StrålevernRapport 2008:3

Mayak Health Report

Dose assessments and health of riverside residents close to "Mayak" PA

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Østerås, 2008

Innhold

1 Introduction

This report complements the Joint Norwegian-Russian Expert Group publication (JNREG, 2004) that evaluated the risk of accidental scenarios at "Mayak" Production Association (Mayak PA) which could lead to radioactive contamination of the adjacent river system and potentially the Arctic seas, and assessed the long term consequences for Arctic populations. In this report, earlier estimates of doses to specific population groups living near Mayak PA and along the Techa River are presented, with regular referral to the published scientific literature, and the likely health effects to these populations are discussed. In addition, a brief overview of recent developments in dose estimation for the Techa River populations is given.

1.1 Objectives

- Assessment of internal and external radiation doses from contamination (past and present) to the Techa riverside populations, with focus on residents in Muslyumovo and Brodokalmak.
- Discussion of health effects on local populations related to discharges from Mayak PA.

1.2 History of Mayak PA

Construction of Mayak PA started in the Chelyabinsk province, close to the town of Ozyorsk (Chelyabinsk-65), in May 1946. The site, now covering about 90 km^2, lies between the cities of Yekaterinburg (Sverdlovsk) and Chelyabinsk, east of the Ural Mountains: 55º44′ N 60º54′ E. The first uranium graphite reactor ("A-plant") at Mayak PA started operation in June, 1948; the first batch of plutonium concentrate was produced by the radiochemical facility ("B-plant") in February, 1949. By August, 1949, the on-site chemical/ metallurgical facility ("V-plant") had converted the concentrate into weapons' grade plutonium. The facility was then expanded and consisted of seven military nuclear reactors in 1987, when production of weapons' grade plutonium ceased. Two of the reactors are still in operation today, producing radionuclides for civil and military purposes and the facility is also used for reprocessing radioactive fuel rods from both military and civil reactors (JNREG, 1997).

Creation of a nuclear weapon industry raised the problem of radiation safety for the workforce and people living in the vicinity of the plant. General sanitary standards and regulations were adopted in 1948, and medical services for workers were provided including a dosimetric service using individual film dosimetry. However, the radiation situation at the facility was not well managed during the first years of operation; average annual external doses to workers were 936 mSv at A-plant in 1949 and over 30% of the workers received doses of more than 1 Sv yr^{-1} in 1950 and 1951. External doses were normalised to 50 mSv year^{-1} in 1957. At B-plant the average annual external dose was more than 700 mSv year^{-1} for workers in the period 1949-1953 (Akleyev and Lyubchansky, 1994). In general, the Mayak workforce at the radiochemical and Pu reprocessing plants had considerable post mortem plutonium body burdens: 4.1 ± 11 kBq (n=120: Suslova *et al.*, 2002); 54 % had body burdens of < 1.5 kBq Pu.

1.3 Environmental legacy

Mayak PA was the first production reactor complex built in Russia and has historically been a source of significant radioactive contamination to the surrounding region (Figure 1). Drainage of the area is mainly via the Techa River, which forms part of the Techa-Iset-Tobol-Irtysh-Ob river system that finally discharges into the Kara Sea. In addition, a number of natural lakes and ponds on the Mayak site have been used as reservoirs to manage intermediate and low-level radioactive effluents. These include Lake Karachay and Lake Kyzyltash, Reservoirs 3, 4 and 17 (originally local ponds) and artificial Reservoirs 10 and 11, created by damming the Techa River. Since the early 1990s, confirmation of activities at Mayak and releases of radionuclides to the environment has become available in a number of publications (e.g., Trapeznikov *et al.*, 1993; Bradley and Jenquin, 1995; JNREG, 1997).

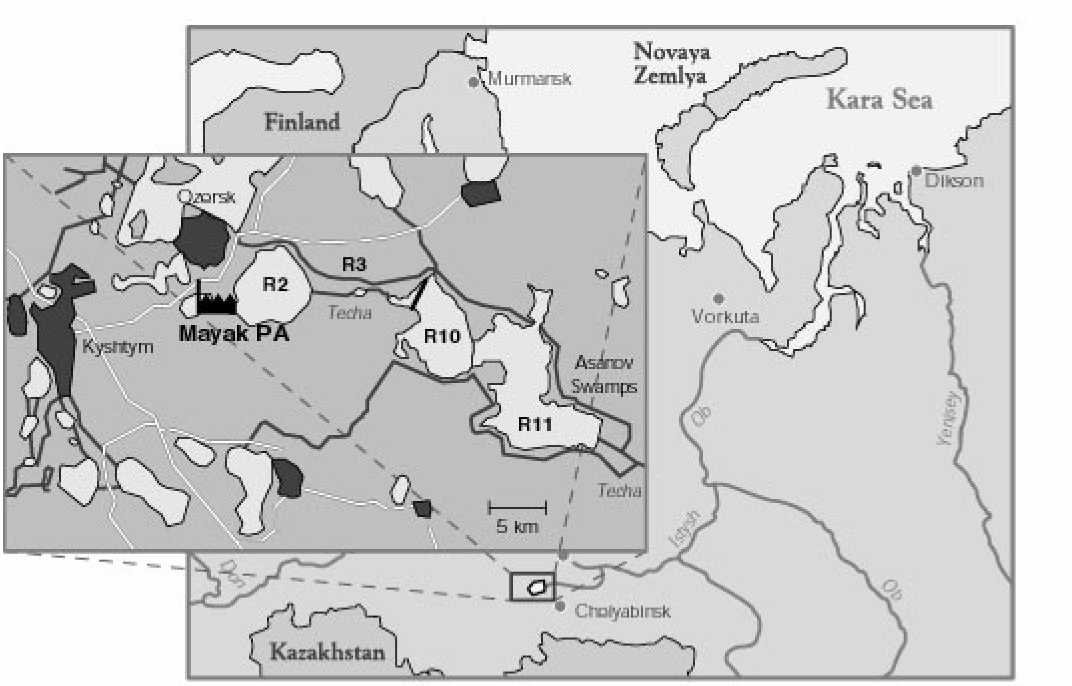

Figure 1. *Map showing Mayak Production Association (inset) and the Techa-Iset-Tobol-Irtysh-Ob river system, draining into the Kara Sea.*

1.3.1 Contamination events

Three significant contamination events have occurred at Mayak PA:

- Direct releases of radionuclides to the Techa (Reservoir 3) between 1949 and 1956
- The Kyshtym accident: an explosion in a high-level radioactive waste tank in 1957
- Wind dispersal of radionuclides from the dried out bed of Lake Karachay in 1967

Direct releases of radionuclides were made to the Techa river system via sedimentation ponds (Reservoirs 3 and 4) between 1949 and 1956, with approximately 98 % of the total activity released between December 1949 and November 1951. Over 100 PBq of radioactive material was discharged during the whole period (JNREG, 1997; Malyshev *et al.*, 1997), causing severe contamination along the entire length of the Techa River. Ruthenium isotopes (^{103}Ru, ^{106}Ru) and rare earth nuclides accounted for over 50 % of total activity releases and an estimated 12 PBq ^{90}Sr and 13 PBq ^{137}Cs were discharged. Alpha releases (including Pu and U isotopes) were lower, amounting to about 2 TBq according to discharge records (JNREG, 1997). Discharges of ^{90}Sr and ^{137}Cs during the period 1949-1957 contaminated 240 km^2 of the Techa River floodplain: an area of 80 km^2 had concentrations above 3.7×10^{10} Bq km^{-2} (Bradley and Jenquin, 1995). Construction of dams along the Techa was undertaken in order to contain the activity and act as a storage basin for low level wastes, creating reservoirs containing high levels of radionuclides such as ^{137}Cs, ^{90}Sr, ^{60}Co and isotopes of plutonium (JNREG, 1997; 2004).

The thermal explosion in a tank containing high-level liquid waste (HLW) in September 1957 created what has become known as the East Urals Radioactive Trace (EURT). Some 740 PBq was released during the accident but an estimated 90 % settled in the immediate vicinity of the explosion site. The remainder, about 74 PBq, was released in a plume that is assumed to have reached an altitude of 1 km and become dispersed by the wind in a NNE direction to form the EURT (Karavaeva *et al.*, 1994; Kryshev *et al.*, 1997; JNREG, 1997). The trace, with an initial contamination density of 3700 Bq m^{-2} ^{90}Sr or above (twice that of global fallout), was 300 km long and 30-50 km wide. The area that became contaminated was estimated as 15000-20000 km^2. Approximately 100 km^2 was defined as being a serious radiation hazard to man (>7.4 MBq m^{-2} ^{90}Sr).

