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Workshop on dosimetry of the population living in the proximity of the Semipalatinsk atomic weapons test site

Lindholm Carita, Simon Steve, Makar Beatrice,
Baverstock Keith (eds.)

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SUMMARY

From 1949 nuclear weapons tests were conducted at the Semipalatinsk test site in Kazakhstan. Until the early 1960s many of these tests were conducted either on the ground or above ground. The radioactive fission products released in these explosions were deposited at substantial distances from the test site (Polygon) and may have exposed populations living in Semipalatinsk Region and the Altai region of the Russian Federation. A much larger number of tests has been conducted underground with only limited release of radioactive material to the atmosphere.

A number of estimates have been made, by Kazak and Russian scientists, of the radiation doses to the populations living in the areas surrounding the test site but few of these are based on actual measurements of radioactivity on the ground and in vegetation. More recently, other international groups have predicted historical doses based on literature data and/or contemporary soil caesium measurements while others have used a variety of modern measurement techniques such as thermoluminescence in ceramic objects, EPR in teeth, and other types of biological dosimetry.

A workshop addressing these issues was organised by the National Cancer Institute (NCI, USA), World Health Organisation (WHO) and Radiation and Nuclear Safety Authority (STUK, Finland) in May 2001. The purpose of the workshop was to review all the available dosimetric data in order to make an assessment of the radiological impact and the associated uncertainties, on populations in the vicinity and identify populations that might be useful subjects of epidemiological study. Particular emphasis was given to assessing doses to members of the public, i.e., off-site populations.

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Avainsanat: säteilyaltistus, annosmääritys

YHTEENVETO

Ydinasekokeet aloitettiin Semipalatinskin koealueella Kazakhsta-nissa vuonna 1949. Monet 1960-luvun alkuun mennessä suoritetuista ydinkokeista tehtiin pääasiassa pintaräjäytyksinä tai ilmakehässä. Räjähdyksissä syntyneet fissiotuotteet levittäytyivät huomattavan kauas koealueesta ja ovat saattaneet altistaa Kazakhstanin puolella olevan Semipalatinskin alueen ja Venäjän Altain alueen väestöä. Maanpinnan alapuolella suoritettiin paljon enemmän kokeita, mutta näistä vapautui huomattavasti pienempiä määriä radioaktiivista materiaalia ilmakehään.

Kazakhstanilaiset ja venäläiset tiedemiehet ovat esittäneet useita säteilyannosarvioita testialueen lähistöllä asuvalle väestölle. Arvioista kuitenkin vain muutama pohjautuu todellisiin maaperän ja kasvillisuuden radioaktiivisuusmittauksiin. Kansainväliset ryhmät ovat hiljattain esittäneet kirjallisuudesta saatuun tietoon ja/tai maaperän cesium mittauksiin perustuvia annosarvioita. Toiset tutkimusryhmät ovat käyttäneet moderneja mittaustekniikoita, kuten keraamisten esineiden termoluminesenssia, hammaskiilteen EPR-mittauksia sekä muita biologisen dosimetrian menetelmiä.

National Cancer Institute (NCI, USA), Maailman terveysjärjestö (WHO) ja Säteilyturvakeskus (STUK) järjestivät toukkuussa 2001 kokouksen, jonka päämääränä oli tarkastella saatavilla olevaa tietoa säteilyannoksista ja tämän perusteella arvioida säteilyn aiheuttamia vaikutuksia väestöön sekä näihin liittyviä epävarmuustekijöitä. Lisäksi pyrittiin löytämään populaatiot, joita voitaisiin käyttää epidemiologisissa tutkimuksissa. Erityisen kiinnostuksen kohteena oli varsinaisen koealueen ulkopuolella asuvan siviiliväestön saaman annoksen arviointi.

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1 THE PRESENT RADIOECOLOGICAL SITUATION OF THE SEMIPALATINSK TEST SITE AND INTERNAL DOSE ESTIMATIONS FOR SELECTED PEOPLE LIVING ON THE SITE

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The Semipalatinsk test site (STS) in Kazakhstan was one of the major sites for testing nuclear weapons used by the USSR. At this 18,500 km^2 site, 456 atomic tests (ref. 1)[1] have been performed between 1949 and 1989, which constitutes 64 % of the total estimated soviet bomb yield. Whilst the tests were being conducted, access to the site was strictly controlled by the Soviet military and no civilian use of the area was permitted. There were three major testing areas identified within the STS: Ground Zero, where 26 above ground and 87 atmospheric bomb tests were performed, the Degelen mountains where more than 200 underground nuclear explosions occurred, and the area Balapan with 123 underground explosions and one excavation leading to the 'Atomic Lake'.

The highest radiation exposures arising from the testing were due to fallout from atmospheric tests carried out up to 1962. Exposure was greatest to the population living close to the test site, or in the direction of the most significant traces of radioactive fallout such as the Altai area of Russia (ref. 2). Estimates of the external and internal doses vary considerably. Reconstruction by Kazak authorities gives an estimated maximum individual dose of 4.5 Sv received by inhabitants of Dolon village, largely due to ^{131}I (ref.3). An increase in the incidence of different cancers in the local population has been attributed to radiation exposure (ref. 4).

Since the early nineteen nineties, responsibility for the site has passed to the Kazak authorities, and there has been a gradual re-establishment of agricultural use (horse and sheep farming), largely by Kazak nationals. It has

[1] This number differs in the literature depending on the source of information and the definition of „nuclear test" and range from a value of 456 to 498

therefore become important to evaluate the current and future risk to people living on and using the contaminated area. Such evaluations within the test site itself are being conducted by Kazak authorities with international co-operation, and the results of one evaluation performed within two EC projects (RESTORE and RECLAIM) are reported here. The evaluation had two major components: a critical evaluation of literature (much of which was not previously openly available) and analysis of newly collected samples.

The major factors which need to be considered in such an evaluation include: deposition of radionuclides, external exposure arising from the contamination, rates of transfer to food products and the consequent internal exposure to man. Several gamma emitting radionuclides can be detected now including ^{60}Co, ^{137}Cs, $^{152/154}Eu$ and ^{241}Am. Experience after the Chernobyl accident has shown that ^{137}Cs has a potentially high environmental mobility, and its potential to be a major long-term dose-contributing radionuclide. Our evaluation of USSR data (ref. 12) shows that ^{137}Cs deposition ranged from 19 to 185 kBq m^{-2} at Ground Zero, between 5 to 11 kBq m^{-2} in grazed pastures in the Balapan area (with localised hot spots surrounding Lake Balapan and Ground Zero of up to 1850 kBq m^{-2} and 15 to 75 kBq m^{-2} in the Degelen mountains (ref. 5 and ref. 6). Results from an aerial gamma survey performed by *Aerogeologia* in 1990/1991 are shown in Figure 1 (ref.7). In the villages surrounding the STS such as Dolon, Sarzhal and Kainar, ^{137}Cs contamination of soils in the range of 3 and 10 kBq m^{-2} have been measured by the IAEA (ref. 8). Analysis of a number of samples taken on the STS has been published by Japanese colleagues (ref.9) and more recently by the same group (Yamamoto *et al.* in a special issue of JER Pu in the Environment, *in press*) and several Kazak and Russian institutions (ref.10 and ref.11).

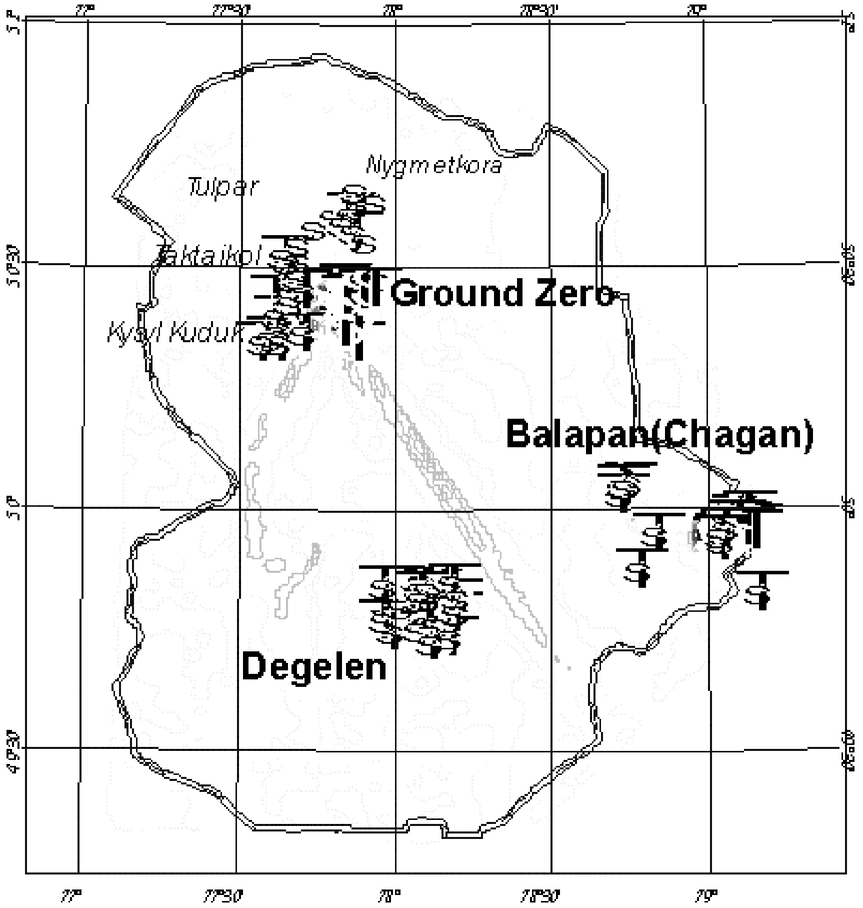

Figure 1. *Results of an aerial gamma survey and sampling sites on the STS.*

Except of the results of an expedition performed by the IAEA, the data on soil contamination presented in Figure 1 and 2 are the most extensive ones carried out by an international team on the STS. Altogether 141 soil samples and 79 vegetation samples deriving from the most contaminated areas of Ground Zero, Lake Balapan and the Degelen Mountains, and representing pastured land (see Figure 1) have been taken and analysed by us for gamma, alpha and beta radiation. According to these results ^{137}Cs contamination of the STS is in general comparable to that in some areas of Western Europe resulting from the Chernobyl accident. There are only small very localised areas where contamination levels approach those of the abandoned areas around the Chernobyl NPP with values reaching 5 kBq kg^{-1} and with one individual value of 700 kBq kg^{-1} soil (Degelen Mountains). The distribution of the ^{137}Cs activity concentrations of the soil samples are given in Figure 2, more than 90% of all samples are below activity concentrations of 250 Bq kg^{-1}.

At the soil sampling sites vegetation samples have been taken. The results of the gamma measurements (Figure 2) show in general low activity levels in these vegetation samples. The information on types of soils and soil characteristics predominant on the STS have been used to run the Cs transfer model as developed within SAVE and RESTORE, and activity concentrations have been predicted. In general the predicted values are about one order of magnitude higher compared to the measured values. Food products were found to be only slightly contaminated by ^{137}Cs: in villages around the STS: milk contamination ranged from 0.03 to 0.1 Bq L^{-1}, leafy vegetation from 0.8 to 8.3 Bq kg^{-1}, meat from 0.2 to 2.9 Bq kg^{-1} and water from 0.003 to 0.01 Bq L^{-1} (summarised in ref.12). Own measurements performed at two farms (Akzhar and Chagan (Balapan)) on the STS show values as given in Table 1. In summary these values indicate that uptake of ^{137}Cs with food by the population is in general low.

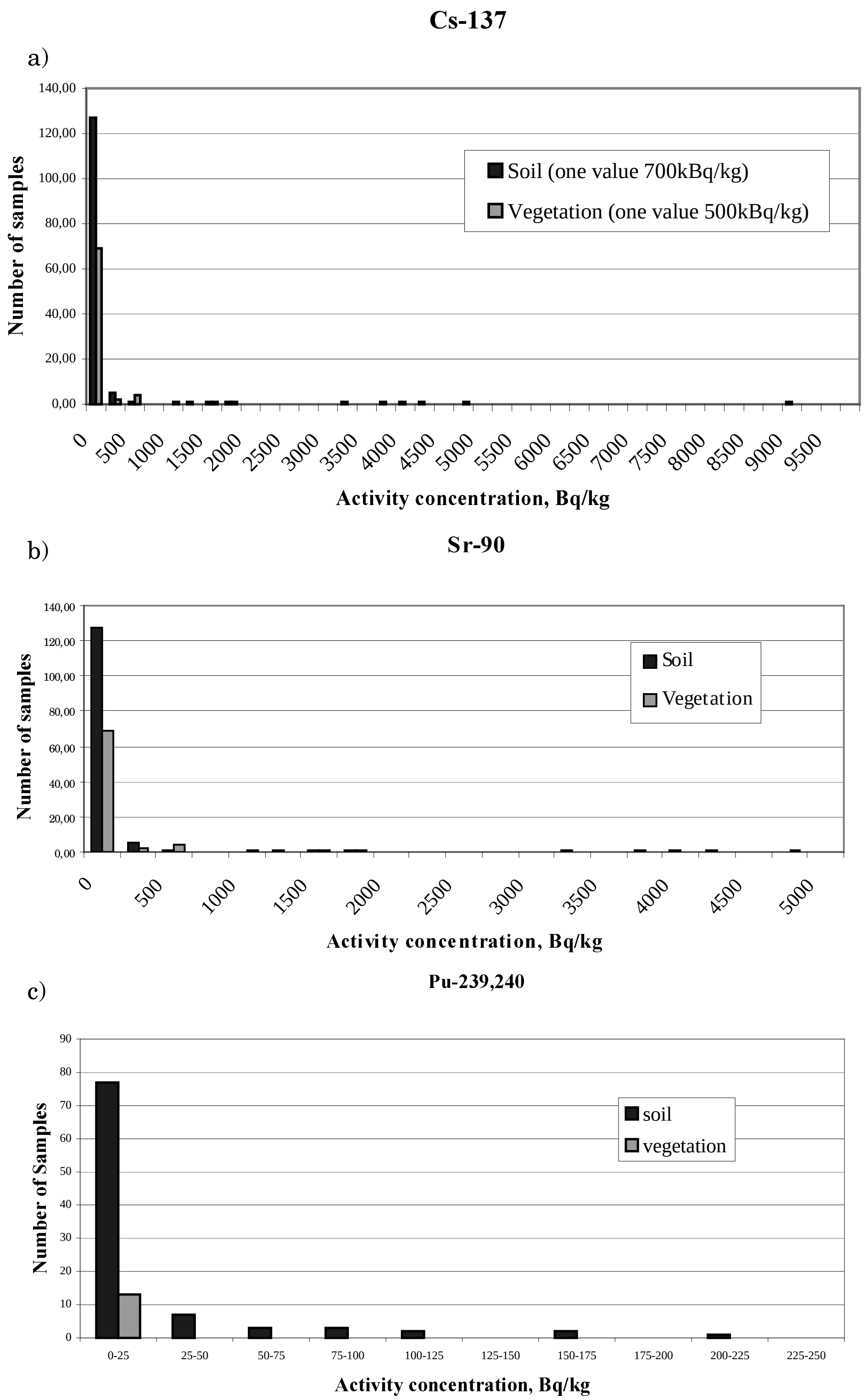

Figure 2. *Distribution of* ^{137}*Cs,* ^{90}*Sr and* ^{239,240}*Pu activity concentrations in soil and vegetation samples.*

