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Preliminary assessment of current radiation doses to the population of Brodokalmak from contamination of the Techa River

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Abstract

Significant quantities of liquid radioactive waste were discharged to the Techa River in the southern Urals region of Russia in the early years of operation of the Mayak PA plant (1948–1951). A collaborative project is underway under contract to the European Commission to consider the radiological impact of radioactive contamination in the Southern Urals. Part of this project involves the calculation of radiation doses currently received by the population of Brodokalmak on the Techa river. The assessment made use of local data on the habits of the population and measurements of radionuclide activity concentrations in food and water. Exposure pathways included in the assessment were ingestion of foods and external exposure to gamma radiation from radionuclides deposited on the banks of the river. A range of doses was calculated for different age groups, firstly, assuming that the restrictions in place are retained and, secondly, assuming that there are no restrictions. These restrictions include bans on drinking river water, fishing and bathing in the river and the prohibition of use of the river and surrounding flood plains by humans and cattle. With restrictions the highest dose estimated was 0.56 mSv y^{-1} for the most exposed adults and without restrictions this increased to 3.4 mSv y^{-1}. Crown Copyright © 2000 Published by Elsevier Science Ltd.

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1. Introduction

The Mayak PA plant was built in the Russian region of Chelyabinsk near the town of Kyshtym (see Fig. 1) after the end of the Second World War to produce and reprocess weapons grade plutonium. The plant started operating at the end of 1948. Between 1949 and 1951 about 108 PBq of intermediate and low-level liquid radioactive wastes were released into the Techa river, which is part of the Iset-Tobol-Irtysh-Ob river system (NRPA, 1997). About 98% of this activity was released between December 1949 and November 1951. From November 1951 radioactive liquid releases of intermediate level waste were diverted to Lake Karachay resulting in a reduction of discharges into the Techa river. After the construction of two reservoirs and bypass canals in 1956 and 1963, to be used as repositories for liquid radioactive waste, releases of radioactivity into the Techa river were further reduced. The radionuclide compositions of the liquid releases varied throughout the years, but consisted mainly of medium- and long-lived beta emitting radionuclides; the main radionuclides discharged were ^{103,106}Ru (28 PBq), ^{95}Zr/Nb (14 PBq), ^{137}Cs (13 PBq) and ^{90}Sr (12 PBq) (NRPA, 1997). Current sources of radioactivity include infiltration