The third contamination event occurred between 10 April and 15 May, 1967, when dried-out, contaminated sediments from Lake Karachay were dispersed by wind up to 50-75 km from the Mayak PA site. An estimated 22 TBq was deposited over 1800 km^2, leading to contamination concentrations in the range 11-210 kBq m^{-2} ^{137}Cs (Academy of Science, 1991; JNREG, 1997). Caesium-137 was the predominant long-lived radionuclide dispersed and may have accounted for 75 % of the total radioactive inventory (Aarkrog *et al.*, 1997).

1.4 Radiation-affected populations

Population groups exposed to radioactive contamination due to Mayak PA operations include:

1) The workforce at Mayak PA
2) Participants in clean-up work carried out after the accidental releases in the Urals
3) Local residents around Mayak PA who were exposed due to radiation discharges and accidents

Members of the third group (offsite population) are the focus of this report and have been subject to detailed studies where personal data on health status in the riverside population groups have been gathered in a registry, the Techa River Cohort (TRC). Highest radiation doses were received by residents in riverside villages along the Techa (28 000 people: Akleyev and Lyubchansky, 1994) and those within the initial deposition area of the EURT.

1.4.1 Local residents downstream of Mayak PA – direct discharges

The population exposed to Techa River contamination resided in four rural administrative districts (two in the Chelyabinsk and Kurgan Regions, respectively) and consisted of ethnic Russians [Slavic], Tartars and Bashkirs [Asiatic]; Tartars and Bashkirs constituted 24 % of the total exposed population. There were 41 villages on the Techa River downstream from the Mayak PA when the main discharges occurred in 1950, with a total population of 23 500. Most of the settlements were small with less than 500 inhabitants (Akleyev *et al.,* 2000). Four inhabited settlements remain on the Techa River in the Chelyabinsk region (in order of proximity to Mayak PA): Muslyumovo, Brodokalmak, Russkaya Techa and Nizhnepetropavlovskoye with a total population of 9229 persons according to the census of 1989 (Shutov *et al.*, 2002). Of the four remaining inhabited settlements along the river, internal and external dose assessments to the resident population have been studied for Muslyumovo and Brodokalmak in particular. The village of Muslyumovo stretches 6 km along both banks of the Techa River, some 47 km downstream of the industrial reservoirs. The population was 2550 in 1995, the majority (96.5 %) being Bashkir. The village of Brodokalmak stretches 4.5 km along the Techa River, 40 km downstream from Muslyumovo. The village population was 3700 in 1995 and mostly Russian (86 %). Inhabitants of both villages work mainly with local agriculture.

About 7500 people were evacuated from 20 settlements and villages along the Techa River between 1953 and 1960 (Figure 2) due to direct releases, after receiving average effective radiation doses ranging from 35-1700 mSv (Akleyev and Lyubchansky, 1994). More recently, a resettlement plan has been initiated for some residents in Muslyumovo, though it is unclear how successful or complete the results are to date.

Figure 2. ***Villages along the Techa River that were evacuated due to radioactive discharges from Mayak PA (JNREG, 1997).***

1.4.2 Local residents affected by the Kyshtym accident

The EURT (Figure 3) exposed populations in some districts of the Chelyabinsk, Sverdlovsk and Tyumen Regions (about 20 000km^2 with initial depositions over 3.7 kBq m^{-2} ^{90}Sr [0.1 Ci km^{-2}, Figure 3]: JNREG, 1997), amounting to 270 000 people in 217 settlements (Akleyev and Lyubchansky, 1994).

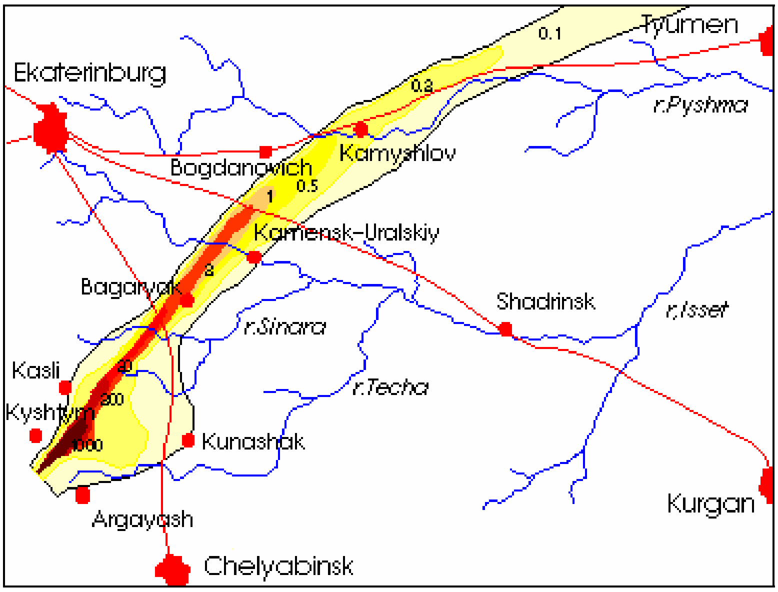

Figure 3. ***East Urals Radioactive Trace (EURT) initial contamination densities (Ci km^{-2}) of ^{90}Sr (SUCON, 2000). [1 Ci km^{-2} = 37 GBq km^{-2}]***

Approximately 10 200 people were evacuated from the contaminated areas after the Kyshtym accident. Residents in three villages located nearest the accident site (1054 people) received the highest doses, with average equivalent doses to red bone marrow of 570 mSv. The collective effective equivalent dose for the evacuated population amounted to 1300 personSv, while it was estimated as 4500 personSv for the whole population remaining in EURT territory (Akleyev and Lyubchansky, 1994).

1.4.3 Local residents affected after Lake Karachay dried out

The 1967 Karachay incident affected an area covering 63 populated areas, with a population of 41 500 enclosed by the 3.7 kBq m^{-2} ^{90}Sr isoline (Akleyev and Lyubchansky, 1994). JNREG (1997) reported that the ^{137}Cs contamination could be divided into two broad areas: 1800 km^2 with contamination densities in the range: 11-210 kBq/m^2 and 34 km^2 with contamination densities in the range: 210-765 kBq/m^2. The average individual dose from external radiation from this contamination was estimated as 13 mSv for 4800 people living closest to Lake Karachay, while doses of 7 mSv were recorded for more distant populations (Akleyev and Lyubchansky, 1994).

1.5 Countermeasures introduced

After the extent of the contamination of the Techa River became known, countermeasures were initiated to limit doses to the local population. Initial prohibitions on water use and evacuation began in 1951 along the upper part of the river. Hydrological engineering works such as damming the upper reaches of the river were performed, and wells were dug to supply newly constructed water pipelines. All villages on the upper part of the river, less than 78 km from the site of contamination release (7500 people), were evacuated between 1953 and 1961. The effectiveness of the evacuation was limited, however, since the riverside village populations had already received their main external and internal radiation dose before evacuation took place. A sanitary-protection regime was established where the Techa floodlands near villages were fenced-off to prevent the use of river water for drinking and domestic purposes. Fishing, breeding waterfowl and the use of floodlands for cultivation and pasture were abandoned (Akleyev and Lyubchansky, 1994). Restrictions on the use of the Techa and its river water were also introduced along downstream parts of the river in 1956. Some of these restrictions are still in place in the area, including bans on drinking river water, fishing and bathing in the river, access to the river banks and use of riparian pasture for grazing animals. However, no strict control of countermeasures is visibly enforced and local people still use the Techa River and the riverbanks to some extent.

After the Kyshtym accident in 1957, several protective measures were put into action in order to reduce population doses: 10 200 people were evacuated from the most contaminated sites at different times after the accident. Some foodstuffs and fodder were discarded and a sanitary control zone was established. In addition, the use of lakes for drinking water and fishing was prohibited, pasture and grassland was put under control and the state farms had to change their production profile (Akleyev and Lyubchansky, 1994).

Contamination from dried-out radioactive Karachay sediments in 1967 mainly affected areas within the 1957 EURT. Between 1976 and 1971, remedial work was carried out to fill in shallow areas of the lake and to re-cultivate the area surrounding it to prevent a similar dispersal event occurring in the future. The surface area of the lake was reduced from 0.51 km^2 in 1962 to 0.15 km^2 in 1994, and this process was planned to continue until the lake was completely filled (JNREG, 1997).

2 Current contamination levels

Several studies of radioactive contamination in the Mayak area have been performed. (e.g., JNREG, 1997, 2004; SUCON, 2000). This section gives a brief overview of current contamination levels around Mayak PA.

2.1 Contamination levels in soils

A summary of contamination densities for soils samples collected during 1994 in the vicinity of Mayak PA is presented in Table 1. Highest levels of ^{90}Sr contamination were observed for those sites in the EURT (14-34 MBq m^{-2} ^{90}Sr) and highest levels of ^{137}Cs contamination were observed in the Asanov Swamp at a distance of 7 km from Reservoir 11 (42 MBq m^{-2} ^{137}Cs). At the inhabited village of Muslyumovo (47 km from the industrial reservoirs) contamination densities of up to 10 MBq m^{-2} ^{137}Cs and 29 kBq m^{-2} total Pu were determined.

