH from the Depository to the House 1 (the residence of RAH and IVH), stayed in House 1 within 6 hours at the distance of 3 m from Source 1,

TUR - took the Source 1 from the pocket of jacket of RIH, carried the Source 1 from the entrance room to the kitchen of House 2, lived in House 2, where the Source 1 was found;

ASA - lived in House 2, where the Source 1 was found;

BYK - lived in House 2, where the Source 1 was found.

There is a number of Kiisa residents (2 adults, 2 juveniles), who have visited the House 2 for a short time (1 hour or less) and were situated at 3 - 4 meters from the Source 1. House 2 is sufficiently remote from other neighbor houses, so the measured gamma dose rates provided the accumulated doses for all other persons (excluding those 6 persons involved in the accident) on the level of 0.5 cGy or lower.

1.3 Uncontrolled pathway of Source 1

From the moment of extraction of the Source 1 from the Depository and till the moment of the source revealing in the House 2, the presumable pathway of Source 1 was the following

Radioactive Waste Depository - RIH (jacket pocket)(October 21, 1994) - House 1 (residence of RAH and IVH) (night from October 21 to October 22, 1994) - entrance room of House 2 (residence of RIH, TUR, ASA, BYK) (October 22 - November 9, 1994) - kitchen of House 2 (November 9, 1994 - November 17, 1994) - Radioactive Waste Depository (night from November 17 to November 18, 1994).

1.4 Accident circumstances

The accidental events sequence can be reconstructed as follows

In November 21, 1994 RIH went down to the Depository, extracted different metal subjects (metal cans, source assembly etc) and handed them up to the top of Depository, where RAH and IVH took them. Two sources have fallen out from the assembly during these manipulations: one of the sources (Source 2) was immediately thrown back to the Depository by RAH, the other source (Source 1) was taken by RIH, who put it to his jacket pocket (possibly he did it, when he still was down in the Depository). Than RIH, RAH and IVH went to the House 1, which is a residence of RAH and IVH (45 minutes walk). RIH has taken off the jacket in House 1 and put it there, so the distance between source 1 and people situating in House 1 was equal to 3-4 approx. 6 hours later RIH put on his jacket (with Source 1 in the pocket) again and he was transported to his residence (House 2) by car RIH has taken off his jacket and left it in the entrance room. Due to the bad health condition RIH stayed at home and did not put on the jacket anymore. Later he was hospitalized in October 25, 1994 and died in November 7, 1994.

Probably, in November 9, 1994 TUR has taken the Source 1 from the pocket of jacket situated in the entrance room of House 2, put it to the tool box, which he has carried to the kitchen cupboard, where the Source 1 was found in the night from 17 to 18, November, 1994. Thus, the source was situated at the distances of 7 to 4.5 m from the sleeping places of people lived in House 2. The Source 1 was found, when TUR was hospitalized with suspecting radiation burns of hands.

2. Doses

The dose assessments given in Table below for local exposures and whole body exposures are based on dose rate measurements, exposition times and geometries and above scenario of accident events. The assessments of local dose of RIH were also confirmed by ESR (electron spin resonance) analysis of underwear clothes. Unfortunately, due to the time elapsed from the exposure moment, the extracted nails were not applicable for proper ESR analysis to be done in SRC-IBP laboratory.

3. Medical information

Taking into account the information obtained by Estonian colleagues, which is given in case histories the following medical picture can be given:

3.1 RIH, M, 25 years old

According to indications of the other persons involved into the accident, he has felt bad when he still was down in the Radioactive Waste Depository. 3 hours later he had many episodes of vomiting, which certifies to the severe initial reaction to the exposure (day "0"). Probably, this fact can be accepted, because the victim has kept himself in bed within all followed days (from day "+1").

Patient was admitted to the hospital in October 25, 1994 (day "+4") with intoxication manifestations; flabby blisters with light contents were determined in the left upper thigh skin and pelvic area.