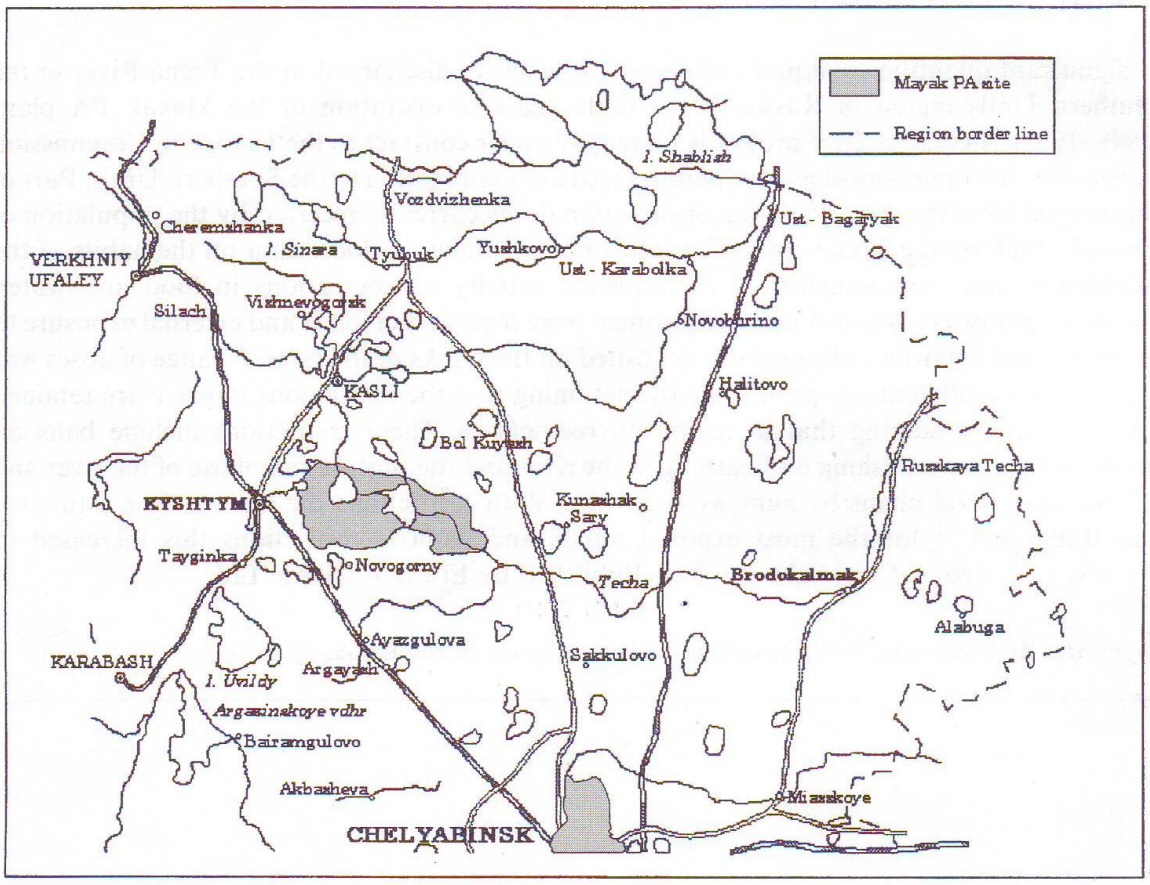

Fig. 1. The MAYAK PA plant and surrounding area.

of water through the reservoirs and by pass channels connecting the reservoirs and the Asanov swamp. The Asanov swamp is a boggy area located in the upper reaches of the Techa river, which became heavily contaminated during the early period of discharges. Run-off from the swamp as a result of the increase in water flow, especially during spring floods, is the main contributor to current releases into the Techa river. Total discharges from this area for the period 1962 to 1992 have been estimated at 108 TBq; the annual release for 1992 was estimated to be 1.7 TBq (NRPA, 1997). Releases due to leakage from the reservoir system are generally lower than runoff from the Asanov swamp by a factor of 3.

More than 120,000 people received high levels of radiation as a result of contamination of the Techa river; 7500 of the residents from 20 villages along the Techa river were evacuated between 1953 and 1961 (Akleyev & Lyubchansky, 1996; Kossenko, 1996).

In June 1996 a collaborative project on the radiological impact of the Mayak complex on the Southern Urals region was initiated by the European Commission. The project, called SUCON, is a collaboration between Danish, Norwegian and British scientists and is part of the IV Framework of the European Union programme on Nuclear Fission Safety. There are also related collaborative programmes with scientists from Russia and the Ukraine. One of the objectives of the SUCON study is the comprehensive assessment of current and future radiation doses received by the population residing in the affected area of the Southern Urals. As part of this task current doses to individuals living in Brodokalmak due to levels of contamination in the Techa river have been calculated. The assessment, presented in this paper, made use of local habit data and measurements of radionuclide activity concentrations in food and water, supplemented by model predictions whenever measurements in environmental materials were not available. Exposure pathways included in the calculations were ingestion of foods and external exposure to gamma radiation deposited on the banks of the river. Doses were calculated for three age groups (adults, children and infants) and two types of individuals: average consumers and users of the river banks, and individuals most likely to receive the highest dose. The latter individuals will be referred to in the remainder of this paper as "the most exposed group".

2. Material and methods

2.1. The study area

Brodokalmak (see Fig. 1) is a village located on both sides of the Techa river about 110 km from the release point. It is the second nearest village to the Mayak complex remaining along the Techa river following the evacuation. Several restrictions regarding the use of the Techa river and surrounding areas were introduced in 1953 (Degteva, Kozheurov & Vorobiova, 1994) and are still in place at Brodokalmak. The restrictions include bans on drinking river water, fishing and bathing in the river; access to the river banks and use of pasture for grazing animals along the river

banks are also prohibited. Farmers using these areas were allocated pastures in uncontaminated areas away from the river. A bridge across the Techa river connects the village to these areas. It seems that there is no strict control over the application of these measures at present and that the population still uses the Techa river and its banks, to some extent, to graze cattle and for fishing.