Table 1. ***Some contamination densities (kBq m^{-2}) for 0-10 cm soil core samples collected in 1994 from areas around Mayak PA (Table adapted from JNREG, 1997).***

Sampling location	**Contamination density (kBq m^{-2})**				
	^{60}Co	**^{90}Sr**	**^{137}Cs**	**Σ Pu**	**^{241}Am**
Repository site	<2.8 - 190	3400 - 11000	1200 - 3800	71 – 120	45 – 100
Health Protection zone	<0.05 - 0.075	97 - 180	210 - 380	2.3 - 2.4	1.0 - 4.3
Asanov swamp	BDL	130 - 10000	400 - 42000	1.1 – 85	n.a.
Techa river	BDL	62 - 350	470 - 2800	0.4 - 7.0	n.a.
Muslyumovo	<0.01 - <0.03	1000	4700 - 10000	13 – 29	<0.1 - <1.3
EURT	2.3 - 3.7	14000 - 34000	530 - 1400	12 – 17	5.9 - <11

BDL. = below detection level; n.a. = not analysed; Σ Pu = sum of alpha-emitting Pu isotopes

The distribution of radionuclide contamination in Techa River floodlands is heterogeneous: Shutov *et al.* (2002) reported ^{90}Sr and ^{137}Cs concentrations ranging between 600 to 4810 kBq m^{-2} and 110 to 1010 kBq m^{-2}, respectively, in floodplain soils taken from near Muslyumovo, consistent with the findings of Kryshev *et al.* (1997). In a comprehensive survey around Muslyumovo: 5000 measurements covering 16.6 km of river (2.5 km^{2}), Chesnokov *et al.* (2000) reported a maximum ^{137}Cs contamination of 30 MBq m^{-2}, although on river banks 7.5 MBq m^{-2} was observed approximately 1 m over normal river water levels. Contamination patterns were localised and visually related to river flooding regimes (86 % of total ^{137}Cs deposition was found in 43% of the sampled area). Kravtsova *et al.*, (1998) reported ^{137}Cs and ^{90}Sr concentrations ranging from 15 to 70 kBq m^{-2} and 7 to 33 kBq m^{-2}, respectively, in soils around Muslyumovo. Expected global fallout values in this area are 2-3 kBq m^{-2} and 1-2 kBq m^{-2} for ^{137}Cs and ^{90}Sr, respectively (Kravtsova *et al.*, 1998). The average ^{90}Sr concentration in Techa river water sampled at Muslyumovo village was 6 times the Russian intervention levels in July – August 2004, such that living in this settlement is seen as potentially hazardous to health by the Russian Federal Medical-Biological Agency (FMBA) (Romanov, 2006).

In Brodokalmak, maximum contaminations reported for ^{137}Cs and ^{90}Sr in floodplain soils were 7.4 MBq m^{-2} and 4.4 MBq m^{-2}, respectively (Kravtsova, 1998). A maximum contamination of 9.4 MBq m^{-2} ^{137}Cs was reported for Techa riverbank soils within the restricted area in the Brodokalmak settlement by Chesnokov *et al.*, (1999), with marked heterogeneity across their approximate 1 km^2 sampling area (97 % of area had contamination densities under 370 kBq m^{-2}). ^{137}Cs contamination densities determined in undisturbed soils in Brodokalmak village ranged from 3 kBq m^{-2} to 47 kBq m^{-2}, with an average of 14 kBq m^{-2} (Kravtsova *et al.*, 1998) i.e., about 5 times the global fallout level of ^{137}Cs contamination. The content of ^{90}Sr in soils from the village was somewhat lower, varying from 1.5 to 35 kBq m^{-2}, with an average value of 7 kBq m^{-2}: nearly 4 times higher than ^{90}Sr from global fallout. These data were obtained for samples collected in areas that do not usually become flooded and, therefore, contamination has probably occurred due to windblown dust, such as from Lake Karachay in 1967. Average values of ^{137}Cs activity in floodlands near the two settlements were estimated as 2070 kBq m^{-2} and 500 kBq m^{-2} for Muslyumovo and Brodokalmak, respectively.

In Cabianca *et al.*, (2000) ^{137}Cs activity concentrations in soils from kitchen gardens in Brodokalmak varied between 42.4 and 73.3 Bq kg^{-1} (mean 57 Bq kg^{-1}) while ^{90}Sr activity concentrations varied between 9.3 and 124 Bq kg^{-1} (mean 74 Bq kg^{-1}). Fieldwork conducted in 1998 yielded similar results for ^{137}Cs (n=7) and ^{90}Sr (n=2) activity concentrations in similar soils: 49±23 Bq kg^{-1} dw and 140±74 Bq kg^{-1}, respectively (Shutov *et al.*, 2002). Activity concentrations measured in comparable soil samples from kitchen gardens in Muslyumovo for ^{137}Cs and ^{90}Sr were 230±160 Bq kg^{-1} and 330±57 Bq kg^{-1}, respectively (Shutov *et al.*, 2002).

2.2 Contamination levels in groundwater, reservoir water and river water

Filtered water samples were collected from 2 boreholes in the vicinity of Lake Karachay in 1994. At a borehole 3.6 km SE of the lake, levels of 4200 Bq l^{-1} ^{60}Co and 8800 Bq l^{-1} ^{90}Sr were determined at depths below 50 m (JNREG, 1997). Caesium-137 activity levels were below 2 Bq l^{-1} at this site. Activity concentrations were considerably lower at a borehole 4 km south of the lake, with maximum levels of 270 Bq l^{-1} ^{60}Co and 68 Bq l^{-1} ^{90}Sr. Data from the regular monitoring of this second borehole show a steady increase in ^{90}Sr levels in the period 1989-1994 (JNREG, 1997).

Surface waters were sampled from the Mishelyak River, Reservoirs 10 and 11, the by-pass channels and Techa River in 1994 (JNREG, 1997). Highest activity concentrations were measured in Reservoir 10 (up to 14 kBq l^{-1} ^{90}Sr, approximately 100 Bq l^{-1} ^{137}Cs and 2 Bq l^{-1} ^{60}Co); activity levels decreased in Reservoir 11 (up to 2.4 kBq l^{-1} ^{90}Sr, 1.5 Bq l^{-1} ^{137}Cs and <0.1 Bq l^{-1} ^{60}Co). Concentrations of radionuclides in Techa River water, which primarily receives radionuclide contamination from the reservoir cascade via filtration of water through the dam from Reservoir 11 and into the by-pass channels, were fairly constant between the Asanov Swamp and Muslyumovo: levels of 7 to 10 Bq l^{-1} ^{90}Sr and 0.6 to 0.8 Bq l^{-1} ^{137}Cs were reported (JNREG, 1997). Results from similar water samples collected in 1996 were consistent with 1994 data. Data reported by Kryshev *et al.*, (1998) are in agreement with these concentrations and show that ^{90}Sr concentrations have decreased by a factor of 10^3 since 1951. Cabianca *et al.,* (2000) reported low ^{137}Cs activity concentrations in Techa River water, (mean 0.15 Bq l^{-1}) and mean ^{90}Sr activity concentrations of 7.2 Bq l^{-1}. Mean activity ^{137}Cs and ^{90}Sr concentrations were 0.0055 Bq l^{-1} and 0.015 Bq l^{-1}, respectively, in drinking water from artesian wells in the Brodokalmak area.

2.3 Contamination levels in biota and food products

Local fish has been recognised as an important source for human exposures in populations living along the Techa River (Kryshev *et al.,* 1997). Samples of pike filet (*Esox lucius*) collected in 1994 from Reservoirs 10 contained 80 to 140 kBq kg^{-1} ^{137}Cs (fresh weight), while whole perch (*Perca fluviatilis*) contained up to 130 kBq kg^{-1} ^{137}Cs. Pike filet samples from Reservoir 11 contained 1.3 kBq kg^{-1} ^{137}Cs, while similar samples collected from the Techa River at Muslyumovo contained 400 Bq kg^{-1} (JNREG, 1997). Kryshev *et al.,* (1997) reported 450±110 Bq kg^{-1} fw ^{90}Sr and

18±8 Bq kg^{-1} fw ^{137}Cs for locally caught fish in the riparian villages along the Techa River between 1991 and 1993.

Results from fieldwork in 1998 showed that the average activity concentrations in fish muscle from the river (samples of mixed species) were higher than any other measured local biota: 79 and 9 Bq kg^{-1} for ^{90}Sr and 220 and 69 Bq kg^{-1} ^{137}Cs near Muslyumovo and Brodokalmak, respectively (Shutov *et al.*, 2002). ^{90}Sr activity concentrations in fish bones were considerably higher with mean values of 6180 and 141 Bq kg^{-1} in samples from Muslyumovo and Brodokalmak, respectively. For the majority of vegetables, root crops and garden berries grown in Muslyumovo and Brodokalmak, activity concentrations of both ^{90}Sr and ^{137}Cs are less than 5 Bq kg^{-1} (Shutov *et al.*, 2002).