Table 1. *Activity concentrations in food samples of the STS (two agricultural farms)*

Site (Winterhut)	*Sample*	*Cs137, Bq/kg,L*	*Pu239+240, Bq/kg*	*Pu238, Bq/kg*	*Sr90, Bq/kg*
Farm Chagan (Balapan)					
Chagan	Cow milk	190.30			
Chagan	Cow milk	6.50	0.02		
Chagan	Mouton	49.00			
Chagan	Mouton	24.00			
Farm Akzhar					
Kyzylkuduk	Cow milk	0.87	0.02	0.005	0.63
Kyzylkuduk	Cow milk	50.50			
Kyzylkuduk	Curds	3.28	0.03	0.013	1.98
Kyzylkuduk	Horse milk	0.06	0.28		
Kyzylkuduk	Horse meat	1.30			
Kyzylkuduk	Horse meat	24.00			
Kyzylkuduk	Horse meat	22.00			
Kyzylkuduk	Intestine	2.80			
Kyzylkuduk	Kurt(cheese)	3.33			
Kyzylkuduk	Water	< 0.001	< 0.001	< 0.001	0.03
Kyzylkuduk	Water	0.90	0.02		
Taktajkol	Water	0.00	0.00	0.000	0.003
Tulpar	Cow milk	0.01	0.00	0.000	0.93
Tulpar	Curds	30.23			
Tulpar	Horse milk	5.57	0.06	0.024	29.81
Tulpar	Kurt(cheese)	1.91	0.02	0.006	2.21
Tulpar	Water	0.01	0.00	0.000	0.01

Measured body burdens of ^{137}Cs in villages adjacent to the STS performed by Hill *et al.* (ref. 13) were below detection limits. The average internal dose due to ^{137}Cs ingestion for the whole body calculated on the basis of activity concentrations in food and intake rates representative for the inhabitants of the STS (ref. 12) is estimated between 1 to 14 µSv y^{-1} for adults. In addition whole body measurements combined with questionnaires of food consumption rates have been performed within RESTORE and RECLAIM. The results and derived doses are given in Table 2.

***Table 2**. Measured whole body burdens and estimated doses of selected population groups living on the STS.*

Site	Number	Below detection limit (700 Bq)	WBC*			Dose estimation based on WBC	Dose estimation based on consumption
			min	max	mean		
Akzhar	Male(26)	25	-	1221	-	45 µSv/year	8 Sv/year
	Female(33)	32	-	1147	-	42 µSv/year	2 µSv/year
Chagan	Male(19)	12	703	1443	1073	37 µSv/year	–
	Female(25)	24	-	777	-	28 µSv/year	–

*According to Balonov *et al.*

Measurements of gamma dose rates 1 m above ground taken by the authors in September 1997 at the most contaminated sites ranged from 0.06 to 1.0 µSv h^{-1}, (with the exception of some localised spots where a value of 35 µSv h^{-1} at the rim of Lake Balapan and 55 µSv h^{-1} at Ground Zero) were measured resulting in an external dose of below 50 mSv y^{-1} for permanent exposure. For pastures, hay stocks and farms dose rates of 0.1 - 0.2 µSv h^{-1} were measured leading to external doses to the local population of below 1 to 1.5 mSv y^{-1}. In addition *in-situ* measurements performed in two villages adjacent to the STS have shown that external doses correspond to normal global environmental background, with only a small contribution of 2 to 5 % to the external dose due to soil contamination of ^{137}Cs (ref. 13).

Conclusions

In summary we conclude from available data, that the additional risk of radiation exposure due to ^{137}Cs for the population living on the STS or in villages around the STS is not significant, neither from ingestion (internal exposure) nor from external exposure. Countermeasures to protect the population from elevated radiation exposure at the STS therefore are not necessary, if the inhabitants are made aware of some very localised hot spots (fenced) not to be used for humans or grazing animals.

However, when evaluating the general radiological situation of the STS, however, exposures due to other radionuclides need to be addressed. Available data for beta emitters such as ^{90}Sr or alpha emitters such as $^{238/239/240}Pu$ and $^{238/239}U$ are sparse, because of the resource-demanding nature of the analysis. There are strong indications that these radionuclides can be found in rather high quantities (ref. 11, ref. 14 and 15). Even though external exposures in this case can be neglected, ingestion of contaminated foodstuff and inhalation of re-suspended material has the potential to lead to high local internal doses, this needs to be addressed and investigated in more detail.

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2 PLUTONIUM FALLOUT IN THE ENVIRONMENT AROUND THE FORMER SOVIET UNION'S SEMIPALATINSK NUCLEAR TEST SITE

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2.1 Introduction

More than 450 nuclear weapons tests were performed at different places within the Semipalatinsk nuclear test site (SNTS). These tests varied in type and size, and they resulted in local and global dispersion of radioactive materials. The radionuclides remaining in the environment represent a potential long-term hazard to humans. The hazard considered here stems from local (early) fallout from atmospheric and near-ground bursts. The effects on human health from ionising radiation, particularly the effects of exposure to long-term low-dose radiation, have scientific and practical importance. Field studies have been conducted in the Semipalatinsk region to contribute to the investigation of the present radiological situation since 1995. Eight investigation missions to the test site and its vicinity, including some settlements, have been conducted so far (Fig. 1).

Emphasis has been given here to the plutonium in soil around the test site. Three objectives are considered in this paper: (1) geographical distribution and geochemical association of Pu (and ^{137}Cs) in ground within and outside the SNTS, (2) identification of the sources of the Pu contamination using ^{240}Pu/^{239}Pu atomic ratio, and (3) preliminary data on Pu and U levels in biological samples (human bone) which have been analysed recently.

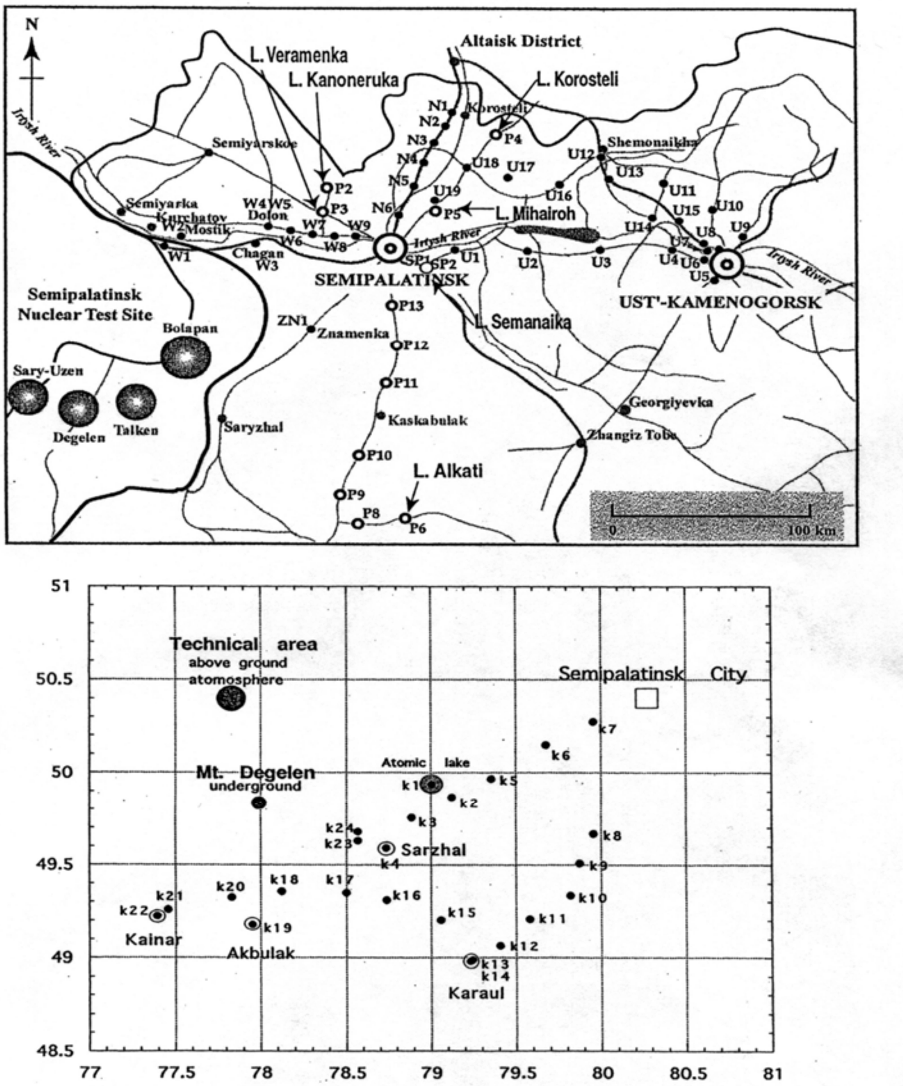

Fig. 1 Sampling locations of soil samples around the SNTS territory. Sampling year: within the test site (1995), W & N-series(1995 &1996), P-series (1997), U-series (1998) and K-series (1999).

2.2 Materials and methods

2.2.1 Samples

Soil samples have been collected at various sites (more than 100 sites) within and outside the SNTS in the mission during the periods of 1995-2000. At each site, three to five surface soil (4.7 cm diameter, 0-10 cm depth) and one core soil (4.7 cm diameter, 0- ca. 30 cm depth) samples were taken by inserting a stainless steel pipe. While the 10 cm-deep soil samples were not divided, most of the 30 cm-deep core samples were carefully subdivided into 6 sections of 5 cm each. After being air-dried and crushed, these samples were sieved through a 2-mm screen to remove pebbles and then mixed homogeneously. In addition, human bone samples, mainly vertebra, were obtained between 1998 and 2000, from several tens of residents by autopsy at the Semipalatinsk Medical Institute. The subjects ranged in age from 38 to 83 y (mostly 60-70 y).

2.2.2 Radioactivity measurements

An aliquot of samples, usually 60-80g, was measured by the γ-ray spectrometer. As for Pu, a sample was completely decomposed with a mixture of HNO_3+HF+$HClO_4$ and/or sequentially decomposed in the following order; 1) leaching with HNO_3+H_2O_2, 2) leaching with 10M HNO_3+0.1M HF and 3) complete decomposition of the residue by alkaline fusion or a mixture of HNO_3+HF+$HClO_4$. Bone ash samples from the vertebra (5-10g) were subjected to of Pu, and U analyses. The Pu and U were sequentially separated and purified using anion exchange column method. The ^{239,240}Pu, and ^{234}U and ^{238}U were determined by α-spectrometry, and the ^{240}Pu/^{239}Pu atomic ratio was determined by high-resolution inductively coupled mass-spectrometry (HR-ICP-MS).

2.3 Results and discussion

2.3.1 Distribution of Pu inventory in soil

Figure 2 shows the results of $^{239,240}Pu$ measurements (Bq/m^2) for the surface soil samples (10 cm in depth) with the highest ^{137}Cs concentration (Bq/kg) and the core soil samples (30 cm in depth) at each site. In general, the $^{239,240}Pu$ inventories are remarkably high at F6 ($3.3x10^5$ Bq/m^2) near the hypocenter of the first nuclear test (1949) and at F5, F4 and F3 ($1x10^4$-$4x10^4$ Bq/m^2) located further away from the F6 towards Kurchatov. The inventories in Sarzhal (S-series), Tailan (K24), Kainar (K20) and Kainal (K14, K15) are more than or about 10^3 Bq/m^2. The $^{239,240}Pu$ levels outside the territory, such as in Dolon and its adjoining pine forest (W-series) and along the road towards Semipalatinsk City, varied largely, ranging from a few 100 to around 10^3 Bq/m^2, with some sites where levels were (2-4) $x10^3$ Bq/m^2. The levels around Semipalatinsk City and in the direction of the Altai and Ust'-Kamenogorsk districts showed lower values of a few 10 to several 100 Bq/m^2. Concerning the global fallout levels of $^{239,240}Pu$ for the Semipalatinsk regions, no data seem to exist, but the average level seems likely to be around 50 Bq/m^2. Unlike ^{137}Cs, the inventories of $^{239,240}Pu$ for most of the sites we visited were several to a few hundred times higher than those (40-120 Bq/m^2) for global fallout found in Japan. These results indicate that the nuclear tests conducted at the SNTS produced local fallout Pu even in the regions in the vicinity of such NTS. The $^{239,240}Pu/^{137}Cs$ activity ratios for their inventories are several times higher than the values (0.02-0.03) for global fallout. On the other hand, $^{238}Pu/^{239,240}Pu$ activity ratios in most of samples were within 0.02-0.03, which appear to be not much different from the values for global fallout.

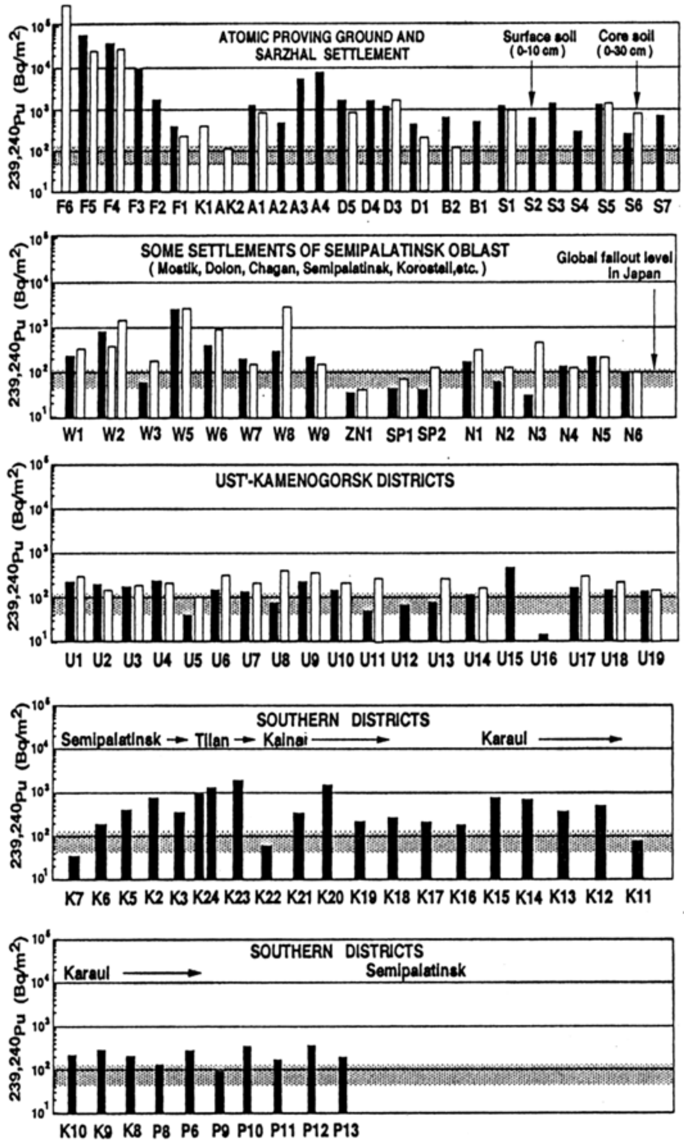

Fig. 2 Comparison of Pu-239,240 inventories (Bq/m^2) in soil from the areas within and outside the SNTS territory.