In 1996 a survey of the habits of the population of Brodokalmak (pop. 3600) was carried out by the Institute of Plant and Animal Ecology (IPAE) of Ekaterinburg. People surveyed were subdivided into three groups: adults aged 18 or more (70 individuals surveyed), children aged between 8 and 10 years (34 individuals) and infants up to 18 months of age (33 individuals). Data collected included the daily intake rates of terrestrial and aquatic foods and the number of days per week when these foods were consumed. Annual ingestion rates were calculated from these data with foods grouped together in broad categories to facilitate the calculation of doses. The arithmetic mean value of the intakes of the highest 10% of consumers was adopted as the ingestion rate of the most exposed group. The arithmetic mean value of the intakes for the remaining consumers was used as the average ingestion rate for the Brodokalmak population. The ingestion rates adopted in the assessment are reported in Table 1. No local data were available to estimate annual occupancy rates of the river bank or the bridge crossing the Techa river. Occupancy rates were therefore based on generalised UK data (Robinson, 1996) taking into account information on the activities of the population of Brodokalmak and the weather conditions for the region. Occupancy rates adopted in the calculations are given in Table 2.

Table 1
Annual ingestion rates of food of the population of Brodokalmak (kg y^{-1})

Food	Ingestion rate (kg y^{-1})					
	Adult		Children		Infants	
	Average	Most exposed group	Average	Most exposed group	Average	Most exposed group
Domestic vegetables	49	190	23	76	12	37
Potatoes	91	250	73	180	39	91
Root vegetables	31	160	20	86	9.2	51
Beef	14	63	11	37	7.4	24
Milk	75	330	79	480	170	370
Milk products	25	93	18	54	8.3	25
Chicken	11	42	6.1	26	4.5	20
Eggs	9.5	34	12	28	5.8	12
Bread	130	270	91	190	26	110
Cereals	17	60	17	37	10	67
Water	820	1200	550	960	170	570
Freshwater fish	24	100	16	34	4.2	16

Table 2
Annual occupancy rates of the population of Brodokalmak (h y^{-1})

Location	Occupancy rate (h y^{-1})					
	Adult		Children		Infants	
	Average	Most exposed group	Average	Most exposed group	Average	Most exposed group
Bridge	25	100	25	100	12.5	50
Flood plain	50	250	37.5	150	25	125

2.2. Measurements and model predicitions

2.2.1. Activity concentrations

Radionuclide concentrations in foods and other environmental materials were extensively measured by IPAE in the Brodokalmak area in 1996 and 1997. The monitoring programme focussed on ^{90}Sr and ^{137}Cs, considered to be the most radiologically important radionuclides because of their relatively long half-lives. The activity concentrations of ^{137}Cs were measured initially using a scintillating sodium iodide detector but later analyses were carried out using higher-resolution germanium spectroscopy. The ^{90}Sr measurements were made radiochemically on the ^{90}Y daughter. The methods used to carry out the measurements are described elsewhere (Trapeznikov et al., 1993).

A summary of the measurements taken is given in Table 3; when more than one measurement was taken the range of the observed value and the arithmetic mean value are given. Vegetables used in the measurements were collected directly from the kitchen gardens of habitations in Brodokalmak, washed and prepared as for consumption before being ashed. All observations of ^{137}Cs in vegetables were below limits of detection. Samples of freshwater fish were taken from both the Techa river and two lakes (Shablish and Miassovo). These two lakes are situated at some distance from Brodokalmak and are not generally used by people living in the village who prefer to obtain their fish from other lakes closer to the village. However, the activity concentrations observed in the two lakes are considered to be typical of the lakes in the Brodokalmak area and were therefore included in the assessment. Radionuclide activity concentrations in fish caught in the Techa river are an order of magnitude higher than those measured in fish taken from the lakes. Samples of water were taken from two artesian wells commonly used by the population for drinking water and from the Techa river. Radionuclide activity concentrations in river water are about two orders of magnitude higher than those observed in water taken from the wells.

Activity concentrations of ^{137}Cs in milk obtained from cows grazing on pasture away from the river bank (mean value: 7.1 Bq l^{-1}) are more than an order of magnitude lower than those in milk taken from cows which also graze on the flood plains of the river (mean value: 175 Bq l^{-1}) in spite of the prohibited access to the river

Table 3
Activity concentrations of ^{137}Cs and ^{90}Sr in foods and environmental materials measured in the Brodokalmak area (Bq kg^{-1} or Bq l^{-1})[a]