Milk is also very important to exposure levels in local populations, as Techa floodlands are used as pasture for local cows. Kravtsova *et al.,* (1998) reported from a database containing 1185 and 1061 values for ^{137}Cs and ^{90}Sr contamination in milk, respectively, including data from 1992 to 1998. All milk samples were divided in two groups. The first group included milk produced by cows which had access to the floodplain, the other included cows grazing beyond the floodplain. The mean activity concentrations of ^{137}Cs and ^{90}Sr were approximately a factor of 10 higher in samples from cows that had grazed on the floodplain. Maximum ^{137}Cs concentrations were 200 Bq kg^{-1} in Muslyumovo compared to 66 Bq kg^{-1} in Brodokalmak. Corresponding maximum concentrations for ^{90}Sr were 37 and 5.6 Bq kg^{-1}.

Other studies give similar results for radionuclide concentrations in food products. Cabianca *et al.* (2000) report that activity concentrations of ^{90}Sr and ^{137}Cs were low (< 10 Bq kg^{-1} of both ^{90}Sr and ^{137}Cs) in most food products consumed by the population of Brodokalmak, except for fish and in milk from cows grazing on the flood plain. The highest activity concentrations of ^{90}Sr in vegetables were found in cabbage from a private garden. The monitoring results from different studies are given in Table 2 for ^{90}Sr and Table 3 for ^{137}Cs.

The monitoring data given in Tables 2 and 3 show small variations between the different studies, and from year to year. Data for ^{90}Sr show that it exists at quite low concentrations in most food stuffs, though fish caught in the Techa River are clearly a possible source of ^{90}Sr to the local population. ^{137}Cs is also present at quite low concentrations in most foodstuffs apart from milk and fish caught in the Techa River. Milk data for cows grazing on non-restricted (i.e. away from the river bank) and restricted pastures show a clear difference for ^{137}Cs with averages of 7 Bq kg^{-1} compared to 175 Bq kg^{-1}, respectively (Cabianca *et al.,* 2000).

Table 2. ***Monitoring data (mean and range) of ^{90}Sr activity concentrations in foodstuffs (Bq kg^{-1}) in Muslyumovo and Brodokalmak from different studies performed in 1990-1998.***

Product	**Cabianca *et al* (2000)**	**RECLAIM report (2000)**		**Romanov (1989)**	
	Brodokalmak	Brodokalmak	Muslyumovo	Brodokalmak	Muslyumovo
Milk	3.6 (1-5.6)	0.8 (0.04-5.7)[a]	1.7 (0.04-37)[a]	0.82 (0.4-1.2)[c]	0.60 (0.37-0.74)[b]
					0.80 (0.7-1.0)[c]
	Non-restricted pastures:				
	3.6 (1-4.9)				
	Flood plain pasture:				
	3.6 (1.6-5.6)				
Potatoes	5.4 (3.2-9.4)	0.63±0.37	0.65±0.34	0.38 (0.21-0.85)[c]	0.30 (0.15-8.1)[b]
					0.55 (0.27-1.5)[c]
Vegetables	5.2-28.5	<4	<5		
Meat	0.6	<1	<4		
Egg	0.6	1.6±1.3	2.0		
Cereals	1.4 (1.26-1.32)				
Fish					
Techa River					
Lakes	340	150	2.7		
	45 (41-48)				

Dates: a = (1990-1997), b = (1994-1997), c = (1998)

Table 3. ***Monitoring data (mean and range) of ^{137}Cs activity concentrations in foodstuffs (Bq kg^{-1}) in Muslyumovo and Brodokalmak from different studies performed in 1990-1998.***

Product	**Cabianca *et al* (2000)** Brodokalmak		**Reclaim report (2000)**		**Romanov (1989)**	
	mean	Range (n)	Brodokalmak	Muslyumovo	Brodokalmak	Muslyumovo
Milk (all)	55	1.8-230 (7)	4.4 (0.04-292) (n=266)[a]	15.3 (0.04-1890) (n=961)[a]	0.71 (0.4-1.1)[c]	1.3 (0.37-6.7)[b]
Non-restricted pastures:	7.1	1.8-12 (5)				2.8[c]
Flood plain pasture:	175	120-230 (2)				
Potatoes	BDL		0.16±0.10	0.36±0.20	0.74 (0.5-1.4)[c]	0.63 (0.37-6.3)[b]
						1.0 (0.8-1.3)[c]
Vegetables	BDL		<0.4	<4.6		
Meat (poultry and beef)	0.6			<14		
Egg	2.8					
Cereals	1.3	1.26-1.32				
Fish						
Techa River	580			220±48		
Lakes	58	38-92 (3)				

BDL – below detection level

Dates: a = (1990-1997), b = (1994-1997), c = (1998)

3 Dose assessment

The populations living along the Techa River were chronically exposed to radiation, both externally and internally. Villagers were exposed via many different pathways, of which drinking water from the Techa River was one of the most significant. External irradiation from the Techa River bottom sediments and shoreline was also an important factor. The river was the main source (sometimes the only source) of water for households in the riverside villages. Techa river water was also given to cattle, used for watering vegetation, breeding waterfowl, fishing, bathing and washing. The radionuclides contributing most to the dose commitment were ^{89}Sr, ^{90}Sr and ^{137}Cs.

3.1 Dietary habits

A survey of dietary habits of the population of Brodokalmak was carried out in 1996 by the Institute of Plant and Animal Ecology (IPAE), Ekaterinburg (reported in Cabianca *et al.,* 2000), investigating the intake of different food products. In 1998, another survey of the dietary habits of the population in Muslyumovo and Brodokalmak was carried out by the Russian Research Institute for Radiation Hygiene (IRH), St. Petersburg (RECLAIM, 2000). In this survey, 112 people (71 women and 41 men) were polled in Muslyumovo, and 20 people (14 women and 6 men) in Brodokalmak. The obtained intake rates for adults from both studies correspond quite well with each other and are given in Table 4. Consumed foods stem mainly from private gardens and local agricultural enterprises.

Table 4. ***Assumed intake of different food products in Muslyumovo and Brodokalmak***

Food product	**RECLAIM (2000) (kg y^{-1})**		**Cabianca *et al.*, 2000 (kg y^{-1})**	
	Average	Range	Average	Most exposed group
Milk	255	0 – 1280	100	423
Meat	55	0 – 175	25	105
Potatoes	146	26 – 365	91	250
Vegetables	55	0 – 110	80	350
Fish	37	0 – 183	24	100
Bread			130	270
Water			820	1200

3.2 The Techa River Cohort

In 1967 a systematic program to define fixed cohorts of Techa River residents was started (Kossenko *et al*., 1997). About 26500 people who lived in villages along the Techa River during the period of the highest releases (1949-1952) and for whom residence records are available were enrolled in a cohort now known as the Original Techa River Cohort (OTRC). Over the years, about 5000 people born prior to 1950 who had moved to one of the riverside villages between 1953 and 1960 were added to the database (“late entrants”). In 1998, these two groups were merged to form the Extended Techa River Cohort (ETRC). In September, 2001, the ETRC included 30136 people of whom 4953 were late entrants (Kossenko *et al*., 2002). A third cohort consists of about 30 000 children born to exposed parents since 1950: the Techa River Offspring Cohort (TROC). The complete registry of exposed populations living around Mayak PA also contains information on exposed persons in the EURT area. Altogether, the database contains personal data for about 80 000 individuals; 17 000 of whom are from the EURT area.

The catchment area for the OTRC included the territory of five rural districts in the Chelyabinsk and Kurgan districts through which the Techa River flows. These districts include all of the contaminated villages, as well as all villages where people were evacuated to from the most contaminated villages. Death certificates and other documents about cohort members could be routinely obtained from these areas. The database also contains information such as residence history and results of medical and dosimetric examinations of a population including individuals who have received unusually high doses, but at low to moderate dose rates.

It is important to note that attaining the required data for such a large population group is not without difficulty: published results for TRC members are based on incomplete follow-up due to migration, missing records and unknown causes of death. Limitations and future plans for cohort analyses are further discussed in Kossenko *et al.,* (2002).

3.3 Dose reconstruction

Reconstruction of the source term and amounts of radioactive material discharged into the Techa River has been very important for dose reconstruction. Operational data like the history of dam construction and watercourse changes have been studied as well as environmental monitoring data to obtain the best possible estimate of the exposure of inhabitants along the river. The reconstructed source term is about 100 PBq (10^{17}Bq) of fission products released into the Techa River: most (~98%) is assumed to have been discharged during 1950-1951 (JNREG, 1997; Vorobiova *et al.*, 1999). Environmental monitoring data were not available for the first three years of operation so modelling has been used to fill in the missing information.