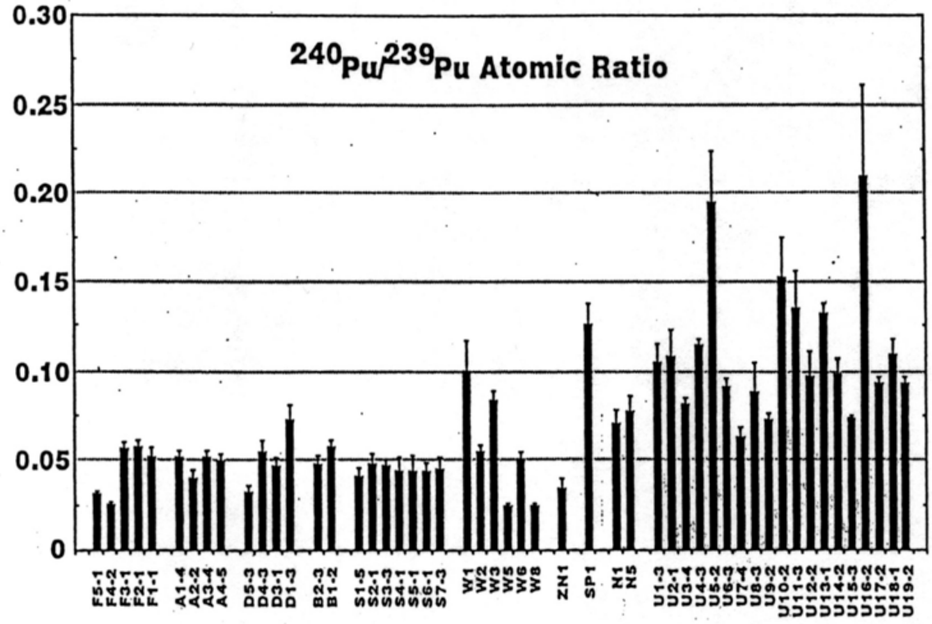

Fig. 3 Comparison of Pu-240/Pu-239 atomiic rarios in soil measured by HR-ICP-MS.

2.3.2 Geochemical association of Pu with soil

A stepwise leaching using the surface soil samples (10 cm in depth) was performed to investigate the geochemical association of Pu with soil. The results are graphically shown in Fig. 4. As is clear from this figure, $^{239,240}Pu$ in soil cannot be fully extracted at every site by hot digestion with concentrated HNO_3 containing a small amount of H_2O_2, even when followed by digestion with a mixture of 10M HNO_3 and 0.1M HF. Generally, the fraction of Pu remaining in the last soil residue seems to decrease with increasing distance from the SNTS. Considering that Pu in soil contaminated with global fallout can be extracted almost quantitatively by leaching with heat using mineral acids such as nitric acid, Pu in soil around the SNTS is thought to be tightly incorporated into various sizes of particles formed in the course of the condensation of molten materials, such as vaporised soil and bomb components. Such knowledge will be particularly important in evaluating and predicting the long-term transport of Pu in the soil of this drought stricken area and for estimating the radiological Pu hazard related to the ingestion of foods and inhalation of re-suspended materials.

2.3.3 Resolving global and SNTS fallout Pu

As described above, $^{239,240}Pu$ and ^{137}Cs from local (close-in) fallout and global fallout intermingle in soil within and outside the SNTS territory. It is extremely important to differentiate global fallout-derived components and to have accurate knowledge of the local fallout-derived $^{239,240}Pu$ and ^{137}Cs concentrations and inventories – especially to be able to reconstruct the radiation doses to which the residents were exposed. It has been shown that a mixture of two sources of $^{239,240}Pu$ in a sample each can be resolved by using $^{240}Pu/^{239}Pu$ atomic ratios, if a representative value for local fallout Pu can be assigned. Figure 3 shows the results for the atomic ratios of $^{240}Pu/^{239}Pu$ measured in the surface soil samples. The atomic ratios $^{240}Pu/^{239}Pu$ for samples within the territory showed fairly low values in the range 0.025 to 0.072 compared to the global fallout value of 0.18. These low ratios strongly indicate that scattered Pu is weapons-grade Pu that escaped fission. The atomic ratios vary considerably amongst the sampling sites but generally they seem to increase with increasing distance from the SNTS. Since various types of nuclear tests of varying magnitude have been conducted, and trajectories of various radioactive clouds are thought to intermingle over the sampling sites, the values of $^{240}Pu/^{239}Pu$ from local fallout Pu is unlikely to be constant across the Semipalatinsk area. In order to resolve this problem, we measured further the atomic ratios of $^{240}Pu/^{239}Pu$ in both Pu fractions, i.e., the one that can be leached with hot HNO_3+H_2O_2 and the non-leacheable Pu fraction, using each layer of the core samples. The value in the soil residue that cannot be leached with hot HNO_3+H_2O_2 was considered as to be representative of the values of local fallout Pu at each site. As a result, for the soil samples from Ust'-Kamenogorsk district, a fraction of 21-80% (mostly 30-60%) of total $^{239,240}Pu$ was found to be due to the local Pu from the SNTS debris.

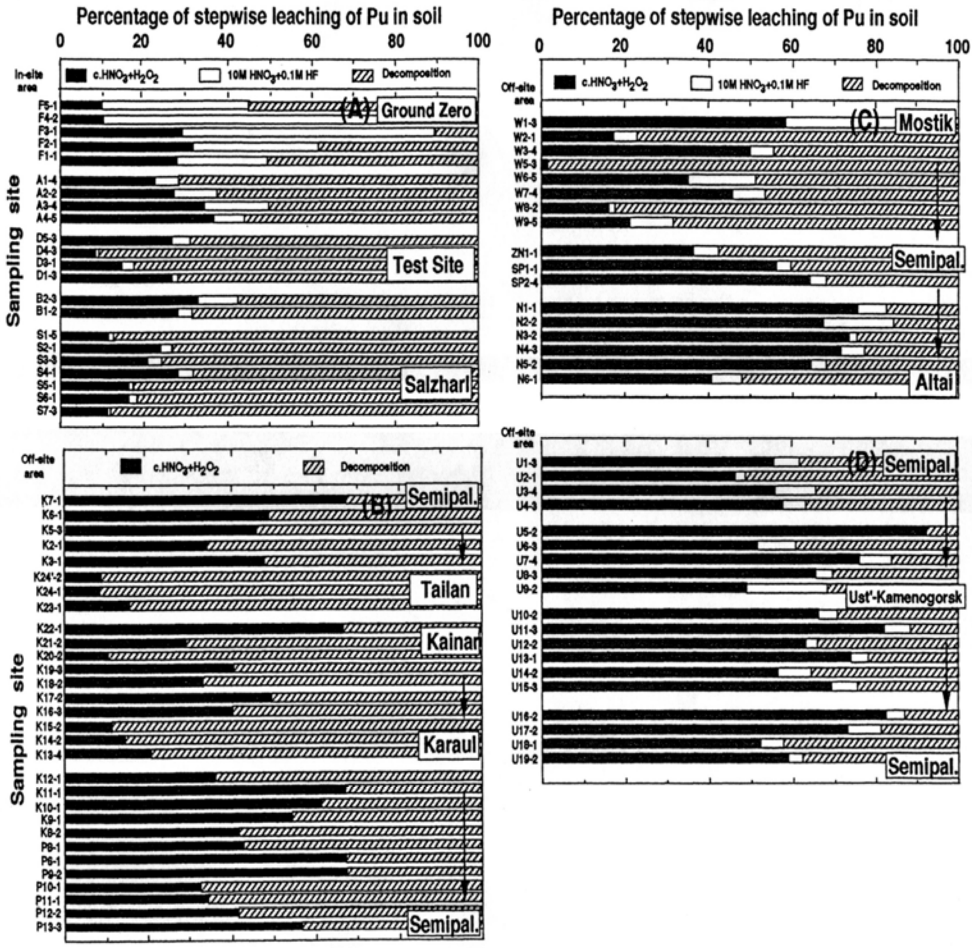

Fig. 4 Results of stepwise leaching of Pu-239,240 in soil samples from the aresa within and outside the SNTS territory.

2.3.4 Concentrations of Pu and U in human bone samples

To serve as an aid to evaluate internal doses by ingestion and inhalation, recently we have started to evaluate the present levels of ^{239,240}Pu, ^{238}U(^{234}U) and ^{90}Sr in human tissues of people living in the vicinity of the SNTS. Preliminary results of ^{239,240}Pu and ^{238}U contents in bone samples (vertebra) from several tens of persons (38-83 years old) living in the Semipalatinsk City and its adjoining areas are shown in Figs. 5 and 6, respectively. The ^{239,240}Pu levels were 0.01-0.22 mBq/g ash, mostly 0.02-0.05 mBq/g ash. The values of ca. 0.2 mBq/g ash found for two samples are several times higher than the values found in the U.S.A. and Japan, although periods of observation were not exactly the same. The ^{238}U concentrations ranged from 0.1 to 0.45 mBq/g ash (a factor of 4). The $^{234}U/^{238}U$ ratios showed a range from 1.2 to 1.9. Now, further measurements of these nuclides are planned using human tissues including lung, liver etc., from the people living in the vicinity (Dolon, Sarzhal, etc.) of the SNTS.

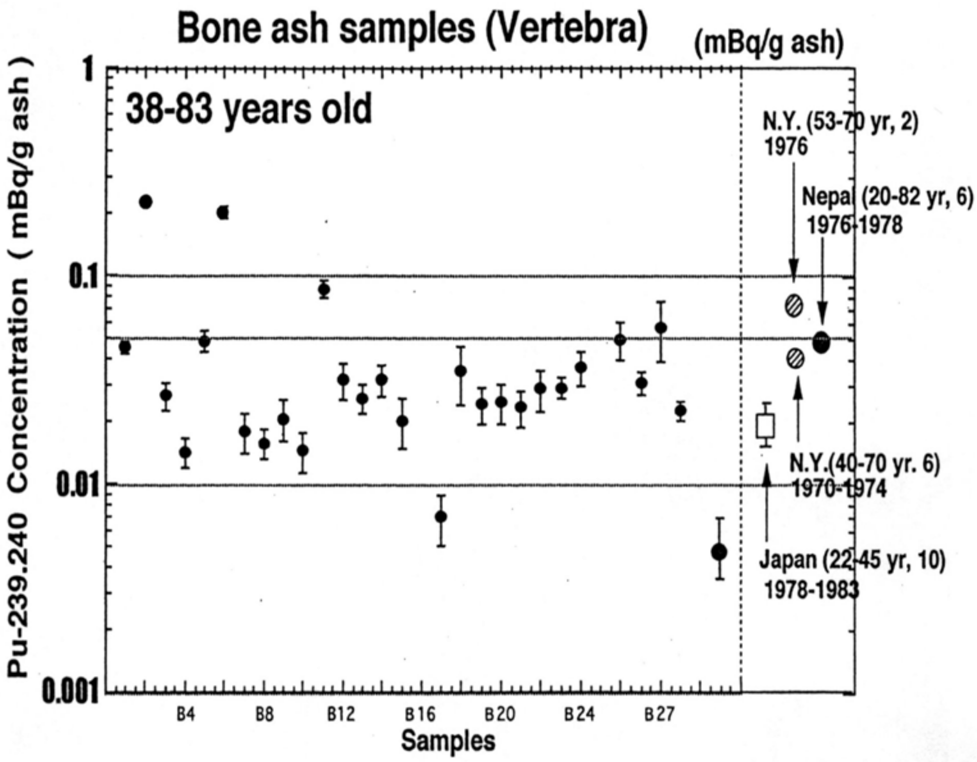

Fig. 5 Pu-239,240 concentrations of bone ash samples (vertebra) collected in and near Semipalatinsk City

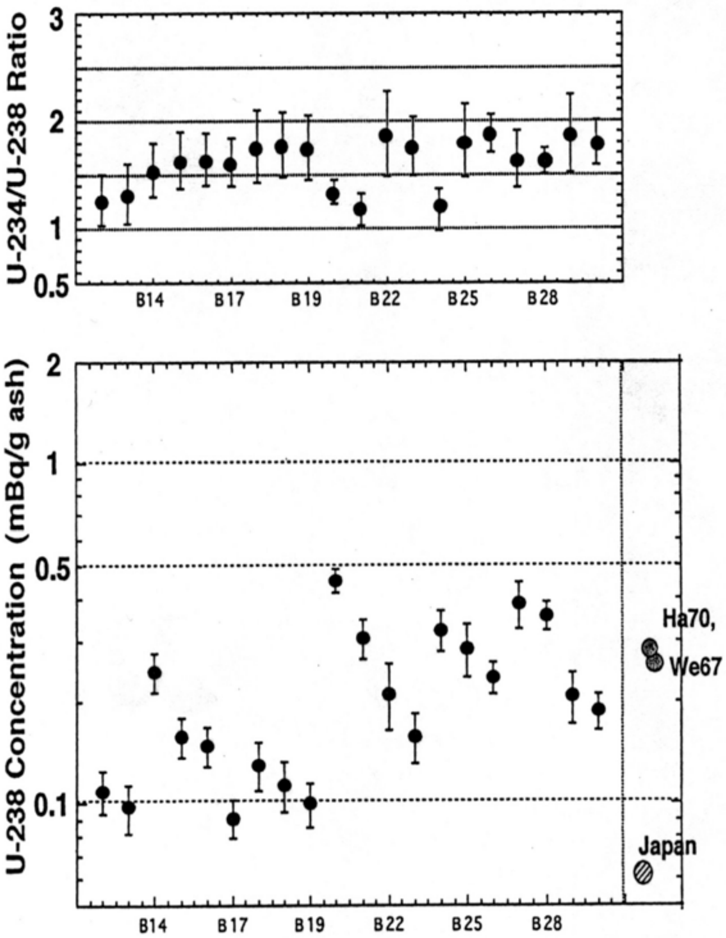

Fig. 6 U-238 concetrations and their U-234/U-238 activity ratios of bne ash samples (vertebra). Pu and U were sequentially separated from the same sample.