The disease was interpreted as "Bywaters' syndrome" and respective treatment was provided (desintoxication, peritoneal dialysis, antibiotics, etc.)

Peripheral blood counts demonstrated leukopenia from lymphopenia and neutropenia with relative monocytosis at the first days of observation.

Retrospective dose assessment of total body exposure basing upon lymphocyte count at day "+5" (October 26, 1994) and day "+10" (October 31, 1994) (no other counts available) gives the dose value of 4 Gy approx. The total lymphocyte counts from day "+4" (October 25, 1994) to day "+12" (November 2, 1994) satisfactorily corresponds to "standard dose curves" for severe degree of bone marrow syndrome of acute radiation disease.

The course of the disease confirmed by laboratory tests demonstrated the development of renal insufficiency caused by massive decay of the soft tissues of thigh.

Thus, the diagnosis can be formulated as follows:

Diagnosis: Acute Radiation Syndrome of the extreme degree of severity (IV) caused by external extremely non-uniform gamma irradiation, local radiation injuries of thigh skin and subcutaneous tissues of IV degree of severity, bone marrow syndrome of III degree of severity.

Death of patient was probably caused by massive decay of thigh tissues and consequent intoxication incompatible with life.

3 2. TUR, M, 13 years old

The exact time of contact with Source 1 is unknown, but possibly the contact was happened in November 11, 1994. In November 14, 1994 the blisters filled with transparent liquid were revealed in the inner surface of 1st and 2nd fingers of right hand. These blisters were extracted in local ambulance

Due to the development of blisters on the right hand, patient was admitted to the oncological department of pediatric hospital in Tallinn in November 17, 1994. In November 25, 1994 the shallow erosions left on the inner surfaces of first and second digits of first and second fingers of the left hand with active granulation at the edges. Dry desquamation of epidermis was also found in the edge digit and in the second digit of the left hand (2x1 cm size) and the edge digit (1.5-0.5 cm of lateral edge) of the firs finger and 1st, 2nd digits of second finger (1.5x2 cm) and of the third finger (1x0.5 cm) of right hand.

The left hand erosions area decreased for two times in November 28, 1994 (from the edge sides, predominantly).

Peripheral blood counts demonstrated progressive leukopenia and thrombocytopenia, nasal bleeding episode is registered, when thrombocyte count was 30 x 10^9 /l, which forced donor thrombocyte transfusions.

External exposure dose assessment based upon the lymphocyte count in November 18, 1994 (day "+9") and neutrophile count dynamics certifies to possible exposure of dose of 2 Gy.

Diagnosis: Acute Radiation Syndrome caused by extremely non-uniform gamma- exposure; bone marrow syndrome of moderate degree of severity, local radiation injury of II degree of severity (distal and middle digits of 1st, 2nd fingers of the left hand) local radiation injury of I degree of severity (distal and middle digits of 3d finger of the left hand and 1st, 2nd, 3rd fingers of the right hand).

3.3 ASA, F, 75 years old

Patient was admitted to hospital in November 19, 1994. No signs of local radiation injury were observed. Somatic status has no peculiarities

Peripheral blood counts demonstrate moderate anemia, transient neutropenia and sufficiently serious thrombocytopenia. Lymphocyte count at day "+10" (November 19, 1994) corresponds to total body dose of 2 Gy, which also correlates to neutrophile dynamics (approximately 2 Gy or more). High color index attracts the attention (1.1 - 1 2), which most probably certifies to B_{12} deficiency status and thrombocytopenia can be the evidence of this status.

Diagnosis: Acute Radiation Syndrome of moderate degree of severity (bone marrow syndrome caused by relatively uniform gamma exposure).

3 4. RAH, M, 28 years old

Patient was admitted to hospital in November 21, 1994. Patient has contact with Source 2, which was thrown back the Depository.