The average effective dose equivalents (representing dose accumulation over 25 years) for persons in the OTRC were estimated to be from 0.074 Sv to 1.4 Sv, with average absorbed doses to bone marrow estimated as from 0.176 to 1.64 Gy (Kossenko and Degteva, 1994). Initial calculations indicated that individual bone surface doses and external doses could have exceeded 2 Gy (Degteva *et al.*, 1994). Dose reconstruction methods are undergoing continuing refinement with the development of the Techa River Dosimetry System (TRDS-1996 and 2000: see Degteva *et al.*, 2000a).

3.3.1 Internal doses

^{90}Sr, with it's half-life of 29.1 years, was the main contributor to internal exposure, as it accumulates in bone tissues (follows Ca) and is retained for many years. Therefore, absorbed doses from ^{90}Sr in red bone marrow and bone surfaces have been calculated for all age cohorts. As ^{90}Sr accumulates in bone tissues, children and adolescents (who are growing) accumulate more ^{90}Sr than adults. Reconstruction of internal dose depends on estimates of intake and models for metabolism of ingested radionuclides. *In vivo* measurements of ^{90}Sr in teeth enamel, performed since 1959, have given information about the annual intake of ^{90}Sr. Measurements of ^{90}Sr whole body content have been necessary for estimating the metabolism of the radionuclide in the human body and thereby find realistic dose conversion factors. Monitoring people living along the Techa River began in 1951, including an extensive program for measuring whole body contents of long-lived radionuclides. Over half of the members of the ETRC have had individual measurements of whole body content of ^{90}Sr.

In the early 1950's, analyses involved radiometric measurements of bioassay and autopsy samples. This program continued up to 1993, with over 7500 analyses performed on bone samples from 5400 autopsies. *In vivo* measurements started in 1959 by measuring beta activity in front teeth. Since 1974, a special whole body counter has been used to measure whole body contents of ^{90}Sr and ^{137}Cs (Degteva *et al.*, 2000b). About 30000 measurements have been collected on more than 14000 people. Further description of the internal dose reconstruction systems can be found in Degteva *et al.* (2000b).

Other radionuclides contributing to internal doses were predominantly ^{89}Sr and ^{137}Cs. Intake rates of ^{89}Sr and ^{137}Cs have been derived from estimates of ingestion of ^{90}Sr scaled in terms of the radionuclide composition of river water. The TRDS database contains age-dependent mean-annual-intake levels for ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{137}Cs and ^{141,144}Ce (Degteva *et al.*, 2000a).

3.3.2 External doses

All available results of dose rate measurements on the shoreline were retrieved for the reconstruction of external dose to the population along the Techa River in the period 1950-1990. The highest dose rates were at the river and by the riverside. Absorbed doses due to external exposure were estimated on the basis of systematic measurements of gamma dose rates along the banks of the river and the typical living patterns of inhabitants in riverside villages. Reconstruction of external dose requires information about population behaviour, such as time spent indoors and outdoors, what areas are frequented and how often; bearing in mind it is difficult to accurately reconstruct behavioral patterns 45-50 years later. Several studies have tried to model behavioral factors, where the most important factor was time spent on the shoreline. More details can be found in Degteva *et al.* (2000a). This approach can give an estimated average annual absorbed dose from external sources for different age groups in each village, but can not provide information on variations in individual doses.

3.4 Doses received from 1950 onwards

3.4.1 Internal doses

Drinking water from the Techa River was the primary pathway for ^{90}Sr incorporation in 1950-1951. Later, milk and fish were the main sources. Internal dose reconstruction was based on individual measurements of ^{90}Sr body contents: ^{90}Sr concentrations in the body and tooth enamel were clearly dependent on age. Maximum body contents, and thereby the largest internal doses, were observed in people who were 13-15 years old during 1950-1951; the period with the largest releases.

Dietary intake of ^{90}Sr in the 1950s and 1960s has been reconstructed from *in vivo* ^{90}Sr measurements in teeth and on a model of its accumulation in the enamel (Kozheurov and Degteva, 1994). The most important factors determining the intake of ^{90}Sr were changes in the radionuclide concentration in the river water, due to dilution, provision of water supply from non-contaminated sources, dietary habits, usage of floodplain lands for pasturing and fodder and the timing and degree of implementation of protective measures. In Muslyumovo, ^{90}Sr intake after 1955 was much less than compared to the period 1950-1955. Estimated mean daily intake of ^{90}Sr for adult residents were as high as 5700 Bq day^{-1} in 1950, about 1200 Bq day^{-1} in 1951 and 1952, decreasing to about 20 Bq day^{-1} in 1956. Estimated daily intakes of ^{90}Sr for adults had decreased further to about 2-3 Bq day^{-1} in the 1970s (Akleyev *et al.*, 2000).

Correspondingly, the average ^{90}Sr content in the skeleton of adult residents from the upper and mid-Techa region has decreased from about 100 kBq in 1952 to about 8 kBq in 1990. The maximum body burdens of ^{90}Sr corresponded with distance from the point of release in the same manner as the concentration of ^{90}Sr in river water, indicating that most of the ^{90}Sr was ingested with river water during this period (Degteva *et al.*, 2000b). Highest annual doses were found in bone surface cells, but also the red bone marrow was exposed to significant radiation doses, with over half ETRC members having internal RBM doses of between 0.1 and 0.5 Gy (Degteva *et al.*, 2000a). Since these doses are primarily due to ^{90}Sr, earlier calculations have not been significantly altered. Kossenko *et al.*, (2000) estimated RBM doses of 0-0.049 Gy (21.3 %); 0.05-0.09 Gy (5.2 %); 0.1-0.24 Gy (22.3 %); 0.25-0.49 Gy (17.7 %); 0.5-1.0 Gy (20.3 %) and >1.0 Gy (13.1 %) in the studied population. The highest individual RBM doses were estimated to be 3-4 Gy and riverside residents accumulated 80 % to 95 % of committed lifetime dose within the first 10 years of contamination. Internal doses calculated for the GI tract have increased when calculating using the new TRDS-2000 system due the inclusion of short-lived radionuclides (Kossenko *et al.*, 2002).

3.4.2 External doses

Calculations of external dose for permanent riverside residents during the main releases presented in Degteva *et al.*, (2000a) were significantly lower than earlier assessments published in 1994. The reasons given for this were the adoption of two assumptions during previous calculations: that exposure rates decreased at the same rate downstream as the concentration of beta emitting radionuclides in river water and that external exposures were the same in 1950 and 1951 because approximately the same amounts of radioactivity were released. Analysis of historical monitoring data and modelling radionuclide transport in river water has shown both these assumptions to be wrong, causing overestimates of external doses. The decrease in exposure rate downstream was actually much greater than the decrease in radionuclide concentrations in river water and amounts of radioactivity accumulated in bottom sediments were significantly greater in 1951 compared to 1950 (Degteva *et al.*, 2000a). Further development of external dose reconstruction also included the decrease in doses that occurred with distance from the river banks and reassessment of behavioural data. The indoor and outdoor dose rates in other areas of the villages were then estimated according to factors like distance from the shoreline and type of area (e.g. building, forest, garden or street).

New estimates of external dose show that approximately 80 % of the population received total doses of less than 0.1 Gy, as opposed to “old” calculations where only 25 % received doses less than 0.1 Gy (Degteva *et al.*, 2000c).

The distributions of total dose accumulated through 1990 for about 30 000 members of ETRC are presented in Table 5 (RBM - red bone marrow; BS - bone surface; LLI and ULI - walls of the lower and upper parts of the large intestine; SI - the wall of the small intestine; ST - stomach wall).

Table 5. **Percentage of about 30 000 ETRC members within different total dose ranges to different organs from 1950 to 1990. (adapted from Degteva *et al.*, 2000c)**

Organ	**≤ 1 mGy**	**1-10 mGy**	**10-100 mGy**	**100 mGy-1 Gy**	**> 1 Gy**
RBM	7.9	12	23	55	1.7
BS	9.0	9.5	13	57	11
LLI	11	12	44	34	-
ULI	12	16	54	18	-
SI	14	56	22	7.7	-
ST	14	58	20	7.6	-
Testes	13	59	20	8.2	-
Ovaries	16	58	20	7.1	-
Uterus	15	58	20	7.1	-

3.5 Current doses

3.5.1 Internal exposure

Assessments of intake of ^{90}Sr and ^{137}Cs in Muslyumovo and Brodokalmak in 1999 were presented in Romanov (1998). Average intakes of ^{90}Sr and ^{137}Cs are given in Table 6. Corresponding estimated internal doses for different ages are presented in Table 7. The internal dose is not estimated for the group using the sanitary zone for food gathering or pasture, but Romanov assumes that this critical group will receive doses about three times higher than the average.