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3 ASSESSMENT OF POSSIBLE DOSES TO THE RESIDENTS OF SOME SETTLEMENTS INCURRED BY RADIATION FALLOUT AS A RESULT OF NUCLEAR WEAPON TESTING AT THE SEMIPALATINSK POLYGON

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3.1 The main nuclear tests that provided the major exposure to the population

Figure 1 presents the traces of the main tests that provided the major exposure to the population. Those traces were the result of the nuclear weapon testing in the atmosphere up to 1962 and a cratering test of January 15, 1965 (Stepanov et al 1984). We identified the traces in 1959, clarified at a later time under field studies as well the additional information received in 1984 was used for those traces. Table 1 presents the dates of the tests resulted in off-site exposure and the names of the corresponding settlements where the population was exposed.

3.2 Conditions of the tests

Table 2 presents the conditions of the tests. A peculiarity of radiation conditions formation as a result of the test conducted on September 24, 1951 was different directions of trajectories of radioactive clouds in various layers of air: (1) the upper part of the radioactive cloud was moved in south eastern direction and (2) the surface part of the radioactive cloud was moved in south western direction. The velocity of average upper-level wind was about 25-27 km/h and that of average surface wind was about 15 km/h.

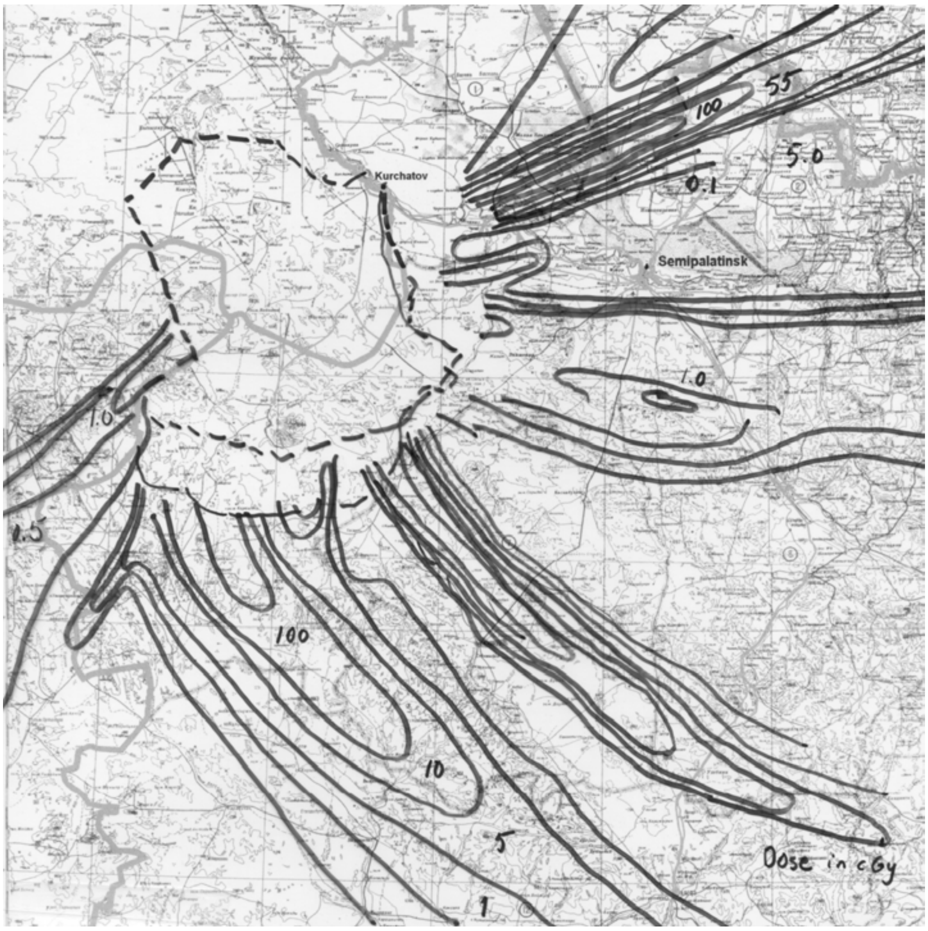
Kurchatov
Semipalatinsk
100
55
5.0
0.1
1.0
1.0
100
10
5
1
Dose in cGy

Figure 1.

Table 1. *The main tests that provided the major exposure to the population and the settlements where such population lived during the test era.*

Date of exposure	The main settlements of interest
29.8. 1949	Cheremushka, Dolon, Kanonerka, Naumovka Topolka, Lokot
24.9. 1951	Akbulak, Kaynar
24.8. 1956	City of Ust-Kamenogorsk, Znamenka, Tarkhanka, Bobrovka
12.8. 1953	Sarzhal, Kara-Aul (Abay), Aigyrzhal
22.8. 1957	Sovkhoz named Abay, kolkhoz named 30 years of Kazakhstan
7.8. 1962	Topolka, Semiarskoe, City of Semipalatinsk, Novoprovka
15.1. 1965	Znamenka, Sarapan

Table 2. *The conditions of the tests (Stepanov 1998a; Stepanov 1998b; Logachev 2000).*

	Date of exposure						
Characteristics	29.8.49	24.9.51	12.8.53	24.8.56	22.8.57	7.8.62	15.1.65
Total yield, kt	22	38	400	26.5	520	10	140
Local time of explosion	7:00	13:10	7:00	6:00	7:00	7:00	12:00
Height, m	30	30	30	100	1900	0	-200
Height of top of radioactive cloud, km	9	11.6	16	12	21	7	4.8
Velocity of average wind, km/h							
-Upper level wind	47	26.4	75	71	29	7	22
-Surface level wind	-	13.0	-	-	-	-	-

3.3 The information on the settlements, life-style and dietary habits of the population, shielding factors of the homes, characteristics of the measuring devices

Tables 3 through 6 present the information on the settlements (Table 3, on the opposite page), life-style and dietary habits of the population (Table 4), shielding factors of the homes (Table 5), characteristics of the measuring devices (Table 6).

Table 4. *Some life-style and dietary habits of the population in the settlements of interest (Kobzev 1960).*

Critical group of residents	Time spent outside; hours / day	Rate of fresh milk consumption; litres / day
Children 1-2 y	12	0.9
Children 3-12 y	12	0.6

Table 5. *Shielding factors for some homes from gamma-radiation of fission products [Stepanov 1985].*

Type of home	Shielding factor	
	from cloud	from fallout
Brick: One-storey home	3.0±0.5	10±3
Three-storey home:		
first floor	5.0±1.0	17±5
second floor	5.0±1.0	15±4
third (the last)	3.0±1.0	10±3
Adobe: One-storey home	4.0±1.5	13±5
Wood: One-storey home	1.4±0.5	3±2.5

Table 3*. General characteristics of the contaminated settlements (Logachev 1997; Stepanov 1998a; Stepanov 1963; Kobzev 1959; Kobzev 1960).*

Table 6. *Characteristics of some measuring devices used to measure exposure rate off-site [Stepanov 1963; Stepanov 1998a; Stepanov 1998b; Stepanov 1999].*

Method of Measurement	Measuring device code	Range of measurement	Measuring error	Application
Gamma-monitoring	UPT	0-100 μR s^{-1}	± 20 %	1949
Field gamma-monitoring	PR-6	0-5000 μR h^{-1}	± 30 % at the 1 st scale ± 10 % at the 2 nd and 3 rd scales	1949, 1951, 1953
Field gamma-monitoring	UR-4M	20-10,000 μR h^{-1}	± 10 %	1953
Car gamma-monitoring	SG-14	1 - 1,000 μR h^{-1}	± 20 %	1958, 1962
Field gamma-monitoring	PGR	3 - 1,000 μR h^{-1}	± 10 %	1958

3.4. The radiation conditions in the settlements considered

Table 7 presents the summarised results of the calculations and measurements of exposure rate. Table 8 presents the results of the measurements of exposure rate conducted in 1962. The data show that local fallout occurred in city of Semipalatinsk and settlement Novopokrovka 24 hours after the explosion of the test of August 7, 1962. The parameters and their values were used according to the methodical directions (Gordeev *et al*., 2000). Intake rate of pasture grass (wet matter) for cows was accepted to be (20-50) kg/d, and the daily milk production was accepted to be equal to 10 l/d.

Under investigation of the soil near river Chagan it was settled that in the cratering nuclear test of January 15, 1965 the main contributors to external exposure were the radionuclides neutron- induced in soil and in device construction. The fission products released due to the cratering test were responsible for 12-20 % of total external exposure. After the explosion the main radionuclides were: ^{24}Na, ^{56}Mn and at a later time up to 1 year: ^{54}Mn, ^{60}Co, and ^{134}Cs (Stepanov *et al*., 1985).

Table 7. *The data on measurements of exposure rate in some settlements [Stepanov 1963; Stepanov 1998a; Stepanov 1998c].*

Table 8. *Exposure rate (Pγ) in 1962 in some settlements (event of August 7, 1962), μR h $^{-1}$ [Stepanov 1962; Stepanov 1999].*

Settlement	Date	Local time	Pγ	Date	Local time	Pγ	Date	Local time	Pγ
Topolka	8.8.	14:34	4000	28.8	15:30	75	-	-	-
City of Semipalatinsk	8.8.	5:00	15	9.8	9:20	170	16.8	15:00	30
Semiyarskoe	8.8.	15:20	5000	28.8	17:00	45	30.8	19:00	38
	8.8.	15:55	900	-	-	-	-	-	-
	8.8.	17:30	900	-	-	-	-	-	-
Novopokrovka	16.8.	16:50	125						

3.5 Realistic doses to the population

According to available data (as of 2001) the estimates of maximum external doses were about 2 Gy in open air in the vicinities of settlements Cheremushka and Dolon. Effective doses of external exposure to the residents might have been realised in the settlements of Cheremushka, Dolon, Naumovka, and Akbulak following the tests of 1949 and 1951 (Table 9).

The value of realistic dose to thyroid due to internal exposure from radioiodines depends upon many factors. The main factors are as follows: the number of dairy cows in the settlement considered, intake rate of contaminated pasture grass for cows, rate of fresh milk consumption by children. The number of children in the settlement is an important factor in order to calculate collective dose. Also, biologically active fraction in radioactive fallout is a very important factor. In our opinion, the estimates of thyroid doses presented in Table 9 are very close to upper limit of possible doses taking into account log-normal distribution of many parameters (critical group of population, the rate of fresh milk consumption, contamination of pasture grass etc.).

Table 9. *Realistic doses in vicinities of the settlements (uncertainty in the external dose is about 30 % in case exposure level higher than 10 cGy and is about 80 % in case exposure level lower than 10 cGy; uncertainty in thyroid dose is characterized by a geometric standard deviation assumed to be equal to 3 (Stepanov 1963; Logachev 1994; Gordeev 2001; Buldakov 2000).*

Year of test	Settlement	External dose in air per year cGy	Realistic dose to critical group of population					
			External gamma-exposure*		Realistic *** doses to thyroid from intake of ^{131}I with milk, cGy			
			Absorbed dose, cGy	Effective dose, cSv	Children 1-2 y		Children 3-12 y	
					Individual	Collective	Individual	Collective
1949	Cheremushka	240	200	120****	50-100	1000-2000	13-30	1400-3000
	Dolon	186	150	90****	100-220	3600-7200	30-60	5200-10000
	Mostik	17	14	8	4-9	100-200	1-2	160-320
	Kanonerka	43	35	21****	35-70	3300-6600	10-20	4900-10000
	Naumovka	72	59	36****	180-340	5300-11000	60-120	8000-16000
	Topolnoe	56	46	28****	170-270	8200-16000	40-80	14000-28000
	Lokot	42	34	21****	230-400	12000-25000	70-140	17000-34000
1951	Akbulak	110	92	55****	1000-2600	18000-36000	250-500	28000-60000
	Kaynar	14	11	7	300-380	6800-14000	110-220	10000-20000
1953	Sarzhal	38	30	18****	-	-	-	-
	Abay (Kara-Aul)	27	23	13****	-	-	-	-
1956	Znamenka	3.6	2.9	1.8	-	-	-	-
	City of Ust-Kamenogorsk	11	9.3	5.6	-	-	-	-
	Bobrovka	3	2.5	1.4	-	-	-	-

Table 9. *Continued.*

Year of test	Settlement	External dose in air per year cGy	Realistic dose to critical group of population					
			External gamma-exposure*		Realistic *** doses to thyroid from intake of ^{131}I with milk, cGy			
			Absorbed dose, cGy	Effective dose, cSv	Children 1-2 y		Children 3-12 y	
					Individual	Collective	Individual	Collective
1957	Sovkhoz: Abay	2.4	2.0	1.2	-	-	-	-
	Kolkhoz named 30 years of Kaz.	2.4	2.0	1.2	-	-	-	-
1962	Topolka	0.9	0.7	0.4	-	-	-	-
	Semiyarskoe	0.2	0.17	0.1	-	-	-	-
	City of Semip.	0.05	0.04	0.02	-	-	-	-
	Novopokrovka	0.2	0.17	0.1	-	-	-	-
1965	Znamenka	2.0	1.6	1.0	-	-	-	-
	Sarapan	2.0**	4**	2	-	-	-	-

* Dose per year is about 99 % of total dose to the time of radioactive decay to negligible level;

** Dose was calculated from the time when the residents returned to the settlement. For settlement Sarapan n=1.6 in "decay law", the residents of Sarapan had received additional exposure in the area of evacuation. The explosion occurred in winter. For the residents of Sarapan settlement exposure to thyroid was derived from the actual measurements of radioactive contamination of milk (water from snow).

*** Dose coefficients for ^{131}I ingestion intake: $1.8x10^{-4}$ mSv Bq^{-1} for children up to 2 y and $7.6x10^{-5}$ mSv Bq^{-1} for children 2-12 y (Gordeev 2001)

**** Effective dose intended use / N 32, ICRP, 1990, 60

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4 MINISATELLITE MUTATIONS AND BIODOSIMETRY OF POPULATION LIVING CLOSE TO THE SEMIPALATINSK NUCLEAR TEST SITE

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4.1 Introduction

During the period between 1949 and 1989 nuclear weapon testing carried out at the Semipalatinsk Nuclear Test Site (STS) resulted in local fallout affecting the residents of Semipalatinsk, East Kazakhstan and Pavlodar districts of Kazakhstan and Altai region of Russia. The Semipalatinsk nuclear polygon in Kazakhstan has been the site for 470 nuclear tests, including 26 tests performed on the ground and 87 in the atmosphere. More than 1.5 million people living in the vicinity of the test site were repeatedly exposed to ionizing radiation (See Gusev *et al.* 1997, Pavlovski 1998).

4.2 Project objectives and collection of biosample database

In order to gain information on the genetic risk caused by chronic exposure to ionising radiation, a cohort of people exposed to the nuclear test fallout was studied. The objectives of the project were: 1) to establish a biosample database of blood samples of families in three generations living close to the STS and control families in three generations from clean areas, 2), to determine the chromosomal translocation frequencies by FISH chromosome painting in the lymphocytes of the exposed and the control people in order to determine the radiation exposure and, 3) to determine the minisatellite mutation rates in the three generations of exposed people and the control families of the same ethnic origin living in non-contaminated areas.