Strong pains in hands occurred when physical load in October 28, 1994. Blisters were revealed in November 11, 1994

Surface erosion left on the inner side of the first finger and thenar of the right hand in November 25, 1994. Dry desquamation in hypothenar of the 1st, 2nd digits of first and second fingers of the right hand (the sites of flabby blisters). Dry peeling of inner surface of 4th and 5th fingers of the right hand. Dry peeling of stump of the first finger of the left hand (posttraumatic amputation was done 12 years ago on the basal digit level) and basal digit of the second hand (former flabby blister sites).

In November 28, 1994 the narrow erosion surface remained on the right hand.

No sufficient changes were found in peripheral blood counts.

Diagnosis: Local radiation injury of moderate degree of severity of both hands, whole body radiation exposure without disease signs.

3.5 BYK, F, 35 years old, IVH, M, 27 years old

Clinical observation and laboratory tests did not reveal changes to be considered as early radiation exposure consequences. The only exposure of doses, which levels do not cause the Acute Radiation Syndrome, can be considered. IVH possibly demonstrates the initial stage of B_{12} deficiency status.

4. Conclusions

4.1 The described incident have caused severe early medical consequences including one lethal outcome, acute radiation syndrome and local radiation injuries. According to the international practice, this case can be classificated as radiation accident, which requires medical assistance in all stages and specialized medical assistance for in-patient treatment.

4.2 Large complications and information losses caused by the absence of the detailed identification of source before its dumping back to the Radiation Waste Depository as well as by the late ESR analysis of victims' nails have significantly aggravate dose assessments for local and whole body exposures and, thus, introduced additional uncertainties for the estimates of radiation damage severity