Individual internal doses to the population in Brodokalmak are approximately half of the doses received by Muslyumovo residents. Annual individual internal doses are in the range 10-30 µSv in Muslyumovo and 7-15 µSv in Brodokalmak

Table 8 presents information about the estimated dose rates in different areas of Muslyumovo and Brodokalmak in 1989 (from Romanov, 1989). The total estimated doses to the population in Muslyumovo and Brodokalmak in 1999, and accumulated up to 1995, are given in Table 9. The contribution of the external dose to the total dose is about 90%.

Table 6. ***Average annual intakes of ^{90}Sr and ^{137}Cs for populations in Muslyumovo and Brodokalmak in 1999 (**Bq y^{-1}**). Data are based on privately produced food (Romanov, 1989).***

Age (y)	**Muslyumovo**		**Brodokalmak**	
	^{90}Sr	**^{137}Cs**	**^{90}Sr**	**^{137}Cs**
<1	58	310	52	130
1	110	620	100	270
5	170	620	160	270
10	230	680	210	300
15	230	830	210	360
>17	230	930	210	400

Table 7. ***Average individual internal dose to the population in Muslyumovo and Brodokalmak in 1999, and accumulated up to 1999, depending on age (**mSv**) (Romanov, 1989).***

Age	**Muslyumovo**						**Brodokalmak**					
(early 1999)	**Accumulated up to 1999**			**Intake in 1999**			**Accumulated up to 1999**			**Intake in 1999**		
	^{90}Sr	**^{137}Cs**	**Total**	**^{90}Sr**	**^{137}Cs**	**Total**	**^{90}Sr**	**^{137}Cs**	**Total**	**^{90}Sr**	**^{137}Cs**	**Total**
<1				0.00022	0.0065	0.0067						
1	0.00042	0.013	0.013	0.00048	0.015	0.016	0.00038	0.0057	0.0061	0.00019	0.0027	0.0029
5	0.0034	0.068	0.071	0.00056	0.012	0.013	0.0032	0.030	0.033	0.00044	0.0065	0.0070
10	0.0087	0.086	0.095	0.00060	0.015	0.016	0.0080	0.038	0.046	0.00053	0.0051	0.0056
15	0.012	0.17	0.18	0.00030	0.029	0.029	0.011	0.074	0.085	0.00036	0.013	0.013
17-18	0.014	0.24	0.25	0.00032	0.036	0.036	0.012	0.10	0.11	0.00023	0.016	0.016
18-48	0.042	1.0	1.1	0.00032	0.036	0.036	0.039	0.44	0.48	0.00023	0.016	0.016

Table 8. ***Estimated average exposure dose rate (**nSv h^{-1}**) in Muslyumovo and Brodokalmak in 1989 (Romanov, 1989).***

Settlement	**personal plots next to river**	**2nd row of personal plots (one row further from river)**	**other areas**
Muslyumovo	300-450	180-250	100
Brodokalmak	150	120	100

Table 9. ***Total individual external and internal dose to the population in Muslyumovo and Brodokalmak in 1999 and accumulated up to 1995 (mSv). Numbers in brackets indicate the contribution of the external dose to the total dose in percent (Romanov, 1989).***

			Muslyumovo (age in 1999)			**Brodokalmak (age in 1999)**	
	year	**Children (> 2y)**	**Teenagers (12-17)**	**Adults (18-48)**	**Children (> 2y)**	**Teenagers (12-17)**	**Adults (18-48)**
Minimum level (no use of the sanitary zone)	**upto 1995:**	0.51 (86)[a] 1.3 (93)[b]	2.3 (92)	11 (90)	0.20 (84)[a] 0.52 (91)[b]	0.92 (91)	7.0 (93)
	1999:	0.15 (91)	0.17 (82)	0.15 (75)	0.0061 (90)	0.068 (81)	0.13 (87)
Maximum level (unlimited use of the sanitary zone)	**upto 1995:**	3.0 (93)[a] 7.8 (96)[b]	14.5 (96)	65 (95)	1.2 (92)[a] 3.1 (96)[b]	5.9 (96)	28 (95)
	1999:	0.78 (94)	1.1 (92)	0.67 (84)	0.32 (94)	0.42 (91)	0.27 (82)

a children 2-7 years; b children 7-12 years

3.5.2 External doses

Another recent study that estimated the current external doses to the population in the Techa area was completed in 1998 (RECLAIM, 2000). Here, doses received in Muslyumovo and Brodokalmak were also investigated. It was found that residents who frequently use the Techa River and riverside areas receive the highest external doses. Despite official restrictions on economic and domestic use of the riverbank area, the local population still uses the riverside to some extent. Activities in the area include:

- Grazing area for cattle and sheep
- Hunting waterfowl
- Fishing
- Collecting fodder
- Gathering wood and other materials needed at home
- Recreation

To make an initial assessment of external dose, gamma dose rates were measured on the floodplains, in the settlements themselves, and outside the floodplain (RECLAIM, 2000): mean dose rates were 1520 nGy h^{-1}, 15 nGy h^{-1}, 22 nGy h^{-1}; and 440 nGy h^{-1}, 8 nGy h^{-1}, 14 nGy h^{-1} for Muslyumovo and Brodokalmak, respectively. Occupancy factor values for floodplains were assessed on the basis of observation data during visits, for different age groups within the settlements. Occupancy factors for other locations (inside and outside of houses) were based on similar investigations in the Bryansk region with conversion factors of 0.7 Sv Gy^{-1}, 0.75 Sv Gy^{-1} and 0.85 Sv Gy^{-1} for adults, school children and pre-school children, respectively.

The total dose (sum of the committed effective dose due to the ingestion of radionuclides in a year and external effective dose received in that year) was assessed for three hypothetical groups in the adult population:

- Group 1, people who do not visit the river floodplain, do not consume milk from cows pastured on the floodplain or fish from the river Techa. This population group's exposure doses are therefore not connected with contamination of the floodplain.
- Group 2, people who visit the river floodplain in accordance with average occupancy factor values (0.03), consume 10 % of their average annual milk consumption from cows pastured on the floodplain and 10 % of their average annual consumption of fish from the river Techa. This population group receives doses that correspond to the average weighted dose in the settlement.
- Group 3, people who visit the river floodplain with occupancy factor values for herdsmen (0.10), consume 100 % of their milk from cows pastured on the river floodplain and 30 % of their average annual consumption of fish from the river Techa. This can be defined as the critical population group.

Main parameter values of the dose distributions calculated for this probabilistic assessment are presented in Table 10.

Table 10. ***Distribution of individual annual doses received by the population of Muslyumovo and Brodokalmak in 1998 (data from RECLAIM, 2000).***

	Annual effective dose (mSv)											
Village	**External**				**Internal**				**Total**			
	mean	geom. Mean	5% conf.	95% conf.	mean	geom. mean	5% conf.	95% conf.	mean	geom. Mean	5% conf.	95% conf.
Muslyumovo												
Group1	0.05	0.04	0.03	0.07	0.07	0.06	0.02	0.16	0.12	0.11	0.05	0.21
Group2	0.28	0.23	0.08	0.70	0.09	0.07	0.03	0.19	0.39	0.34	0.15	0.78
Group3	0.89	0.67	0.19	2.34	0.25	0.20	0.06	0.62	1.13	0.93	0.34	2.57
Brodokalmak												
Group1	0.03	0.03	0.02	0.04	0.05	0.04	0.01	0.12	0.08	0.07	0.03	0.15
Group2	0.09	0.08	0.03	0.21	0.05	0.04	0.02	0.12	0.15	0.13	0.06	0.29
Group3	0.27	0.21	0.06	0.67	0.10	0.08	0.03	0.20	0.37	0.31	0.12	0.81

The contribution of external exposure to the total dose varied between 40 % and 80 % depending on the population group. Contributions from ^{90}Sr and ^{137}Cs to internal doses were similar: the main dietary components contributing to internal dose were fish (29-61 %) and milk (11-63 %). Results of this initial dose assessment suggested that the established dose limit for a population (1 mSv per year) will probably only be exceeded by the critical group in Muslyumovo.

For comparison, Romanov (1989) assessed predicted average annual equivalent external doses in 1999 for children, teenagers and adults in Muslyumovo and Brodokalmak. External doses were estimated for normal activity, not using the sanitary zone, and for additional external exposure due to activities within the sanitary zone such as the gathering of wood and hay, linen washing, keeping cattle and waterfowl on the floodplains and especially fishing and recreation by and on the water. The average gamma dose rates in different areas in Muslyumovo and Brodokalmak in the end of the 1990's are given in Table 11.

Table 11. ***Average gamma dose rate*** *(nSv h^{-1})* ***predicted in different areas in the villages of Muslyumovo and Brodokalmak in 1999 (Romanov, 1998). The data refers to additional exposure over the average regional background gamma dose rate.***

Territory	**Muslyumovo**	**Brodokalmak**
Village area	65	30
Total flood land	530	290
Flood land near the river	1900	700

Table 12 presents the estimated external doses calculated by Romanov (1998). Most of the population will be within the lowest dose category i.e., are not using riverbank areas for pasture, fishing and recreation; comparable to Group 1 in Table 10. Romanov estimates are somewhat higher than estimates made in RECLAIM (2000) for this low-exposure group. The people who receive maximum doses use the flood and the floodplain without any restrictions and are comparable to Group 3 in Table 10 whose dose estimates correspond well.