To conduct this study it was necessary to select the population living near to the STS and subjected to the greatest radiation exposure. Selection of places for sample collection has been based on the information of the radiological situation of the Semipalatinsk nuclear test site. Of particular interest was the first test of 29th of August 1949 as this was reported to have caused heavy fallout along a narrow trajectory extending north-east from the Polygon, also covering parts of the Altai region of Russia and parts of Pavlodar and Karaganda regions in Kazakhstan. This first explosion occurred at an altitude of 30 m above ground with an energy release of 22 kT. The wind velocity at the time of the test was 45-50 km/h, and within 2 hours a radioactive cloud reached densely populated areas inside a 100-km radius from the hypocentre. Due to the resulting radioactive fallout, the initial dose rate at ground level in some populated areas exceeded the natural level by millions of times. For our study we selected the population living in the villages of Dolon, Bodene, Cheremushki, Mostik, Kanonerka, Chagan and Karamyrza settlement (close to Kanonerka) of the Beskaragai District of Semipalatinsk region. According to the doses received by the population, all selected villages belong to Zone 1 with very high effective doses (usually more than 1 Sv) (Gusev *et al.* 1997).

The selection of exposed families. The subjects available for the study (three-generation families) were defined by a feasibility study identifying altogether 1029 persons in 83 families living in 7 villages in the Beskaragai district of the Semipalatinsk region. These villages were affected by the fallout from the first nuclear test in August 1949. Families for the final study were selected according to pre-set criteria ensuring that the grandparent generation was exposed at the time of the nuclear test, that their children were conceived after the main exposure (born after September 1950), and that there was an adequate number of family members available for genetic analyses. Finally, members of 40 families (361 individuals) were interviewed and sampled.

The inhabitants of Dzerzhinsk, Zhanatalap and Ushtobe villages of former Taldy-Kurgan District were included in the study as a control group. After careful interviews and matching (age, ethnic origin, socio-economic factors) of the controls, a group of 28 control families (total 250 people) were chosen.

According to the selection criteria of families for study we choose families where the P_0 array of exposed group included fathers born between 1926 -1948 years, e.g. they have been directly irradiated to the first explosion in August 1949. The year of birth of mothers (P_0) was between 1926-1954. However, the number of mothers born after 1949 was small. The ethnical characteristics of both cohorts reflect the basic ethnical structure of the population of Kazakhstan. In the exposed cohort the Kazaks formed 58.45 % of the subjects while other ethnicities formed 41.55%. In the control cohort, the corresponding numbers were 57.54 % and 42.46 %, respectively. Among other ethnic origins, Russians represented the majority in both cohorts. All studied individuals of exposed and control cohorts were interviewed on lifestyle habits, among them smoking. Non-smokers formed a majority in both exposed and control cohorts. No cases of cancer or other severe illnesses in exposed and control cohorts were observed in the exposed and control cohorts. Only a few cases with tuberculosis, hypothyroidism and asthmatic bronchitis were detected in both cohorts. The collected medical information from studied populations also show that all individuals have not received radiotherapy or cytostatics treatment.

Sample Collection. The sample collection was conducted during the period from June 1999 to October 1999 from exposed and unexposed individuals in local hospital of each village. Thirty to forty persons were sampled per week. Altogether 20-40 ml of Heparin blood (for FISH analysis, for Biosample Bank and for GPA analysis) and 5-10 ml of EDTA blood (for minisatellite analysis) was collected from each person of both exposed and control groups.

The subjects were interviewed simultaneously with the sample collection. Background data on family, residential history, radiation exposure, age, gender, smoking habit and lifestyle of all studied families were recorded using a questionnaire and were computerised.

The Biosample Bank and Database. The Biosample Bank consists of the frozen EDTA blood (at -20^{0}C) and isolated whole blood DNA (at -70^{0}C), the fixated erythrocytes (at -70^{0}C), isolated lymphocytes (in liquid nitrogen) and lymphocyte cultures (at -20^{0}C). The Biosample Bank is supplemented with a computerised database identifying the samples and number of vials stored, and information on the individuals studied (all questionnaire data) and family tree.

Finally, the results of demographic analysis of two human populations (exposed cohort from STS area and control cohort from clean area) are presented in this paper. The ethnicity, gender, occupation, smoking habit, age structure parameters were elaborated on both cohorts and they were matched by all these characteristics.

4.3 Retrospective dosimetry using FISH translocations

Translocation analysis using FISH (fluorescence *in situ* hybridization) chromosome painting was performed to evaluate the magnitude of cumulative exposure to ionizing radiation among the population living close to the Semipalatinsk nuclear test site in the Beskaragai district in Kazakhstan. Altogether 60 persons were selected from the cohort living in the area affected by the fallout and 40 persons from the control cohort living in non-contaminated areas. In both groups, approximately half of the subjects represented the P_0 generation. Individuals for the control cohort were chosen to match the exposed cohort with respect to, age, smoking and ethnic background, among others. Furthermore, in order to minimize the number of confounding factors affecting the results, only male subjects were included in the FISH analyses. Obtaining an adequate number of analysis data in FISH failed from one subject. The villages from the exposed area included Bodene (20 subjects), Chagan (1), Cheremushki (5), Dolon (13), Kanonerka (18), Karamurza (1) and Mostik (1). Sample processing for FISH, i.e. local collection of blood, transportation to Almaty, lymphocyte isolation and culturing was conducted within the same day. Fixed lymphocyte cultures were transported to Helsinki and Warwick, where FISH painting using whole chromosome probes for chromosomes 1, 2 and 4 was conducted.

FISH analysis of almost 2000 metaphases per subject was performed. Similar translocation frequencies were observed in the Semipalatinsk cohort and in the matched control group. In the P_0 generation, i.e. individuals who lived in the area of radioactive fallout from the first nuclear test in August 1949, translocation yields were almost equal to the corresponding controls. Neither was there a difference in the mean translocation frequencies between the various test villages. Assuming translocation stability in peripheral blood lymphocytes over several decades, these findings suggest that on average, the magnitude of exposure to the studied cohort in the Semipalatinsk area has been considerably smaller than that reported in the literature. Previously reported doses of more than one sievert (Gusev *et al.* 1997) cannot be confirmed by the present data. In the multiple regression analysis performed to evaluate the effect of various confounders, only age had statistically significant relationship to the translocation frequency.

A number of studies have shown age-dependency in the control level of translocations and inter-individual heterogeneity in this effect (Sorokine-Durm *et al.* 2000 and references therein). It is obvious that these factors have a direct influence on the sensitivity of the FISH method as a retrospective dosimeter. Due to the uncertainties, a positive dose effect can be considered if a doubling of the age dependent control level is observed. In the grandparent generation in the present study, a minimum average dose of 0.5 Gy would have been reliably detected by the technique. Thus, it can be concluded that the studied subjects, who lived in the area of radioactive fallout in 1949, have received cumulative doses of less than 0.5 Gy.

Retrospective biodosimetry is based on the long-term persistence of translocations. Since information on translocation frequencies immediately after exposure has usually not been available, the persistence has been tested by comparing translocation yield to the initial dicentrics yield. Lloyd *et al.* (1998) reported that the yield of FISH translocations 11 years after an accident involving intake of tritiated water was comparable to initial dicentrics yield. Salassidis *et al.* (1995) found constant translocation frequencies in eleven Chernobyl victims studied between 1991 and 1994. However, with regard to the Goiania accident victims exposed in 1987, translocation frequencies studied during 1992 and 1995 were reported to be much lower than the initial dicentric frequencies, and a dose-dependent ratio between dicentrics and translocations was implied (Natarajan *et al.* 1998). In one of the first applications of FISH painting for dose assessment after a considerable time of the exposure, the translocation frequencies of 20 Hiroshima atomic bomb survivors were analysed (Lucas *et al.* 1992). The dose estimates based on the dose response for translocations were in line with DS86 dose estimates to the bone marrow. Furthermore, persistence of translocations has been shown in rhesus monkeys exposed to whole-body radiation 28 years earlier (Lucas *et al.* 1996).

4.4 Minisatellite mutations

The analysis of germline mutation at tandem repeats minisatellite loci has previously been used to evaluate genetic consequences of exposure to ionizing radiation in humans and mice (Dubrova *et al.* 1996, 1997, 1998, 2000). The results of these studies have shown that, in sharp contrast to traditional genetic systems, radiation-induced changes in mutation rate can be detected in very small population samples and following a relatively low-dose exposure to ionizing radiation. Using this approach, germline mutation rates were estimated in the exposed cohort of families from the rural area near the Semipalatinsk nuclear test site and in a control group of families of the same ethnic origin living in non-contaminated areas.

Blood samples were collected from 40 three-generation families (parental year of birth 1926-1948) inhabiting the rural areas of the Semipalatinsk District and from 28 three-generation families (parental year of birth 1920-1951) inhabiting the rural area of the Taldy-Kurgan District. All families were profiled using eight hypervariable single-locus minisatellite probes B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31 and MS32, chosen for their relatively high spontaneous mutation rate. Minisatellite mutation analysis was performed on samples from 516 persons. Parental allele sizes and allele-length frequency distributions were indistinguishable between the control and irradiated families. However, minisatellite mutation rate in the cohort of P_0 parents directly exposed to radioactive fallout from the surface and atmospheric nuclear tests was 1.8-fold higher than in the control non-exposed population from the Taldy-Kurgan District. Less marked 1.5-fold increase was also found in the F_1 parents from the affected area. Most importantly, minisatellite mutation rate in the cohort of F_1 parents from the affected area showed a significant negative correlation with the year of birth, consistent with the decay of radioisotopes after the cessation of surface and atmospheric nuclear tests. Despite an elevated mutation rate in the exposed group, the size spectrum of mutants in control and exposed group were similar. The results of our study provide support for our previous findings showing an elevated mutation rate in the families exposed to the post-Chernobyl radioactive fallout (Dubrova *et al.* 1996, 1997) and are important for the further studies of genetic risks of ionizing radiation for humans.

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5 ESTIMATES OF RADIATION DOSES TO MEMBERS OF A COHORT RESIDING IN VILLAGES NEAR THE SEMIPALATINSK NUCLEAR TEST SITE

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The National Cancer Institute in the United States is conducting a radioepidemiologic cohort study on the relationship of thyroid cancer and other thyroid diseases with radiation exposure received from radioactive fallout from weapons tests conducted at the former Soviet nuclear test site at Semipalatinsk, Kazakhstan (see Carr et al, this conference). The study subjects which comprise the 3,000 person cohort lived in numerous villages within several hundred km distance of the test site. Hence, for the purposes of this study, it is necessary to estimate person-specific doses received by each study subject. This paper briefly describes the objectives, methods, sources of input data, and preliminary findings of the dosimetry component of the study.

The most important exposures received by local populations were a consequence of a very few nuclear explosions, in particular: a 22 kt test on 29 August, 1949, a 38 kt test on 25 September, 1951, a 400 kt test on 12 August, 1953, a 4 kt test on 5 October, 1954, a 1.3 kt test on 29 July, 1955, and a 9.9 kt test on 7 August, 1962. Of those tests, the 1949 and 1953 test contributed most to the population dose.

The dosimetry component of the study is a collaborative effort between the Institute of Biophysics in Moscow and the National Cancer Institute (NCI), though input from consultants to the study (see author list) has also benefited the effort. The dosimetry component of the study relies on expertise and experience gained over nearly five decades by Russian and United States investigators in estimating doses to members of the public from nuclear test sites in the former Soviet Union and in the U.S. Specifically, the goals of the dosimetry for this study include:

- To develop methods to estimate thyroid absorbed doses to identified individuals from external and internal radiation in support of the epidemiologic investigation;
- To use methods which account for the particulars of the environmental situation in Kazakhstan villages (e.g., close proximity to test site, specifics of diet, and lifestyle, etc.);
- To locate and use documented data input for the dosimetric calculations.

A longer-term goal is to synthesize the various dosimetric methods available into a single, consistent methodology that is a sum of the experience and knowledge from both U.S. and Russian investigators.

The dosimetric concepts used in this study include quantitative descriptions of the transfer of radioactive iodines through the foodchain to man, principally by the 'vegetation to cow to milk to man' pathway. Because the movement of radioiodines to man via the dairy animal is so important to the dose received by most persons, many parameters in the plant-cow-milk-man pathway model are critical to estimating the dose with reasonable levels of precision. In particular, model sensitivity studies have identified that the fraction of fallout (deposited radionuclides) intercepted and retained on plant surfaces, and the fraction of that deposition that is soluble are particularly important to correctly estimating the dose. Those phenomena are particularly difficult to model at close-in distances to the test site (<200 km) where the size of particles deposited rapidly changes (generally becoming smaller) with increasing distance.

Both Russian and U.S. based methods to describe vegetation interception and retention are being considered. It is generally well known that small particles (<50 μm) are preferentially retained on vegetation, hence, a model is required to estimate the fraction of fallout deposited that contaminates plants available to grazing animals, particularly, dairy cows. One model, based on Simon (1990), uses the surrogate variables of distance (d, km from test site) or time-of-fallout arrival (TOA, hours post detonation) to predict the vegetation interception fraction, F_v:

$F_v = 1 - \exp(-\alpha\, Y)$ (1)

where, α (m^2/kg) = 0.0007 x $d^{1.127}$ or α = 0.0417 x $TOA^{1.063}$ and α is restricted to values of 3.0 m^2/kg or less (<1650 km or TOA <57 h), and Y = standing vegetation biomass (kg/m^2, dry).

An alternative interception model, based on the Russian experience and knowledge (Gordeev, 1999) estimates the 'biologically available fraction' of fallout. In that method, F_v is a function of $\eta_{d<50}$:

$\eta_{d<50} = 1 - [1 - 0.6\,(H_{max}\ \overline{V}\,)^{-0.9}]\ x\ \exp(-4X_r^3)$ (2)

where H_{max} is the elevation achieved by the nuclear debris cloud, $\overline{V}$ is the weighted wind velocity where the weighting factors are the proportion of the total height (H_{max}) over which the velocity is relatively constant, and X_r (the 'reduced distance') is a distance at which $\eta_{d<50}$ reaches its asymptotic value of unity. The interception fraction is determined from the Russian formulation (eq. 2) by substituting $\eta_{d<50}$ (multiplied by appropriate unit conversion constants) into equation (1) in place of α. In addition, the Russian method involves an explicit submodel (not shown here) to describe solubility of fallout as a function of X_r. The Russian and U.S. models address the same basic phenomena, primarily, the change in particle size distribution deposited with changing distance, though the Russian method can be more precisely tailored to individual test events since it explicitly includes wind speed and cloud height. The importance of accounting for the efficiency of interception and retention, as well as particle solubility, is a consequence of the close distances where subjects resided (see Table 1). The two different modeling approaches give remarkably similar predictions under certain wind conditions. A detailed comparison of model predictions is now underway.