5. Acknowledgments

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Fig. 1

RADIATION SOURCE ASSEMBLY

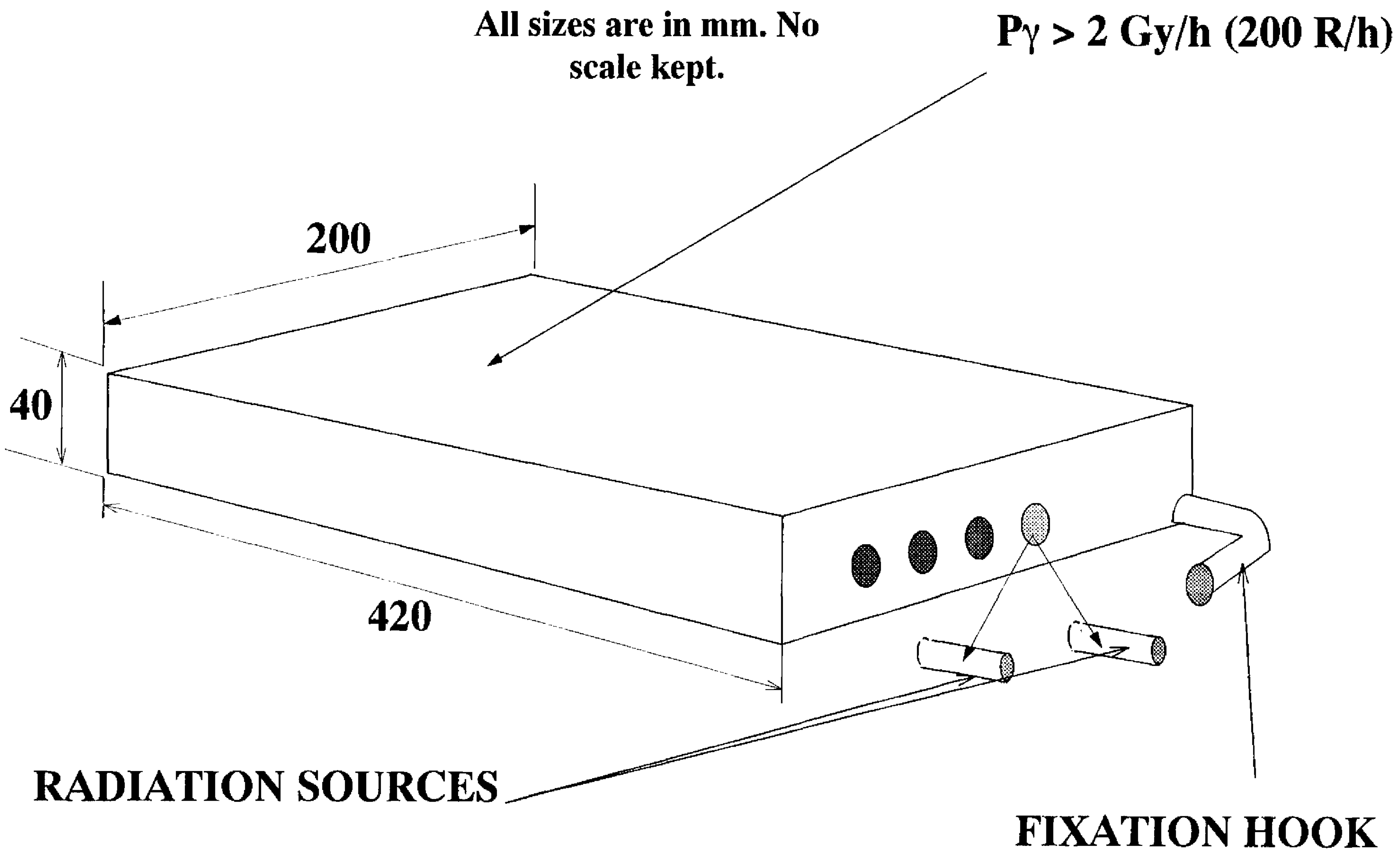

FIGURE 2

A SCHEME OF LOW-LEVEL RADIATION WASTE DEPOSITORY NEAR KIISA (ESTONIA)
(INDOOR ARRANGEMENT)