Table 12 also presents calculated average accumulated equivalent doses for the period 1951-1999, for all residents in Muslyumovo and Brodokalmak. The most exposed group were born in the late 1940's and early 1950's. The younger general population (aged up to 48 yrs in 1999) receive accumulated doses of less than 2.7 mSv in Muslyumovo today, compared to people who were 48 years old or more in 1999 that have about three times as high accumulated doses. Cabianca *et al*. (2000) reported higher doses for Brodokalmak with highest doses of 0.56 mSv y^{-1} for the most exposed adults when restrictions are in place, rising to 3.4 mSv y^{-1} without restrictions.

Table 12. ***Estimated average annual effective external doses in 1999 and accumulated equivalent external dose for the period 1951-1999 in Muslyumovo and Brodokalmak (Romanov, 1998).***

	Estimated average annual effective external dose in 1999 (mSv y^{-1})					
Exposure level	**Muslyumovo**			**Brodokalmak**		
	Children	**Teenagers**	**Adults**	**Children**	**Teenagers**	**Adults**
Normal (not using the sanitary zone)	0.14	0.14	0.11	0.055	0.055	0.11
Maximum (using the river and flood plain)	0.74	1.0	0.56	0.30	0.38	0.22

Estimated average accumulated effective external dose for the period 1951-1999 (mSv)										
	Muslyumovo					**Brodokalmak**				
	Age in 1999 (years)					**Age in 1999 (years)**				
	2-7	**7-12**	**12-17**	**18-48**	**>48**	**2-7**	**7-12**	**12-17**	**18-48**	**>48**
Normal (not using the sanitary zone)	0.44	1.2	2.1	2.7	9.6	0.17	0.47	0.83	1.1	6.5
Maximum (using the river and flood plain)	2.8	7.5	14	18	62	1.1	3.0	5.6	7.2	27

4 Health and well-being of riverside residents

The registry of the exposed population (See section 3.2: ETRC) serves as the basis for conducting epidemiological cohort studies. The registry of mortality contains information from death certificates retrieved from the State Registrar's Office archives for the entire population in administrative districts across which the Techa River flows. Altogether, the registry contains information from more than 70000 death certificates. By cross-matching these certificates with TRC data it has been possible to select more than 6000 death certificates for people who had been exposed along the Techa River and died between 1950 and 1982. These data have made it possible to study possible health effects caused by the contamination in the Techa River (e.g., Kossenko and Degteva, 1994; Kossenko *et al.*, 2002). Epidemiological studies of Techa River residents have several advantages such as the protracted exposure at low dose rates, a wide range of doses, inclusion of both males and females, and long-term follow-up.

4.1 Potential health effects

There is circumstantial evidence to indicate that DNA in chromosomes is the principal target for the biological effects of radiation (e.g., ICRP, 1991; Hall, 1994; Testa *et al.*, 1998) and that a connection exists between biological damage and radiation energy absorbed, or dose. Two types of damage can occur when a cell or an organism is irradiated. Cell death is usually observed after irradiation at high doses. The cell can also survive being irradiated and sometimes will reproduce itself in an altered form due to the radiation energy absorbed. Such a transformation of the cell can result in the formation of cancer cells and genetic damage. The effects of such cell transformation may take years to express and such radiation induced cancers therefore are termed as "late effects" of radiation.

Several studies of health effects in populations exposed to ionising radiation have been performed. Population groups studied include survivors after the detonation of atomic bombs over Japan in the Second World War, residents near nuclear plants and nuclear weapons production facilities and individuals exposed to fallout from nuclear weapons testing. Studies of survivors after the nuclear bombs detonated in Japan have shown a significant dose dependent increase in the risk of cancers in the stomach, colon, lung, breast, ovary, urinary bladder and thyroid gland. Among persons who were under the age of 20 years at the time of the bomb there was also an increased risk of tumours in neural tissue, excluding the brain (Thompson *et al.*, 1994). Leukaemia was one of the earliest effects seen and remains one of the most striking findings from the follow-up study of the atomic bomb survivors: a significant dependence between radiation dose and leukaemia was established. An increased risk for lymphoma was also observed among men. The excess in leukaemia mortality has declined with time, while excess deaths still increase with time for cancers other than leukaemia (Thompson *et al.*, 1994).

Chronic radiation sickness (CRS) has also been suggested as having detrimental health effects on local residents around Mayak PA. Dr. A.K. Guskova and Dr. G.D. Baysogolov first described CRS in several hundred workers at Mayak PA: it was later diagnosed in riverside residents during the early 1950s (Kossenko *et al.*, 1998). Little agreement on what specific symptoms arise from chronic exposure to doses approaching 0.5 to 1.0 Gy yr^{-1} was found in the wider scientific community, though a key symptom was impairment of the hemopoietic system (formation of blood cells) often accompanied with neurological and immune disorders and hypotension. According to Kossenko *et al.*, (1998) no new cases of CRS have been diagnosed in recent years and symptoms declined when patients were removed from chronic exposure environments, usually resulting in recovery.

4.2 Observed health effects in the Techa River area

Kossenko and Degteva (1994) reported an increase in total cancer mortality for riverside residents during the period 1950-1982 compared to unexposed residents in the same region with significant differences between the two ethnic groups, Russians and Tartar-Bashkir in both exposed and unexposed groups. Buldakov (1995) also reported the existence of CRS and increased frequencies (up to 2 to 5 times as many cases) of leukopenia, neutropenia, thrombopenia, immuno-suppression and still-births in upper Techa residents.

4.2.1 Leukaemia

A study in the early 1990's performed by Kossenko et al. (1992), shows a significant increase of the incidence of leukaemia in the exposed population (OTRC) compared to control groups. The dose estimates were based on reconstruction of external (gamma dose rates) and internal dose (^{89}Sr, ^{90}Sr and ^{137}Cs). The excess cases of leukaemia in the study group compared to the controls were primarily acute and chronic granulocytic leukaemia. Significant correlation of leukaemia, morbidity and mortality with dose was observed. Most of the excess leukaemia cases were observed 5-20 years after the contamination started. Further analyses (Kossenko *et al.*, 1997) suggested that 40 % of the 50 deaths from leukaemia were related to radiation exposures and that the excess rate for leukaemia was 0.85 excess cases per 10000 person-year Gy (95 %, CI: 0.2-1.5) [estimated excess cases were computed as the difference between the observed number of cases and an estimate of the number expected in the absence of exposure]. For doses over 0.5 Gy on RBM (22 % of person-years recorded: person-years were computed through to date of death/loss to follow-up or 31 December 1989)), 50 % of leukaemia cases were related to exposure. The absolute risk value of leukaemia genesis calculated (Kossenko *et al.*, 1999) of 2.94 per 10000 person-year Gy was lower than atomic bomb survivors, possibly a result of the chronic nature of exposures. A statistically significant increase in leukaemia incidence was also observed in patients diagnosed with CRS, though this increase did not cause a decrease in lifespan (Kossenko *et al.*, 1998).

4.2.2 Solid cancers

Kossenko *et al.* (1997) reports a statistically significant dose-response relationship for solid cancers. Results suggested that about 3 % of the 969 recorded deaths from solid cancers were associated with radiation exposure with an excess relative risk per Sv of 0.65 (95 %, CI: 0.3-1.0). Absolute risk values for solid cancers in OTRC members were comparable to atomic bomb survivors (Kossenko *et al.*, 1999).

4.2.3 Chromosome aberrations/ Biodosimetry

During 1994-1996 a research team of the Siberian Medical University conducted an investigation of chromosome aberrations and whole body doses in the radiation exposed population of four settlements in the Techa River Region. The methods used were chromosome analysis, electron spin resonance (ESR) of tooth enamel and whole body measurements of ^{137}Cs and ^{90}Sr (Ilyinskikh *et al.*, 2000). Approximately 60 individuals from each of the four most exposed remaining settlements in the Techa River Region participated in the survey.

Compared to the control group there was a significant increase in frequencies of chromosome aberrations in the peripheral blood of inhabitants of all the four exposed villages. A high frequency of lymphocytes with dicentric and ring chromosomes was observed, corresponding to whole body activity levels of ^{90}Sr measured by the whole body counter. The highest whole body ^{90}Sr activity levels and frequency and chromosome aberrations were found in Muslyumovo: highest levels of both chromosome aberrations and whole body ^{90}Sr activity were found in adults, born between 1949 and

1957 when the largest exposures took place. This indicates that chromosome aberrations can still be found a long time after irradiation that occurred around the time of birth.