Other considerations important to the dose assessment include composition of diet, efficiency of transfer of radioiodines for each food type, ingestion rates of foods, age of subjects at time of exposure, type of residence, and the number of hours normally spent in- and outdoors.

The diet for residents of Kazakhstan varies primarily according to ethnic group (Kazak or Russian) and age. Specific foods available to rural residents of Kazakhstan in the 1950s varied considerably from diets of most Americans at the same time. In particular, dairy and animal products were more important to residents of Kazakhstan than to the American public. To determine diets specific to the study subjects, the National Cancer Institute conducted interviews of cohort members in Kazakhstan as well as older women in several

Table 1. *Summary of distance (km) from villages to Semipalatinsk test site and number of study subjects residing at each village.*

Village Name	Distance from center of experimental field to village (km)	Number of subjects resident in the village at the time of the first deposition
Dolon	106	121
Sarzhal	112	1456
Bolshaya Vladimirovka	127	120
Kanonerka	135	212
Kaynar	139	356
Novopokrovka	186	342
Karaul	191	514
Korostely	233	330

Table 2. *Differences in composition of milk among different species and preliminary estimates of feed-to-milk transfer coefficient (d/L) for ^{131}I.*

Species (common name)	Fat (%)	Protein (%)	Lactose (%)	Milk production (L/d)	Estimate of f_m for ^{131}I
Camel	5	4	5	8+	0.02
Cow	4	4	3-4	~10	0.01
Goat	3.5	3	4-5	~2	0.08-0.3
Horse	1.5	3	6	~10	0.01
Sheep	5	5-6	4-5	~2	0.1
Human	4	0.3	>4	~1	0.35

villages familiar with child-rearing practices during the years of exposure (1949 through 1962). The various dairy products identified to have been consumed by local populations included fresh cows' milk, sour cows' milk/yoghurt, fresh ('cottage') cheese, fresh goat milk, fresh sheep milk, sheep cheese, fresh horse milk, fermented horse milk, camel milk (fresh or fermented), as well as human breast milk. There are differences in the composition of milk from different species (see Table 2) as well as milk production rates. These factors likely contribute to species-specific differences in the transfer coefficient (f_m, in units of d/L). Significant information is available in the published literature on the transfer of radioiodines to the milk of cows and goats. Less information is available for sheep though more data has recently become available following the Chernobyl accident. No information has been found that quantitatively describes the transfer to the milk of horses or camels. Presently, the NCI has a small-scale experimental study underway to determine the transfer coefficient for all five species.

At the time of this conference, preliminary dose estimates have been computed (see Table 3) for eight villages, primarily using the methods devised by Gordeev at the Institute of Biophysics (Moscow). These preliminary estimates will continue to be revised and should not be considered as final or precise. Estimated internal doses from ingestion and inhalation of ^{131}I varied according to village from a low of 57 mGy (Novopokrovka) to a high of 6.1 Gy (Kaynar) for a child of 1-year of age at the time of first deposition. Estimated internal doses for an adult in those same villages were 23 mGy and 0.77 Gy.

The National Cancer Institute has also supported biodosimetric measurements, in particular, in situ fluorescent hybridization (FISH) of peripheral blood lymphocytes to detect stable translocations, and of electron paramagnetic resonance (EPR) measurements of teeth. The EPR technique quantifies free radicals that are produced by ionizing radiation in tooth enamel and that are captured by defects in the crystal lattice of the enamel in numbers proportional to the absorbed dose. Both types of measurements are viewed as useful for corroboration, or to determine biases, in calculated (estimated) doses that depend on environmental transfer models.

Table 4 presents a limited comparison of measurements and estimates. Presently, there is considerable disagreement between dose estimates and FISH or EPR measurements for several villages, including Bolshaya Vladimirovka, Dolon and Novopokrovka. Reasonable agreement was seen for the villages of Sarzhal, Kanonerka, Karaul, and Korostely.

Considerable efforts are still needed to characterize individual doses in Kazakhstan villages with any reasonable degree of precision. Extensive model testing and examination of parameter values is presently underway at the National Cancer Institute as are further biodosimetric measurements. Within the next year, considerable changes will undoubtedly be made to the dose estimates presented in Table 3.

***Table 3**. Preliminary estimates of doses received in eight villages as a function of age. Calculations for 1 year old assume intakes of 0.5 L/d mother's breast milk plus 0.5 L/d fresh cows' milk. Calculations for 20 year old assume 0.7 L/d cows' milk. **NOTE:** These estimates are subject to considerable revision.*

Village	1 year old at time of the first deposition event			20 year old at time of first deposition event		
	External (Gy)	Internal (Gy)	Total (Gy)	External (Gy)	Internal (Gy)	Total (Gy)
Bolshaya Vladimirovka	0.0026	0.074	0.077	0.0036	0.029	0.033
Dolon	1.2	2.3	3.5	1.7	0.31	2
Kaynar	0.026	6.1	6.1	0.067	0.77	0.84
Kanonerka	0.25	1	1.3	0.35	0.15	0.5
Karaul	0.26	3.1	3.3	0.69	0.39	1.1
Korostely	0.027	0.63	0.66	0.038	0.084	0.12
Novopokrovka	0.001	0.057	0.058	0.0014	0.027	0.0282
Sarzhal	0.5	0.66	1.2	1.3	0.083	1.4

***Table 4.** Comparison of biodosimetry estimates and calculated (estimates) doses to representative subjects in villages. NOTE: FISH is florescent in situ hybridization, EPR is electron-paramagnetic resonance, a dash (–) indicates no data is available.*

Village	Estimated dose (mGy) from FISH analysis (mean translocation rate/1000 cells)	Variance mean EPR (mGy) With background/ Bckgrnd adjusted	Mean of calculated (estimated) external dose to the thyroid (mGy)
Bolshaya Vladimirovka	-	285/222	14.9
Dolon	-	192/129	956
Kaynar	~350	-	28
Kanonerka	-	247/183	162
Karaul	230	256/195	300
Korostely	~0	-	27
Novopokrovka	~20	218/156	18.9
Sarzhal	~430	-	544

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6 THYROID DISEASE PREVALENCE AND FALLOUT EXPOSURE IN KAZAKHSTAN

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6.1 Introduction

Fourteen years of atmospheric nuclear weapons testing program in Northeast of the former Soviet Republic of Kazakhstan resulted in radioactive contamination of territories downwind from the Semipalatinsk Nuclear Test Site (STS) and exposure of the resident population. Between 1949 and 1963 88 atmospheric and 30 surface nuclear explosions were conducted at the STS (Gusev *et al.*, 1997). Three tests in particular, in 1949, 1951, and 1953, are believed to have contributed over 90% of total fallout exposure to local residents. Exposure to the thyroid gland was from gamma radiation from external sources and beta radiation from radioactive iodine in milk.

Childhood radiation exposure is a known risk factor for subsequent thyroid cancer (Ron *et al.* 1995), yet most of our information on radiation-related thyroid cancer comes from studies of populations with external medical exposure. Much less is known about risk associated with childhood exposure to internal I-131. Increased prevalence of thyroid nodules and papillary thyroid carcinoma was observed among children living downwind from the Chernobyl accident in 1986 (Yamashita, 1997). Both conditions are usually indolent and likely to be long undetected in the absence of special diagnostic efforts. The purpose of the current study was to evaluate thyroid disease prevalence and to estimate the risk of radiation dose-related thyroid disease, including cancer, in a population with protracted exposure to mixed gamma and beta radiation from weapons test fallout. The design of our study was based on an approach previously used by NCI to screen Estonian clean-up workers involved in Chernobyl nuclear reactor accident (Inskip *et al.*, 1997)

6.2 Study population

Since 1960 the Kazak Institute for Radiation Medicine and Ecology (IRME, Semipalatinsk) has developed and followed a cohort now numbering 10,000 residents of heavily exposed villages downwind of the STS, plus another 10,000 residents of more distant, and presumably non-exposed, villages.

The present study was based on a thyroid screening survey of 3,000 residents of eight villages near the STS (six presumably exposed villages: Karaul, Kainar, Sarzhal, Dolon, Korostely, and Kanonerka; and two presumably non-exposed villages not included in the IRME cohort: Novo-Pokrovka and Bolshaya Vladimirovka). Study villages were selected based on accessibility and estimated gamma-ray dose to residents. Subjects of the study were current residents who had been 20 years of age or younger at the times of the three major fallout events (in 1949, 1951, and 1953). Subjects identified by the IRME as ‘exposed’ cohort members were treated as exposed for the present analysis, and subjects from the two presumably non-exposed villages, or who had migrated to a study village later from relatively unaffected areas, were treated as non-exposed. In the analysis, residential history information from the IRME archives, used to identify potentially exposed individuals for subject selection, was supplemented by questionnaire items for the interview portion of the screening procedure. These interview items were aimed at determining where each participant was living at the time of the fallout events affecting the settlement of current residence.

6.3 Screening program

Each study participant was informed about the purpose of the screening and gave his/her signed consent. At the time of screening participants were measured for height and weight and interviewed in their native languages (Kazak or Russian) by trained medical interviewers to ascertain medical, residential history and nutritional information with emphasis on milk product consumption around the time of fallout deposition. Four American radiologists and four local physicians, working in bi-national teams, conducted ultrasound thyroid scan for nodules. Repeat examination using blind cross-checking was done for quality control. Malignancy of suspicious nodules was determined by cytopathology assay of fine-needle aspiration biopsy specimens. Duplicate slides were made from each needle pass and preliminary cytopathology diagnosis was made on site, subject to later confirmation using Papanicolaou staining at the VA Medical Center, Albuquerque in the U.S. Finger-stick blood samples were collected and later assayed for level of thyroid stimulating hormone (TSH) as an indicator of thyroid gland function. Informed consent was obtained separately for study participation, biopsy, and phlebotomy.

6.4 Analysis

For this presentation, disease frequencies were compared between exposed and non-exposed study participants. Linear logistic regression, using the GMBO algorithm of the Epicure package (Preston, 1991), was employed to compute relative risks adjusted for age and sex.

6.5 Preliminary results

A total of 2998 subjects met the study eligibility criteria. Of these, 1989 were classified as exposed and 1009 as non-exposed for purpose of this analysis. The distribution of subjects by ethnicity, sex, and age at the time of screening is given in Figure 1. Of the total, 6.1% were born within 5 years after the major fallout event affecting their village of residence, including 2.4% who were *in utero*; 26.3% were younger than 5 years of age, 20.9% were between 5 and 10, 28.2% between 10 and 15, 18.4% were between 15 and 20, and 0.1% between 20 and 25. The study population was 60% female and 40% male, with a mean age of 56.2 at the time of examination. Two major ethnic groups with different diets and life-styles were Kazaks (66%) and Europeans, including Russians, Ukrainians, and Germans (34%).

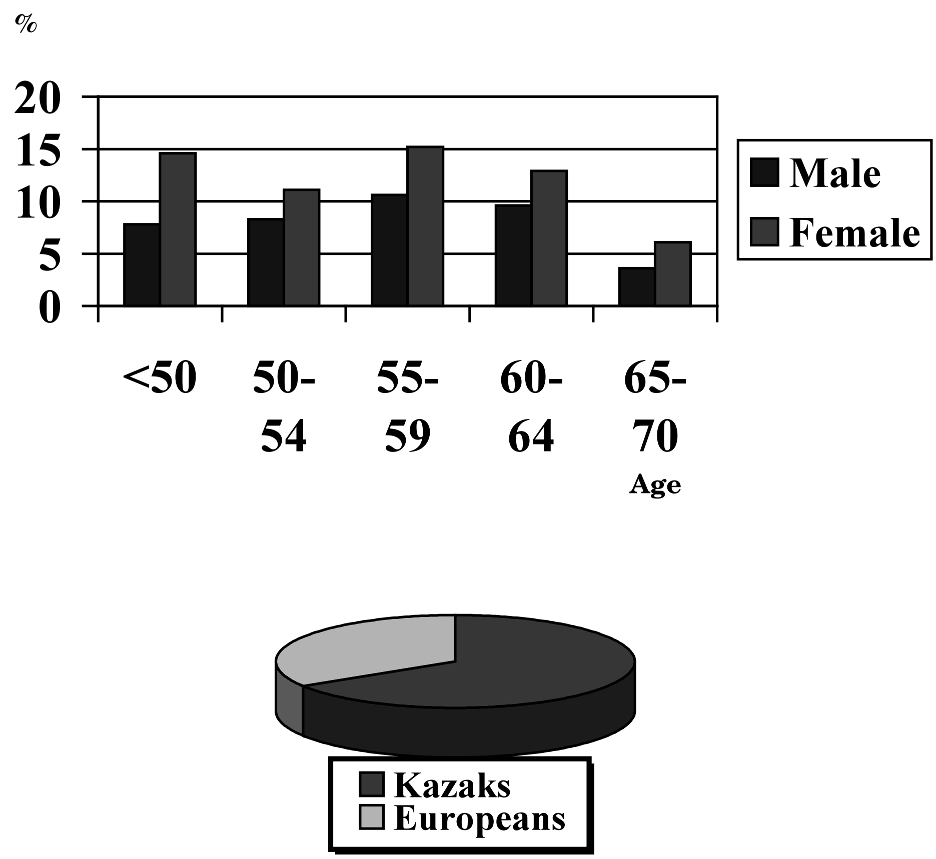

Figure 1. *Distribution of study population by sex, ethnicity, and age at the time of screening*

Thyroid nodules, ranging from 0.2 to 8.0 cm in diameter, were detected in 920 of 2998 eligible participants (31%). Biopsy and cytopathology of 635 nodules from 491 subjects found 30 malignant thyroid papillary tumors in 27 participants (3 male and 24 female) (Table 1).

The prevalence of thyroid nodules was significantly higher among females compared to males (39% and 18%, respectively) and increased by 3.5% per year from age 40 to age 70 at examination (Table 2).