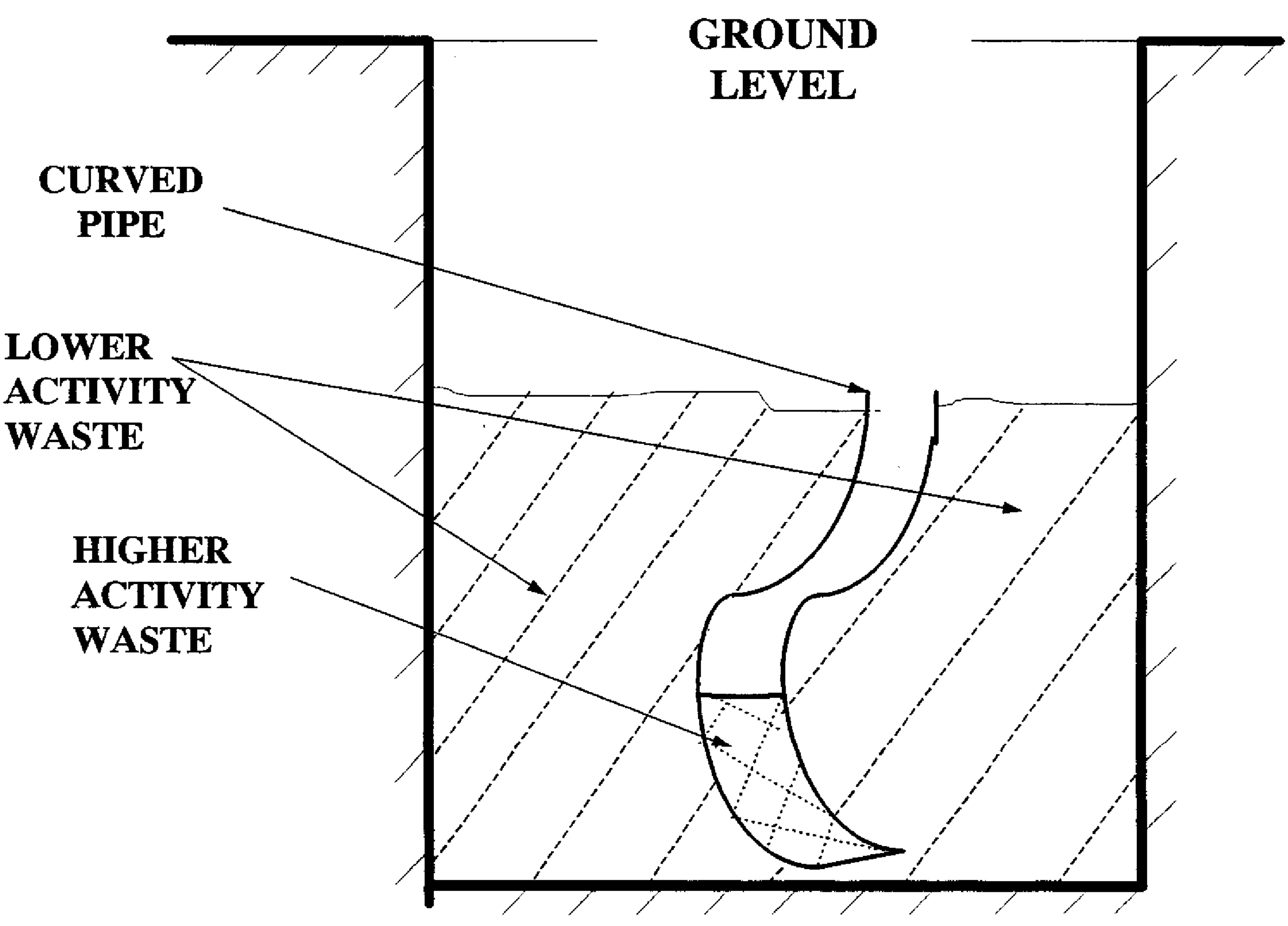

FIGURE 3

ACCIDENTAL PATHWAY OF RADIATION SOURCES

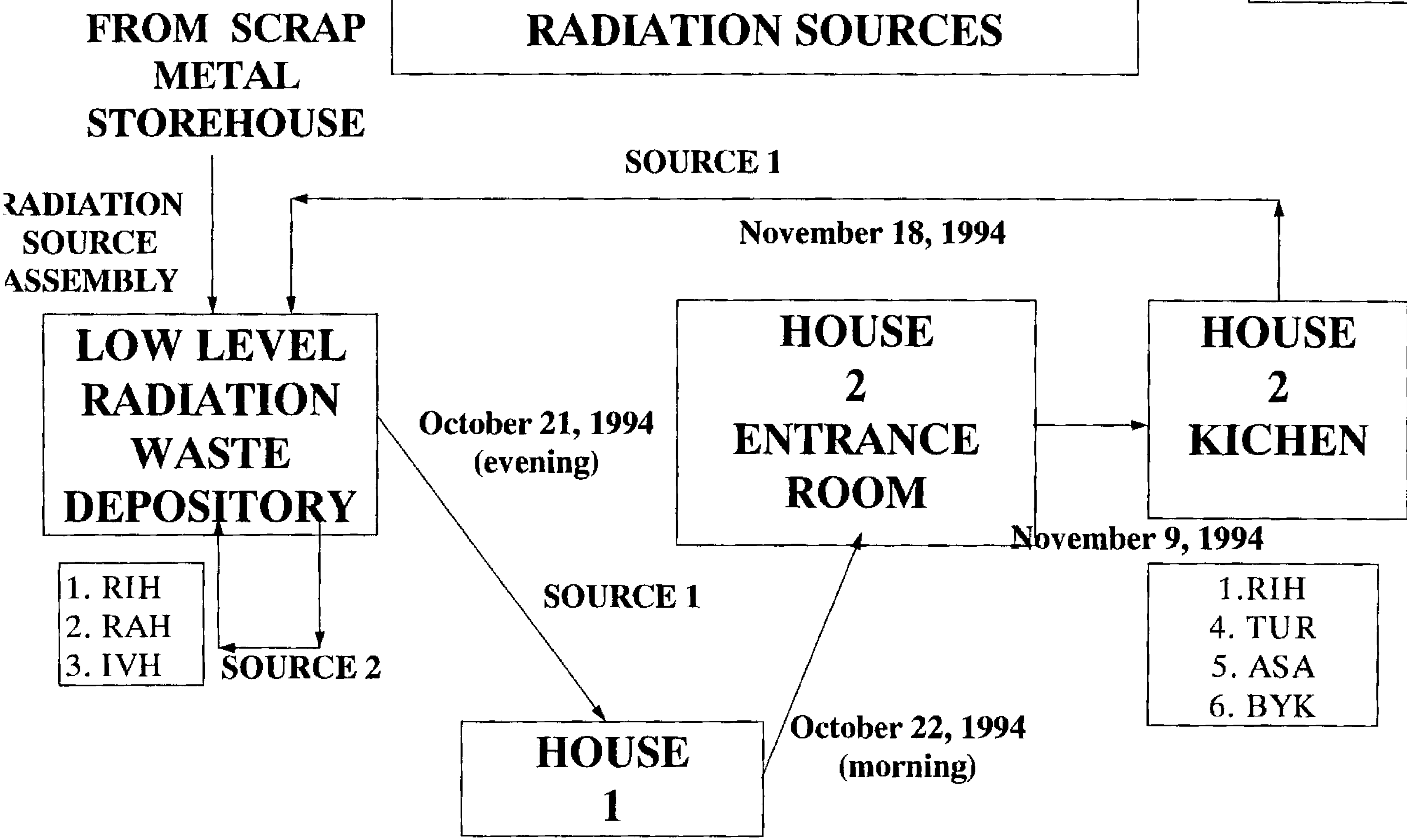

FIGURE 4

PLAN OF THE HOUSE 2 IN KIISA (ESTONIA), WHERE THE RADIATION SOURCE WAS EXTRACTED

Dose rates are expressed in cGy/h. No scale kept.