4.2.4 Effects in progeny of exposed persons

The Techa River Cohort data has also been used to study the malignant neoplasms among the progeny of exposed people (Kossenko, 1996c). The study group comprised children aged 0-4 years during the period from 1950 to 1954, children aged 0-9 years during the period from 1955 to 1959 and persons aged 0 - 29 years by the end of the year of the follow-up study. The progeny were divided in 6 groups after the estimated doses to parental gonads. The average doses to parental gonads in the six groups were from 0.032 Gy to 1.3 Gy. The study showed that there was no increased number of cancer deaths in the progeny of exposed persons compared to the persons in the control group. However, the small number of deaths by the time of the study makes the dose dependencies and conclusion uncertain at this time.

Studies of chromosome aberrations showed a significant difference between Muslyumovo children (n=15) and an age-matched control group (n=11) from an uncontaminated Russian village, where 0.56 ± 0.08 chromosome aberrations per 100 cells were recorded in Muslyumovo compared to 0.29 ± 0.07 in the controls (Testa *et al.*, 1998).

4.2.5 Assessment of risk of radiation induced cancer in the Techa area population

The probability of stochastic effects of radiation is estimated to 125×10^{-4} Sv^{-1} for solid carcinoma and leucosis (ICRP, 1991). According to Romanov (1998) the probabilities for radiation induced cancerogenic effects in the population of the Southern Urals are estimated to 83×10^{-4} Sv^{-1} for solid carcinoma and 19×10^{-4} Sv^{-1} for leukaemia. These numbers are based on the ICRP recommendations (ICRP, 1991), corrected for the age and sex distribution of the investigated population. Risk assessments for the population in Muslyumovo and Brodokalmak were then estimated (Table 13) from the information on intake and doses in these villages presented in Tables 9 and 12.

Table 13. ***Risk assessments calculated for the residents of Muslyumovo and Brodokalmak (Romanov, 1989).***

	Muslyumovo (population 2550)		**Brodokalmak** (population 3700)	
	Min	Max	Min	Max
Estimated effective individual dose (mSv)	4.5	29	2.6	12
Estimated collective dose (personSv)	11.6	73.8	9.6	42.8
Maximum estimated individual annual risk (10^{-6} year^{-1}) of:				
Solid carcinoma	37	240	22	100
Leucosis	8.6	55	4.9	23
Total	46	295	27	123
Remaining lifetime risk (per 1000 persons) of:				
Solid carcinoma	0.04	0.23	0.02	0.09
Leucosis	0.008	0.06	0.005	0.02
Total	0.5	0.31	0.03	0.11

Leucosis: an excess of leucocytes (white blood cells) in the circulation and other parts of the body

Leukaemia: characterised by an abnormal increase in the number of leucocytes in the tissues of the body with or without a corresponding increase of those in the circulating blood

For the population who have lived in Muslyumovo since the late 1940s the risk for developing a solid carcinoma or leucosis was estimated to be 46×10^{-6} y $^{-1}$ and 300×10^{-6} y $^{-1}$ for the lowest and the highest exposure levels, respectively. The corresponding risk estimates are 27×10^{-6} y $^{-1}$ and 120×10^{-6} y $^{-1}$ for Brodokalmak. The risk assessments show that current residents in Muslyumovo and Brodokalmak who did not live there during the period of initial discharges (either because of moving in later, or because of age) have a 2-3 orders of magnitude lower risk of developing cancer than those who have lived there since the late 1940s.

The estimated increase of cancer incidences due to radiation, based on the minimum estimated exposure level, will not be distinguishable from the general cancer incidences according to Romanov (1998). The frequency of cancer incidences is increasing in the population of the former USSR: the mortality risk due to malignant tumours was 1506×10^{-6} y^{-1} in 1985, having increased 4 % from 1975 to 1980 and 8 % from 1981 to 1985 (Romanov, 1998). In comparison, the frequency of mortal cancers (solid tumours) is about 2.3×10^{-6} in Norway (Norwegian Cancer Association statistics).

5 Conclusions

Although contamination has decreased by about a factor of three, external and internal exposure of Techa riverside residents resulting from initial discharges at Mayak PA are still measurable. The main reason for slightly increased exposures to residents of Muslyumovo and Brodokalmak in recent years is probably due to increased use of the sanitary zone: today, teenagers receive the highest external doses because they use the floodplain more. Adult residents, especially those born before 1951, have received the highest accumulated effective doses.

Average external dose rates in the settlements were estimated as 65 and 30 nGy h^{-1} in Muslyumovo and Brodokalmak, respectively, in 1999. Within the sanitary zones, dose rates will be higher: average values were 530 and 290 nGy h^{-1}, respectively, with maximum levels of about 1900 and 700 nGy h^{-1} on the floodplain, though dose rates are heterogeneous. Average annual equivalent external doses were 110-140 µSv/year in Muslyumovo and 50-55 µSv/year in Brodokalmak: maximum external doses (frequent use of the floodplain) were estimated as 450-860 and 110-325 µSv/year in Muslyumovo and Brodokalmak, respectively.

Concentrations of ^{90}Sr and ^{137}Cs in privately produced agricultural food products are low for the most important products (milk, potatoes, vegetables, meat), mainly in the range 0.1-1 Bq/kg. This leads to an average intake of about 58-230Bq ^{90}Sr/year and 310-930 Bq ^{137}Cs/year in Muslyumovo, 52-210 Bq ^{90}Sr/year and 130-400 Bq ^{137}Cs/year in Brodokalmak (lowest levels for children, highest for adults). Average effective internal doses following this intake are estimated as 10-30 µSv/year in Muslyumovo and 7-15 µSv/year in Brodokalmak. With frequent use of the floodplain for food and fodder production the intake and dose estimates will be about 3 times higher.

Effective annual external and internal total doses increase with age and are in the range of 0.5-11 mSv/year in Muslyumovo and 0.2-7 mSv in Brodokalmak. External dose due to ^{90}Sr and ^{137}Cs accumulated up to 1999 contributes 84-96% of these values. In 1999, the annual effective doses at minimum exposure levels were estimated as 0.15-0.17 mSv/year in Muslyumovo and 0.06-0.13 mSv/year in Brodokalmak: maximum levels were 0.7-1.1 mSv/year and 0.3-0.4 mSv/year, respectively. The maximum estimate for Muslyumovo is for teenagers, due to their frequent use of the floodplain, and it exceeds the 1 mSv/year limit established by Russian legislation.

For people who have lived in the area since the discharges of radioactive wastes in the 1940s and early 50s, the risk for solid carcinoma and leukosis was estimated as 46×10^{-6} y^{-1} for minimum exposure level and 300×10^{-6} y^{-1} for maximum exposure level in Muslyumovo. Corresponding estimates were 27×10^{-6} y^{-1} and 120×10^{-6} y^{-1}, respectively, in Brodokalmak. Up to 1995 the estimated radiation induced increase in cancer was 6 % and 4 % in Muslyumovo and Brodokalmak, respectively. At maximum possible exposure level this increase was estimated as 40 % and 20 %, respectively. It is important to note that residents in the area who were not exposed to the highest contamination period (due to age or migration) experience a 2-3 orders of magnitude lower risk for developing radiation induced cancer than those who lived in the area during the period of intensive discharges.

6 Recent information

A critique of the TDRS-2000 system was put forward (Mokrov, 2002), suggesting that doses could be higher than estimates. To investigate this claim, an independent group of experts was formed who reviewed the assumptions and methods underpinning TDRS-2000 (Balonov et al., 2006). Their conclusion was that the system was basically sound though they called for restraint when drawing conclusions where TDRS-2000 had been used "pending resolution of several issues" such as the re-evaluation of the activities released from Mayak PAduring the earliest period of operations, validation of external dose estimates and a reconsideration of the uncertainties. Correspondence in the same journal (Anspaugh et al., 2006) suggests that work is on-going to improve TDRS-2000 with respect to the above criticisms. Reconstructing historic doses and predicting health risks is inherently difficult. However, the cooperative work of many scientists from Russia, Europe and the US is moving forward towards ever more accurate low dose and chronic dose rate estimates of health risks attributable to exposure to radioactivity in discharges from Mayak PA.

Rosatom and Chelyabinsk Regional Administration allocated money to the resettlement of Muslyumovo in 2006. Residents who wanted to move were offered two different resettlement options:

- the authorities would pay an allocated sum of money per house and issue a house certificate which could then be exchanged for a house situated in the residents region of choice;
- In the second option, residents were offered a house in a newly built village not far from Muslyumovo, called Novo-Muslyumovo.

According to Rosatom, some 200 million roubles have been allocated to residents who have decided to leave Muslyumovo. About 600 families have confirmed that they want to leave the village, of which 198 families have ordered new houses in Novo-Muslyumovo. The majority of the residents have chosen to move into new apartments in the nearby city Chelyabinsk.

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