Material	Number of samples	Radionuclide activity concentration (Bq kg^{-1} or Bq l^{-1})			
		^{90}Sr		^{137}Cs	
		Range	Mean value	Range	Mean value
Soil (kitchen garden)	4	9.3–124	74	42.4–73.3	57
Pasture (on flood plain)	1		65		31
Water (artesian wells, drinking)	1/2		0.015	0.0036–0.0074	0.0055
Water (Techa river)	1		7.2		0.15
Milk (all cows)	7	1–5.6	3.6	1.8–230	55
Milk (cow grazing on non restricted pasture)	5	1–4.9	3.6	1.8–12	7.1
Milk (cows grazing on flood plain)	2	1.6–5.6	3.6	120–230	175
Potatoes	7	3.2–9.4	5.4		BLD
Domestic vegetables (cabbage)	1		28.5		BLD
Root vegetables (beetroot)	1		5.2		BLD
Fish (Techa river)	1		340		580
Fish (Shablish and Miassovo lakes)	2/3	41–48	45	38–92	58
Beef	1		0.6		0.6
Chicken	—		N/A		N/A
Egg	1		0.6		2.8
Cereals (wheat)	1/2		1.4	1.26–1.32	1.3

[a]*Note*: BLD Below limit of detection.
N/A Measurement not available.

banks. The activity concentrations of ^{90}Sr measured in the same milk samples did not show this effect. In the calculation of doses, radionuclide activity concentrations in milk products were assumed to be the same as those in milk and activity concentrations in bread were assumed to be the same as those in cereals. It was only possible to make one measurement of activity concentration in the meat of a cow grazing on unrestricted pasture; activity concentrations of ^{90}Sr and ^{137}Cs were also measured in eggs and cereals.

2.2.2. Gamma dose rates

Measurements of gamma dose rates were taken on the banks of the Techa river, the bridge and the village. Gamma dose rates were measured at 1 m above the ground using a portable DRG-01T1 with an uncertainty of $\pm$ 10%. Measurements in the village ranged from 70 to 110nSv h^{-1}. These observations are consistent with background radiation levels in the region and were therefore taken to be background. Measurements on the river banks were taken on both sides every 10 m starting from the bridge and up to 300 m each side of the bridge. Values measured ranged from 70 to

1400 nSv h^{-1}. A summary of the gamma dose rates measured in Brodokalmak is given in Table 4.

2.2.3. Model predictions — validation of measurements

Environmental transfer models (Brown & Simmonds, 1995; Simmonds, Lawson & Mayall, 1995; Carey, Jones & Mobbs, 1999) were used to predict radionuclide activity concentrations which had not been measured or which were below the limit of detection and to verify the consistency of the measurements taken. Activity concentrations of ^{137}Cs in domestic vegetables were determined from activity concentrations of this radionuclide in soil samples taken from the kitchen gardens where the vegetables were collected using equilibrium transfer factors (Brown & Simmonds, 1995). To ensure that this approach gave reasonable results activity concentrations of ^{90}Sr in vegetables were also calculated using the same method. As shown in Table 5, activity concentrations calculated using environmental models are in good agreement with the measurements. Similarly, activity concentrations of ^{90}Sr and ^{137}Cs in chicken were calculated from activity concentrations measured in eggs using equilibrium transfer factors (Simmonds et al., 1995; see Table 5). Environmental models were also used to calculate activity concentrations in milk and beef from the radionuclide activity concentrations in grass collected on the banks of the Techa river. Model predictions agree well with observations for ^{90}Sr, while the model seems to underestimate activity concentrations of ^{137}Cs in milk and overestimate activity concentrations of ^{137}Cs in meat. This discrepancy may indicate that the animal from which the beef sample was obtained did not spend as much time on the river bank pasture as the milk cow. The model for ^{137}Cs transfer to meat was, therefore, not used directly in the calculations but activity concentrations in the meat of cows grazing on the river flood plain were determined by scaling the activity concentration of this radionuclide measured in the meat of cows grazing on unrestricted pasture using the ratio of activity concentrations measured in milk in the two groups of cows.

Gamma dose rates measured on the banks of the Techa river were also validated against predictions of a computer model (Simmonds et al., 1995; Carey et al., 1999) calculated using profiles of activity concentrations of ^{90}Sr and ^{137}Cs in two soil samples taken by IPAE. Gamma dose rates measured in the village were added to the model predictions to take account of background. The model predictions were generally lower than the values observed though of the same order (see Table 6).