Table 1. *Number of screened subjects and diagnostic findings by residency at the time of screening (August, 1998).*

Village (year of exposure)	Number of people examined	Number of nodules diagnosed	Number biopsied	Papillary carcinoma
B.Vladimirovka	188	62	42	1
Novopokrovka	620	188	108	7
Dolon (1949)	146	49	25	2
Kanonerka (1949)	336	129	71	4
Korostely (1949)	435	114	50	2
Kainar (1951)	470	150	84	3
Sarzhal (1953)	172	49	22	2
Karaul (1953)	631	179	87	6
Total	**2998**	**920**	**491**	**27**

Table 2. *Thyroid nodule prevalence by sex and age.*

Age	Male	Female
At the time of fallout (ATF)		
0-4	55 (16%)	200 (32%)
5-9	48 (18%)	139 (39%)
10-14	71 (20%)	212 (43%)
15-20	41 (19%)	152 (46%)
At examination		
<50	22 (9.5%)	136 (31%)
50-54	55 (22%)	124 (37%)
55-59	65 (20%)	190 (42%)
60-64	51 (18%)	162 (42%)
65-70	23 (21%)	92 (51)

Table 3. *Prevalence and relative risks by cohort status of thyroid nodules, papillary carcinoma, and follicular neoplasms.*

Thyroid disease	Number of cases	Prevalence (%)	RR (95% CI)
All nodules			
- exposed	700	35.2	
- non-exposed	220	21.8	1.8 (1.5-2.1)
Papillary carcinoma			
- exposed	20	1.0	
- non-exposed	7	0.7	1.2 (0.6-5.6)
Follicular neoplasm			
- exposed	5	0.3	
- non-exposed	5	0.5	0.5 (0.1-1.8)

Prevalence of benign nodules and malignant tumors were positively related to exposure (Table 3). Among presumably exposed subjects, the RR for all nodules was 1.8 (95%CI = 1.5 to 2.1). For papillary thyroid carcinoma the increased RR was not significant, a result that is not surprising given the small number of cases. Determination of malignancy was not always possible; there were 86 cases of “deferred diagnosis” (13.3% of all biopsy cases), which may have included undetected cancers. Another 53 subjects (2 males and 51 females) had received thyroid surgery prior to our screening program in 1998.

More detailed analyses including dose-response analysis are in progress.

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7 SEMIPALATINSK HISTORICAL COHORT: CAUSES OF DEATH IN A STUDY GROUP FROM SETTLEMENTS ADJACENT TO THE SEMIPALATINSK NUCLEAR TEST SITE

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7.1 Abstract

From 1949 until 1989 more than 450 nuclear tests were conducted at the Semipalatinsk test site (STS). This paper presents first descriptive data from a longitudinal study that includes settlements adjacent to STS. Already in 1965, two study groups had been identified and followed up by the ‘Dispanser No. 4’ in Semipalatinsk, an institution conducting health research in exposed and comparison areas of the Semipalatinskaya oblast. After the dissolution of the Soviet Union in 1991, follow-up has been continued by the successor institution of the Dispanser, the Kazak Research Institute for Radiation Medicine and Ecology (KRIRME). In the framework of an EC-funded collaborative project, a database is established using data of KRIME archives. This database comprises follow-up data on 19,454 people from an exposed and a comparison group in the Semipalatinskaya oblast. The exposed group includes 9,850 people born until 1960 who lived permanently in the settlements Cheremushki, Dolon, Kainar, Kanonerka, Karaul, Kaskabulak, Kundyzdy, Mostik, Sarzhal, Znamenka during atmospheric nuclear testing.

7.2 Introduction: The Semipalatinsk cohort study

In the early 1960s, Soviet authorities ordered a long-term study on health effects in the exposed population the Semipalatinskaya oblast from the ‘Dispanser No. 4’ in Semipalatinsk. The study was supervised by the Moscow Institute for Biophysics (IBP) and initially included 12 villages, which were later grouped into 10 settlements. Exposure status of settlements was defined according to measurements of Sr-90 and Cs-137 in soil samples performed in

1963. At that time, approximately 20,000 people lived in settlements with considerable exposure. According to a directive by IBP, only approximately 10,000 persons were assigned to each study group. All individuals born between 1949 and 1960 were included into the study groups, whereas for those born before 1949, only approximately 50% of the population in the settlements under study became members of the cohort. Inclusion criteria for the cohorts were permanent residence in the exposed settlement during the period of atmospheric nuclear testing, those diagnosed with tuberculosis or brucellosis was excluded from the study groups at the beginning of follow-up in 1965. Formerly classified documents confirm residence and migration in these settlements from 1960 until 1990. In the last 10 years, KRIRME continued the follow-up in collaboration with local staff in each settlement. The data for the comparison cohort were collected and followed-up the same way as for the exposed group and included six settlements of the Kokpektinsky rayon located several hundreds of kilometres east/south-east of the Semipalatinsk test site. The population of the Kokpektinsky rayon was approximately 30,000 people in 1965; again according to the directive, 10,000 individuals were included into the comparison cohort following the same protocol as applied for the exposed cohort. Archive data held at KRIRME for both study groups as identified in 1965 and presently comprising follow-up data from 1960 until 1999 are used for the cohort study.

7.3 Data sources

Exposure data

Among the exposed cohort, exposure onset differs depending on the location of the settlement and test fallout. The settlements northeast of the test site (Dolon, Kanonerka, Mostik) were exposed mainly due to the first Soviet nuclear test on 29 August 1949. In the settlements southeast of STS, i.e. Znamenka and Kaskabulak, Kundyzdy the surface nuclear tests of 24 August 1956 and the first hydrogene bomb test on 12 August 1953, respectively, were the most relevant contributions to radiation dose. In the south of STS, first exposure was due to the test on 24 September 1951 in Kainar and due to the test of 12 August 1953 in Sarzhal and Karaul. During the test on 12 August 1953 all inhabitants of Sarzhal, Kundyzdy and Kainar were evacuated to Karaul from 9 until 28 August.

For each member of the exposed cohort, preliminary individualized estimates of cumulative effective doses (ED) based on data of eight most dose-contributing nuclear tests (yield, altitude above ground, meteorological conditions at time of the test), settlement of residence, age at exposure, dietary habits were calculated by the Kazak Research Institute for Radiation Medicine and Ecology (Kurakina *et al.* 2000).

7.4 Health data

The historical cohort studies are based on mortality, causes of death were recorded based on information from death registration acts. Different from the medical death certificate, the causes of death stated in the act were to considerable extent based on autopsy findings until the early 1990s. Since autopsy rates decreased after the dissolution of the Soviet Union, cause of death information in the 1990s is based on both documents, i.e. the medical death certificate and death registration act. Causes of death were coded according to ICD-9 by KRIRME staff.

7.5 Data base and follow-up

The data base consists of the following information for each person: ID, gender, ethnicity, date of birth, status (‘deceased’, ‘alive’, ‘emigrated’), date of death or date of emigration, cause of death (ICD-9 codes), preliminary dose estimate, and settlement. Quality control (search for duplicates, multiple control procedures) is currently being performed. The accuracy of coding procedures is assessed in the framework of a complementary cause-of-death-registry project funded by the European Commission in four exposed regions in New Independent States.

Follow-up started in the 1960s and has been conducted until present, i.e. each death and emigration occurring among the study groups is registered. At present time, 22.1% of the individuals of the exposed cohort and 12.4% of the comparison cohort have emigrated from their settlements, for each migrant the year of emigration is known and can be taken into account in the analysis (person years at risk).

7.6 Expected results

The data compiled for the time period from 1960 to 1999 makes it possible to perform cohort analyses for various cancer sites using a person-years approach. In addition to cancer effects, non-cancer effects of radiation exposure can be investigated in the cohort analysis based on the mortality follow-up. Due to differing sampling methods, data for the birth cohorts born between 1949 and 1960 will be analyzed separately from those born before 1949. Since the cohort has been established only in 1965 beginning with 1960, i.e. 11 years after the first exposure, in the early years possibly radiation-induced cancers might be missed. Thus, the radiation related risk of cancer might be underestimated in the early years in the forthcoming analysis. Due to the early onset of data collection, late effects of the exposure can be evaluated. With the forthcoming analyses, various sources of bias have to be taken into account, i.e. selection of persons in 1965, errors in dose estimation, accuracy of information on death registration acts, and implications of changes in diagnostic and registration practices between 1960 and 2000. Results for the cohort study will be available at the end of the year 2001. Furthermore, nested case-control studies can be implemented at a later stage in order to include further information on other risk factors.

A first analysis on the basis of several cross-sectionals studies, which have been carried out every five years and include incidence data, revealed a higher cancer incidence in the exposed area compared to the unexposed area (Gusev, *et al.* 1998). The on-going development of the health database, improvement of exposure assessment, and implementation of analytical studies will provide important information on the health impact of the experienced external and internal exposures due to fallout from nuclear weapon's testing in the Semipalatinskaya oblast.

Table 1. *The Semipalatinsk cohort study: status of follow-up*

Exposed group				
Settlements	Deceased # (%)	Alive # (%)	Emigrated # (%)	# of cohort members
Cheremushki	248 (46.1)	160 (29.7)	130 (24.2)	538
Dolon/Budene	376 (40.0)	225 (23.9)	340 (36.1)	941
Kainar/Abraly	351 (46.4)	312 (41.2)	94 (12.2)	757
Kanonerka	529 (42.7)	466 (37.6)	244 (19.7)	1,239
Karaul	1,225 (43.2)	1,053 (37.1)	558 (19.7)	2,836
Kaskabulak	201 (39.0)	215 (41.8)	99 (19.2)	515
Kundyzdy	256 (41.8)	168 (27.4)	189 (30.6)	613
Mostik	218 (45.0)	136 (28.0)	131 (27.0)	485
Sarzhal/Sarapan	496 (49.0)	370 (36.5)	147 (14.5)	1,013
Znamenka	372 (40.7)	299 (32.6)	242 (26.5)	913
Exposed group	4,272 (43.4)	3,404 (34.6)	2,174 (22.1)	9,850 (100)
Comparison group	3,238 (33.7)	5,173 (53.9)	1,193 (12.4)	9,604 (100)

Table 2. *Preliminary dose estimates due to internal and external exposure (average values by settlement) for the Semipalatinsk cohort (Kurakina et al. 2000).*

Exposed group		
Settlements	Mean cumulative ED [mSv]	# of individuals in the exposed group
Cheremushki	1,746	538
Dolon/Budene	1,590	941
Kainar/Abraly	718	757
Kanonerka	448	1,239
Karaul	451	2,836
Kaskabulak	455	515
Kundyzdy	225	613
Mostik	233	485
Sarzhal/Sarapan	665	1,013
Znamenka	302	913
Total Exposed group	634	9,850

Table 3. *Causes of death for deceased persons until 1999 by main groups of ICD 9 in the exposed group.*

	ICD main group	Exposed group #	%	Comparison group #	%
1	Infectious and Parasitic Diseases	408	9.6	454	14.0
2	Neoplasms	577	13.5	368	11.4
3	Endocrine, Nutritional and Metabolic Diseases and Immunity Disorders	3	0.1	3	0.1
4	Diseases of the Blood and Blood-forming Organs	0	0	2	0.1
5	Mental Disorders	0	0	1	0.0
6	Diseases of the Nervous System and Sense Organs	43	1.0	33	1.0
7	Diseases of the Circulatory System	1,981	46.4	1,358	41.9
8	Diseases of the Respiratory System	466	10.9	479	14.8
9	Diseases of the Digestive System	439	10.3	225	6.9
10	Diseases of the Genitourinary System	146	3.4	116	3.6
11	Complications of pregnancy, Childbirth, and the Puerperium	9	0.2	21	0.6
12	Diseases of the Skin and Subcutaneous Tissue	0	0	0	0
13	Diseases of the Muscoskeletal System and Connective Tissue	0	0	0	0
14	Congenital Anomalies	0	0	3	0.1
15	Certain Conditions Originating in the Perinatal Period	2	0	2	0.1
16	Symptoms, Signs and Ill-defined Conditions	0	0	0	0
17	Injury and Poisoning	198	4.6	173	5.3
Total		**4,272**	**100**	**3,238**	**100**

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8 EXTERNAL DOSES IN RESIDENTIAL AREAS AROUND SEMIPALATINSK NUCLEAR TEST SITE

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Estimated external doses to residents near the Semipalatinsk nuclear test site are presented as a result of study of bricks using thermoluminescence technique. The areas where samples were acquired include Dolon and other villages, Semipalatinsk City and Ust-Kamenogorsk City. The external doses to population were estimated from the brick measurements to be up to 1.0 Gy for resident in Dolon. The doses in the two cities were evaluated to be several hundreds milligray.

8.1 Introduction

A total of 459 nuclear tests were conducted by the former USSR between 1949 and 1989 at the Semipalatinsk nuclear test site (SNTS) of Kazakhstan, including 87 atmospheric, 26 on the ground, and 346 underground explosions[2]. The total release of the energy equivalent of trinitrotoluene (TNT) of about 18 Mt was eleven hundred times that of the Hiroshima atomic bomb. However, previous reports concerning the effects of radiation on residents near the SNTS based on data provided by the Defence Department of the former USSR[3,4] did not involve direct experimental data concerning the total effective dose. The previous reports only estimated external doses based on dose rate measured in particular settlements after certain nuclear explosions. Therefore the value of dose reported was not the total integrated doses from the whole nuclear testing program.

The technique of thermoluminescence dosimetry (TLD), which has been successfully applied in dosimetry for the Hiroshima and Nagasaki atomic bombs[5,6], enabled us to estimate the accumulated external gamma ray doses from all the nuclear explosions at specific locations near the Semipalatinsk test site. The TLD technique is well established, not only for instantaneous exposure as in A-bombs (Hiroshima and Nagasaki) [7,] but also in prolonged exposure to natural radiation, which is used in archaeological sample dating[8]. Moreover the TLD technique was applied for dosimetry studies of radioactive contamination from the Chernobyl accident [9,10]. We applied the TLD technique to the problem of dosimetry for the local population due to the Semipalatinsk nuclear tests.

In this report accumulated external doses to the local populations are presented as a results of study by the thermoluminescence technique for bricks sampled at several settlements in 1995, 1996 and 1997. The areas include Dolon and other villages, Semipalatinsk City and Ust-Kamenogorsk City.

8.2 Samples

The number of samples taken from a building at each location is presented in this report (Table 1). The bricks were obtained from the outer surface of the buildings. The number of brick buildings was very limited, especially in the villages.

We sampled bricks from the surfaces of the outer wall of buildings mainly in three settlements near the SNTS[11]. Two of them were Semipalatinsk City and Ust-Kamenogorsk City. They are located at 100 km and 270 km from the boundary of the SNTS.

The third settlement was Dolon, which is, located about 55 km from the boundary of the SNTS and was one of settlements with the highest doses in the former report[12]. Geographic coordinates of the sampling sites were determined with a GPS Navigator (Magellan Systems Corp., Trailblazer).

The experimental procedure for estimation of external gamma-ray dose by the TLD technique was previously described [6,13]. The quartz inclusion method was applied to sample preparations [13]. A 5 to 10 mm thick layer of the surface of the brick was removed. The remaining 20 mm of the brick was used for measurement. High temperature analysis of thermoluminescence was applied by using the TLD device with a single photon counting system (Daybreak Nuclear and Medical Systems, Inc., 1100 TL system.