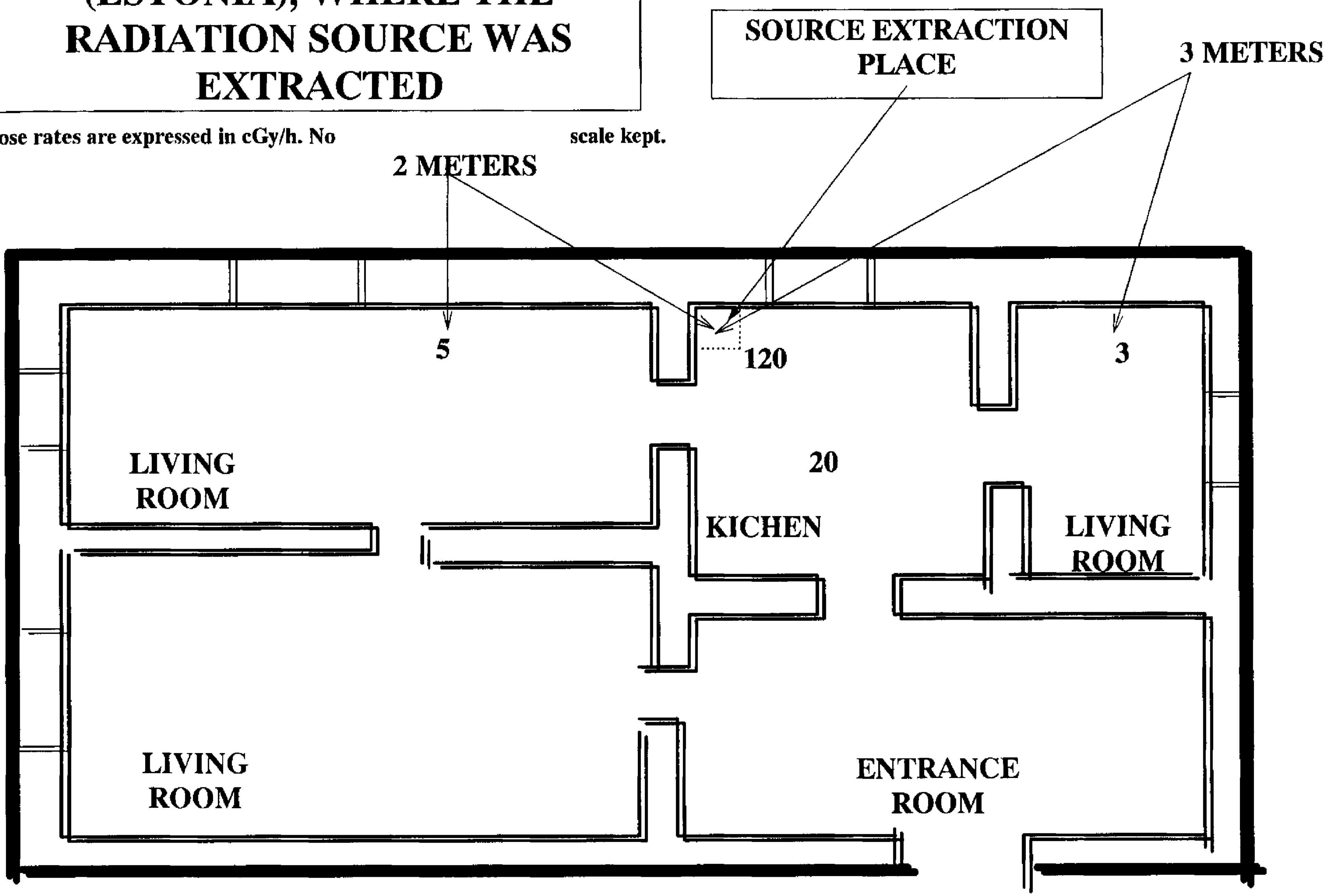

Table External exposure doses in victims of Kiisa accident (Estonia, 1994)

No.	Patient	Distance from the source to the specific body part		Dose rate, cGy/h	Time of contact [3]	Exposure doses and localisations	
		Distance, m	Body part			Dose, Gy	Localisation
1	RIH	0.01	thigh	$(2-3) \bullet 10^5$	55 min/single	≅4	whole body
		0.5	whole body	108	55 min/single	≅1830[1]	thigh
		7.1	whole body	0.5	110 hours		
2	TUR	0.01	hands	$(2-3) \bullet 10^5$	15 - 25 s	≅20 - 30	left hand
		0.5	whole body	108	30 - 40 min	≅8 - 10	right hand
		5.4	whole body	0.9 - 1.2	99 hours	≅2.5	whole body
3	ASA	3.0	whole body	3	27 ÷àñ	≅2 - 2.5	whole body
		4.5	whole body	1.3 - 1.5	153 hours		
4	RAH[2]	0.01	hands	$(2-3) \bullet 10^5$	15 s/single	< 1	whole body
		0.5	whole body	108	15 s/single	≅12 - 20	right hand
						≅8 - 10	left hand
5	BYK	7.1	whole body	0.5 - 0.8	72 hours	≅0.5	whole body
6	IVH	≥ 2	whole body	< 5	≤1 hour/single	<1	whole body

1 According to ESR-analysis data for clothes of RIH (underwear) the dose of local gamma exposure of thigh was 2100 Gy.

2 Local exposure of hands of RAH was caused by Source 1, which characteristics are unknown because RAH has thrown the Source 1 back to the Depository immediately after contact. It is accepted herein this report that the characteristics of Source 1 are similar to those of Source 2.

3 The contact periods of the transportation of source 2 from the Depository to the House 1, of staying of Source 2 in the House 1, of the transportation of source from House 1 to the entrance room of House 2 are taken into calculation but they are not shown separately.