Table 4
Gamma dose rates measured in the Brodokalmak area (nSv h^{-1})

Location	Gamma dose rate (nSv h^{-1})	
	Range	Mean value/mid point
Village	70–110	90
Bridge	290–300	295
Techa river banks	70–1400	520

Table 5
Activity concentrations of ^{137}Cs and ^{90}Sr in foods and environmental materials predicted by environmental models (Bq kg^{-1} or Bq l^{-1})[a]

Material	Radionuclide activity concentration (Bq kg^{-1} or Bq l^{-1})			
	^{90}Sr		^{137}Cs	
	Measured	Model prediction	Measured	Model prediction
Potatoes	3.2–9.4	3.7	BLD	0.4
Cabbage (domestic vegetables)	28.5	22.3	BLD	0.4
Beetroot (root vegetables)	5.2	7.4	BLD	0.28
Chicken (from eggs)	N/A	0.08	N/A	25
Chicken (from wheat)	N/A	0.0056	N/A	0.58
Milk (cows grazing on flood plain)	1.6–5.6	1.1–13	120–230	10–56
Beef (from grass on Techa river banks)	0.6	0.2–1.9	0.6	60–340
Beef (from meat of cows grazing on unrestricted pasture)	0.6	0.6	0.6	15

[a]*Note*: BLD Below Limit of Detection
N/A measurement not available

Table 6
Gamma dose rates in air predicted by environmental models (nSv h^{-1})

Location	Gamma dose rate (nSv h^{-1})		
	Measured (range)	Model prediction	
		Without background	Including background
Left river bank	1000–1200	590	660–700
Right river bank	200–260	86	160–200

2.3. Dose assessment

2.3.1. Methods and assumptions

The doses estimated are the sum of the committed effective doses due to the ingestion of radionuclides during one year and the external effective radiation dose received during one year as defined by the International Commission on Radiological Protection (ICRP, 1991) for comparison with the annual dose limits. Committed effective doses due to internal irradiation are integrated to age 70 years for all age groups. Adults are taken to be 20 years of age for the purpose of this assessment. The doses are, therefore, not the doses actually received in a year but those that the population are committed to. Their actual doses include exposures from intakes in previous years, especially in the case of ^{90}Sr which has a long biological half-life. The

dose due to ingestion of radionuclides in a particular food is calculated by multiplying the activity concentrations in the food, the annual ingestion rate and the dose coefficient for ingestion. The dose coefficients for the three age groups considered are taken from ICRP 72 (ICRP, 1996). Doses due to external exposure were calculated using the mean value of the gamma dose rates measured on the flood plain or the mid-point of the range given for the bridge; the mid-point of the range of gamma dose rates measured in the village was subtracted from both values to take account of the contribution of background radiation.

Two scenarios were considered in the calculations. In the first scenario it was assumed that access to the river banks, for both people and cattle, was restricted. For the second scenario, doses were calculated assuming that restrictions were lifted and people had free access to all areas in the village. Doses due to ingestion of vegetables, chicken, eggs, bread and cereals remain unaffected by the lifting of restrictions, because crops are not grown on the river flood plains.

Assumptions for scenario 1 — restrictions in force

Radionuclide activity concentrations in milk and meat taken from cows which do not graze on the river flood plain were used in the calculation of doses for this scenario. Doses due to ingestion of fish and drinking water were calculated using activity concentrations in fish caught in the lakes Shablish and Miassovo and water extracted from artesian wells. Doses due to external exposure were calculated using gamma dose rates measured on the bridge only.

Assumptions for scenario 2 — restrictions lifted

For this scenario it was assumed that cows can graze on the river flood plains as well as on other pastures. Doses due to ingestion of milk and milk products were therefore calculated based on measurements of ^{137}Cs in milk from cows which also grazed on the flood plain. Doses due to ingestion of fish were calculated assuming that people in Brodokalmak consume only fish caught in the Techa river. Although it appears that the population of Brodokalmak drink exclusively water extracted from wells it was conservatively assumed that water used for human consumption is taken directly from the river. It was also assumed that people are allowed free access to the banks of the river. For this scenario, therefore, doses due to external exposure calculated using the mean value of the gamma dose rates measured on the river banks were added to the doses calculated using gamma dose rates measured on the bridge.