Dolon Chagan Izvyestka

Semipalatinsk City

Ust-Kamenogorsk City

***Photo 1**. Sampling sites with relatively high dose.*

We measured the in situ gamma ray dose rate at the surface of the sampling point with a pocket survey meter (Aloka PDR-101) that uses a CsI(Tl) (20 x 25 x 15 mm) detector. We used the survey instrument measurements for the estimation of natural gamma ray exposure to bricks in our analysis. The beta ray internal dose rate for quartz grain in the brick was measured for each brick sample in the laboratory as follows. We put $CaSO_4$:Dy TL powder between two disks of brick samples, which were stored in a 10 cm thick Pb shielding box with N_2 gas [6], and performed beta counting of the surface of a brick sample using [ZnS(Ag)] plastic scintillator (Aloka TCS-35, active area, 72 cm^2). The TL powder was used to determine the absolute value and the surface measurement was used for a relative value. A clean surface was prepared by cutting each brick sample for beta measurements.

The dose component due to alpha particles originating within the clay matrix was determined to be negligible by etching the surface of quartz. The age of the brick was assumed to be the same as the age of the building.

8.3 TLD and external dose reconstruction

The method of external dose estimation from TLD doses for brick is summarized in Fig. 1. The external dose of free space in air (D_{Air}) at 1 m above the ground surface is assumed to be approximately twice the surface dose (D_{Sur}) of a brick-building wall since there is no radioactivity due to the radioactive fallout and cloud contained inside building[14].

The D_{Sur} is estimated by using the dose (D_{F*}) in the brick due to the radioactive cloud and fallout by using the transmission coefficient (T_{av}) of the brick for gamma rays from fission products, as expressed by Eq.1.

$$D_{Sur} = D_{F*} / T_{av} \qquad (1)$$

We applied the transmission coefficient (T_{av}: 0.8~0.7) of bricks for the gamma ray of Cs-137 to the estimated dose measured for each sample.

The main radionuclides that contribute external dose to residents more than several tens of km from the test site (from the point of view of half-life) are fission products of Sr-91, Sr-92, Zr-97, Ru-105, I-132, I-133, I-134, I-135, La-140 and La-142. Weighted mean values of γ energy for each nuclide are calculated for γ rays with an intensity per decay of more than 10%. The effective energy of gamma rays from these fallout activities is estimated to be 855 keV as a weighted average of effective gamma ray energy for each nuclide by its dose contribution (3h ~ 7d)[15]. The difference of transmission coefficient between the 855 keV gamma ray and 662 keV Cs-137 gamma ray, which is estimated to be about 10 %, is acceptable in the present dosimetry study. This conclusion is supported by TLD studies of fallout from atomic power plant accidents. The Monte Carlo calculation for isotropic irradiation from a homogenous source distributed on the ground surface with Cs-137 consists of TLD dose-depth profiles for bricks exposed by Chernobyl fallout[14]. Then, D_{F*} can be expressed by the following equation:

$$D_{F*} = D_{TL*} - D_{Bkg} \qquad (2)$$

where D_{TL*} and D_{Bkg} are the raw value of dose in the brick and natural background dose, respectively. Correction of the measured D_{TL*} values for supralinearity was less than 10 %.

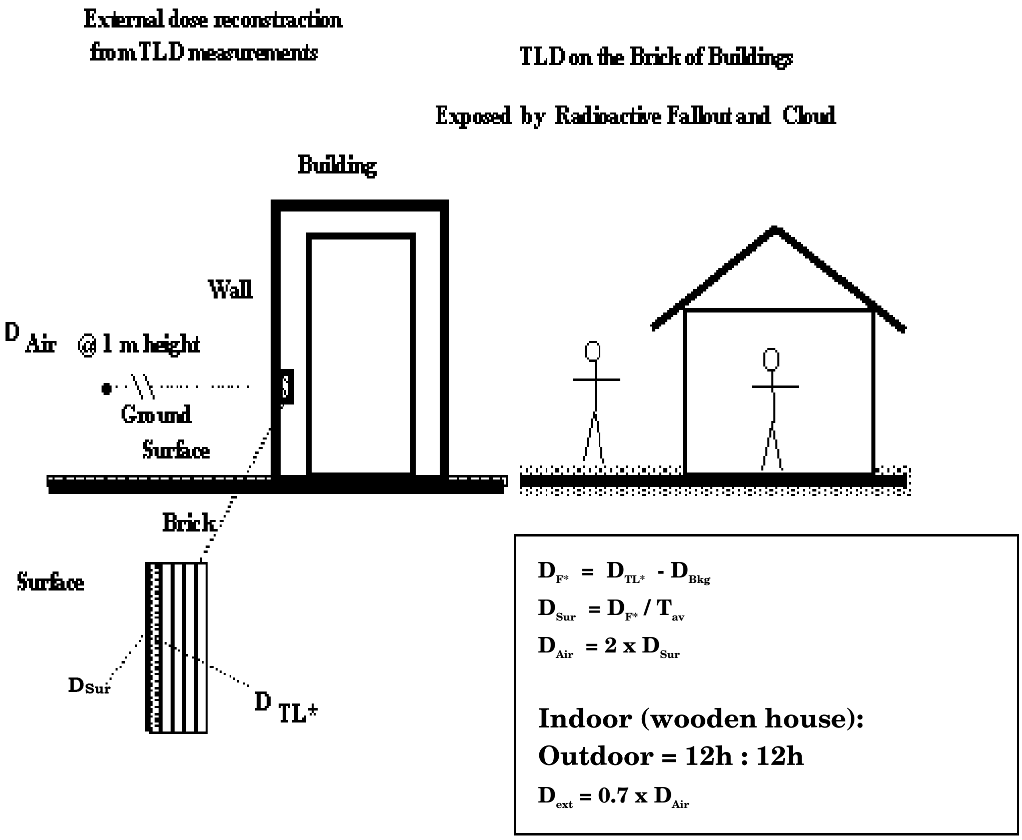

Figure 1. *Schematic illustration of dose reconstruction of residents from brick TLD measurements.*

The external dose (D_{Ext}) for people is somewhat less than D_{Air} after accounting for body shielding and time spent indoors. The radiation level indoors from the fallout is less than that outdoors. The ratio (D_{Ext}/D_{Air}), which depends on the structure of the building and the person's lifestyle, is reported to be 0.73[17] or 0.65[18] for nuclear weapon explosions and the Chernobyl accident. We notice that no special measures were taken for radiation protection of residents for most of the explosions. Therefore, D_{Ext}/D_{Air} is likely to be about 0.7. Hence, we estimated D_{Ext} by

$$D_{Ext} = 0.7\ D_{Air} \qquad (4)$$

8.4 External doses to populations

The external doses are summarized in Table 1. The present results of external doses at small settlements such Dolon and Chagan are generally consistent with previously reported values. We confirmed that the external dose of residents in Dolon due to the radioactive cloud and fallout from the SNT was at a level of 1 Gy.

The external doses at six sites in whole Semipalatinsk City were as large as 0.69 Gy. Three sites in the center of city exhibited 0.62 + 0.10 Gy. This is remarkably high compared with the previously reported value that was 0.004 Sv. Doses in other three sites were at background level.

Table 1. *Dose values in settlements.*

Settlement	n of site	Dose		
		D_{fs} (Gy)	D_{air} (Gy)	D_{ext} (Gy)
Dolon	1	0.71	1.42	0.99
Izvyestka	1	0.30	0.60	0.42
Chagan	1	0.25	0.50	0.35
Semipalatinsk City				
- Center of city	3	0.44±0.77	0.89±0.14	0.62±0.10
- Other sites	3	BG	BG	BG
Ust-Kamenogorsk City	7	0.20±0.12	0.41±0.25	0.29±0.18

BG: Background Level

Such a large discrepancy requires further investigation. The total number of reported doses after each nuclear explosion was very small compared with the total number of nuclear explosions (459). For example, there were only 21 explosions during the period from 1949 to 1965 in an iso-dose line map, as reported by Logachev[19]. Moreover, no information on doses exists in and around Semipalatinsk City on the map.

Some underground explosions near the ground surface were equal to surface explosions from a viewpoint of the radioactivity release to the environment. For example, in Sakha, where twelve underground nuclear explosions were conducted between 1974 and 1987, two of them were actually accidental surface explosions[20]. In the SNTS, an explosion of a hydrogen bomb on 15 January 1965 was classified as underground in the Russian report [2]), although the explosion, which had an output of 240 kt at a depth of 100 m, made a crater on the ground surface[11]). Such a nuclear explosion should be classified as surface explosion[21]). Moreover, a huge amount of radioactive rare gas, which came out from the ground after explosions, seems to be the source of radiation exposure.

Additionally, the amount of military data on Semipalatinsk City, that was available for dose reconstruction was extremely limited in the calculation of Stepanenko[3]). Therefore, previously calculated doses might not be totally accurate. The most important work will be the dose reconstruction based on data of direct measurement of accumulated dose, which does not require any information of radioactive sources.

The external doses at three sites in the center of the city were larger than those in other parts of city. We also note such dose distribution around Dolon. The distance between Dolon and Chagan is within 15 km. This similarity may be due to a difference in the local weather conditions or the narrow trajectory of radioactive clouds. Detailed studies of dose distribution in Semipalatinsk City may require more measuring points in the future.

The external doses at seven sites in whole Ust-Kamenogorsk City were as large as 0.51 Gy. The average value was 0.29 + 0.17 Gy. M43 isodose map shows dose in outdoors higher than 0.15 Gy as dose in air for Ust-Kamenogorsk City due to the Aug. 1956 explosion (26 kt at h=100m). On the other hand, Loborev reported value between 0.09 and 0.32 Gy as dose in air for the city due to four explosions (1956, Sep. and Oct. 1961, 1962). There were acute diseases such hair loss and nausea among the citizens in Ust-Kamenogorsk just after the 1956 fallout[22]. The present value of external dose appears consistent with the human health effect.

8.5 Conclusion

Accumulated external doses to residents near the Semipalatinsk nuclear test site were evaluated from a study of the absorbed dose to bricks using the thermoluminescence technique. The sampled locations included Dolon and other villages, Semipalatinsk City and Ust-Kamenogorsk City. The external doses to population were estimated from the brick measurements to be up to 1.0 Gy for residents in Dolon. The doses in the two cities were estimated to be several hundreds milligray. The present dose in Ust-Kamenogorsk City was consistent with the human acute health effect on the citizens just after 1956 fallout.

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Date of explosion	Settlement	Distance from ground zero	Number of the residents at the year of test			The prevalent nationality of the population	The values of the parameters used in calculations		Shielding factor for gamma-radiation	
			Total	Children 1-2 y	Children 3-12 y		Type of mater. of the homes	No of dairy cows in settlem.	From cloud	From fallout
29.8.49	Cheremushka	85	500	20	110	Russians	Wood	400	1.4	3
29.8.49	Dolon	118	837	35	180	Russians	Wood	300	1.4	3
29.8.49	Mostik	90	620	25	140	Russians	Wood	200	1.4	3
29.8.49	Kanonerka	135	2430	100	530	Russians	Wood	800	1.4	3
29.8.49	Naumovka	195	730	30	160	Russians	Wood	200	1.4	3
29.8.49	Topolnoe	200	1330	50	300	Russians	Wood	200	1.4	3
29.8.49	Lokot	250	1200	50	260	Russians	Brick	300	3	10
24.9.51	Akbulak	165	500	20	110	Kazaks	Adobe	10	4	13
24.9.51	Kaynar	150	450	18	100	Kazaks	Adobe	10	4	13
12.8.53	Sarzhal	110	633	25	140	Kazaks	Adobe	10	4	13
12.8.53	Abay (Kara-Aul)	190	2370	100	520	Kazaks	Adobe	40	4	13
24.8.56	City of Ust-Kamenogorsk	342	130000	5200	20000	Russians	Brick	-	3	10
24.8.56	Bobrovka	345	1500	60	330	Russians	Wood	300	1.4	3
24.8.56	Znamenka	130	830	35	180	Russians	Wood	100	1.4	3
22.8.57	Sovkhoz: Abay	85	680	30	150	Kazaks	Adobe	9	4	13
22.8.57	Kolkhoz: 30 years of Kaz.	90	130	5	30	Kazaks	Adobe	3	4	13
7.8.62	Topolka	75	500	20	110	Russians	Wood	200	1.4	3
7.8.62	Semiyarskoe	70	4000	160	900	Russians	Wood	400	1.4	3
7.8.62	City of Semipalatinsk	170	145000	5800	32000	Russians	Brick	-	3	10
7.8.62	Novopokrovka	180	900	35	200	Russians	Wood	400	1.4	3
15.1.65	Znamenka	44	830	35	180	Russians	Wood	100	1.4	3
15.6.65	Sarapan	14	150	6	130	Russians	Adobe	10	4	13

Settlement	Estimated time of arrival, h	End-of-fallout time, h	Measured exposure rate, (Pγ), R h $^{-1}$	Time of measurement (Pγ), h	Exposure rate at H+24h	The value of parameter "n" in a "decay law" t^{-n} in order to decay exposure rate to a common line	Exposure rate at fallout arrival time, R h $^{-1}$
Cheremushka	1.8	3.5	0.12*	173	1.3	1.2	10.6
Dolon	2.5	4.5	0.098	173	1.1	1.2	7.5
Mostik	1.9	3.5	0.01	173	0.085	1.2	1.1
Kanonerka	2.9	5.1	0.24*	24	0.24	1.2	1.5
Naumovka	4.1	7.3	0.42*	24	0.42	1.2	1.8
Topolnoe	4.2	6.4	0.398	24	0.39	1.2	1.6
Lokot	5.3	9.4	0.016	220	0.26	1.2	0.8
Akbulak	6	11.0	0.9;(1.6)***	20; (42)	0.7	1.2	2.0
Kaynar	10	18.0	0.27	10	0.1	1.2	0.14
Sarzhal	-	2.9	0.026**	360	0.95****	1.3	0.026
Akbay (Kara-Aul)	-	4.9	0.03**	218	0.56****	1.3	0.03
Znamenka	2.2	3.3	0.0003	720	0.018	1.2	0.2
City of Ust-Kamenogorsk	5.7	8.6	0.0012	720	0.071	1.2	2.4
Bobrovka	5.7	8.6	0.0003	720	0.018	1.2	0.06
Sovkhoz: Abay	8.5	3.1	0.012	26	0.013	1.2	0.08
Kolkhoz: 30 years of Kaz.	9.0	3.3	0.05	8	0.014	1.2	0.076
Topolka	10.7	18	0.004	31.5	0.0044	1.2	0.008
Semiyarskoe	32.0	33	0.001	33	0.0014****	1.2	0.001
City of Semip.	36.0	38	0.00017	50	0.0003****	1.2	0.00025
Novopokrovka	38.0	40	0.000125	230	0.0018****	1.2	0.0011
Znamenka	4.1	3.0	0.003	24	0.003	1.6	0.36
Sarapan	-	2.5	0.03**	48	0.07	1.6	0.03

* - estimated data;
** - the data for the end-of-fallout time or for the day of returning of the residents to the settlement;
*** - the results of measurement in the settlement and at the sampling place (in parentheses);
**** - there was no exposure to the residents because the residents had been evacuated prior to the time of exposure or there was no fallout at H+24h.