3. Results

Additional doses to individuals living in Brodokalmak calculated in the assessment are reported in Table 7. As discussed earlier these are the sum of the annual effective doses from external irradiation and the committed effective dose from ingestion during a year. In the calculation of doses to the most exposed groups it is unlikely that individuals in these groups consume all their foods at the highest intake rates. Therefore, doses due to ingestion of the two foods which give the highest doses were summed with doses of all other foods consumed at average intake

Table 7
Additional current annual doses received by the population of Brodokalmak (mSv y^{-1})

Age group	Dose (mSv y^{-1})					
	Scenario 1			Scenario 2		
	Average	Most exposed group		Average	Most exposed group	
		Two foods	All foods		Two foods	All foods
Adult	0.14	0.43	0.56	0.92	3	3.4
Children	0.17	0.39	0.53	0.95	2.3	2.7
Infant	0.13	0.26	0.37	0.72	1.6	2.0

rates. For purposes of comparison, doses calculated assuming that individuals in the most exposed group consume all their foods at the highest intake rates are also presented in Table 7. Tables 8 and 9 give the percentage breakdown of the doses by pathways and radionuclides. Only percentage contributions higher than 1% are shown in Table 8. The radionuclide percentages given in Table 8 were calculated as percentages of the total doses (sum of doses due to ingestion and doses due to external exposure).

3.1. Results for scenario 1

All doses calculated assuming that restrictions are still in place are lower than the annual effective dose limit for members of the public of 1 mSv recommended by ICRP (ICRP, 1991) and the annual whole body dose limit of 5 mSv imposed by current Russian legislation (NRS, 1987). In both cases the limits apply to the additional dose over and above that incurred by natural background radiation; furthermore, ICRP's dose limit applies to the dose that results from practices that are subject to its system of control. The Russian general dose limits for the population will change in year 2000 and will then include an effective dose limit of 1 mSv y^{-1} (NRS, 1996). For average consumers annual doses vary between 0.13 and 0.17 mSv y^{-1} for infants and children, respectively, while annual doses to individuals in the most exposed group range from 0.26 to 0.43 mSv y^{-1}. The latter doses would increase by between 0.11 and 0.14 mSv, if individuals were assumed to eat all their foods at the highest intake rate. The most significant pathways (see Table 8) for this scenario are ingestion of fish, milk and domestic vegetables. The contribution of ingestion of milk to the total dose is highest for infants while the contribution of ingestion of fish to the total dose is highest for adults. Ingestion of domestic vegetables accounts for between 18 and 35% of the total doses. Potatoes form an important part of the diet of people living in Brodokalmak and this is reflected in the contribution of ingestion of this food to the total doses (up to 14%). External exposure is not an important pathway for this scenario, accounting for less than 6% of the total dose.

Table 8
Exposure pathway contributions to the additional doses received by the population of Brodokalmak (%)

Scenario	Group	Age group	Ingestion										External
			Vegetables			Milk	Milk products	Bread	Water	Fish	Chicken	Others	
			Domestic	Potatoes	Root								
Restrictions in place	Average	Adults	27	10	3.2	10	3.4	5.1		33	2.5	1.5	3.6
		Children	23	14	3.8	14	3.2	5.3		31		3	3.1
		Infants	18	12	2.7	46	2.2	2.3		12	1	1.7	1.9
	Most exposed group	Adults	35	3.3	1.1	3.4	1.1	1.7		48		1.3	4.7
		Children	33	6.1	1.6	36	1.4	2.3		13		1.3	5.3
		Infants	29	5.9	1.4	49	1.1	1.2		6.3		1.4	3.9
No restrictions	Average	Adults	4.3	1.6		19	6.5		18	45		2.2	3.1
		Children	4.1	2.5		16	3.8		25	43		2.2	2.4
		Infants	3.4	2.2		57	2.7		13	18		1.6	2.0
	Most exposed group	Adults	1.3			26	2		5.6	59		1.1	4.6
		Children	1.7	1		41	1.6		11	39		0.9	4.0
		Infants	1.5			54	1.2		5.7	31		1.7	4.4

^{90}Sr is the more important of the two radionuclides considered, contributing between 72 and 85% of the total dose.

3.2. Results for scenario 2

The additional annual doses to individuals in the most exposed group calculated assuming that restrictions are lifted were between 1.6 and 3.0 mSv y^{-1}. These doses are significantly higher than the annual effective dose limit recommended by ICRP (1 mSv y^{-1}) and the effective dose limit that will come into force in Russia in year 2000. The doses are within the range of doses that people receive from natural radiation (2–10 mSv y^{-1}; Pavlenko, Los & Aksenov, 1995). People in this group would receive an additional dose of about 0.4 mSv y^{-1} if all foods were assumed to be consumed at the highest rates. Annual doses to average consumers range between 0.72 and 0.95 mSv y^{-1}. The two most significant exposure pathways for this scenario are ingestion of fish and ingestion of milk. This is a result of the high activity concentrations of ^{90}Sr and ^{137}Cs measured in fish caught in the Techa river and of ^{137}Cs in milk from cows which also graze on the flood plains. Ingestion of drinking water is a significant pathway for this scenario, contributing up to 25% to the total dose. This is due to the high activity concentration of ^{90}Sr in the water of the Techa river and the assumption made in the calculations that the water used for human consumption is extracted directly from the Techa river and consumed untreated.

Doses due to ingestion of vegetables and bread calculated for this scenario are the same as those calculated for scenario 1. The breakdown of the doses by radionuclide (Table 9) shows that the contributions of the two radionuclides included in the assessment are comparable. Doses due to ingestion of ^{90}Sr account for between 39 and 69% of the total, while the contribution of ^{137}Cs varies between 28 and 58%.

The percentage contribution of external exposure to doses calculated for this scenario is similar to that of scenario 1 (less than 5%) despite the increased exposure during time spent on the river bank.

Table 9
Radionuclide contributions to the additional doses received by the population of Brodokalmak (%)

Scenario	Group	Age group	^{90}Sr	^{137}Cs
Restrictions in place	Average	Adults	72	24
		Children	85	12
		Infants	82	16
	Most exposed group	Adults	73	22
		Children	82	12
		Infants	82	14
No restrictions	Average	Adults	51	46
		Children	69	28
		Infants	40	58
	Most exposed group	Adults	42	53
		Children	49	47
		Infants	39	56

4. Discussion

Doses have been calculated for the people of Brodokalmak for two scenarios, assuming that the restrictions described earlier in this paper are followed completely (scenario 1) and assuming that no restrictions are in place (scenario 2). In reality the situation is somewhere in between these two extremes with some restrictions being followed and some being ignored on occasion. For example, it is known that some cows graze on the river flood plain periodically but a lot of the cows do not. Also, people may spend some time on the river banks and may fish but such occasions are likely to be limited and it is unlikely that all of their fish would be obtained from the river. It is unlikely that people drink any water directly from the river other than inadvertently while swimming. Intakes from this source and the resulting doses are very small. For the majority of people in Brodokalmak their doses are likely to be as assessed for scenario 1. However, there may be individuals whose doses could approach those for scenario 2 depending on the extent to which they ignore the restrictions.

The people of Brodokalmak may be exposed through additional routes than those considered here. Some other pathways have been considered, notably those from wild foods such as mushrooms and berries, but the contribution to the total dose from these sources is insignificant as the river is the primary source of contamination. The possibility of cattle drinking the river water and people swimming in the water have also been considered, but again these pathways do not make a significant contribution to the total dose. There is the possibility that wild game birds (ducks, geese, etc.) could live in the area and be eaten by the local population: this pathway could contribute to the doses received by the population of Brodokalmak and this requires further investigation.

The assessment presented here should be regarded as preliminary, as further measurements are being made at the village. It should also be recognised that such an assessment inevitably has associated uncertainties. These arise from uncertainties in the measured activity concentrations, the habit data assumed and the methods used to determine doses. In the next phase of the work a probabilistic dose assessment will be carried out for Brodokalmak. In this future study, ranges will be adopted for the key parameter values (activity concentrations, intake rates, dose coefficients, etc.) and used to determine ranges on the calculated radiation doses.

5. Conclusions

Current annual committed effective doses have been determined for the population of Brodokalmak situated on the banks of the Techa river in the Southern Urals region of Russia. The doses should be recognised as preliminary and the uncertainties associated with the dose assessment have yet to be assessed. Nevertheless, the assessment does give an idea of the order of the radiation doses received and the main pathways of exposure. The doses calculated assuming that restrictive measures are in place are a small proportion of the annual dose limit for members of the general public recommended by ICRP for both average individuals and those people most exposed. However, the Techa river still represents a significant source of contamination for the

population of Brodokalmak. If restrictions were lifted doses could rise significantly, particularly for the most exposed individuals. Therefore, this preliminary study indicates that the restricted access to the Techa river and use of its banks should be kept in place.

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