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An Overview on GSF Activities at the Semipalatinsk Test Site, Kazakhstan

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Atomic explosion/^{137}Cs/^{90}Sr/food contamination/internal dose assessment/Semipalatinsk Test Site/whole-body counting.

The Semipalatinsk Test Site (STS) in Kazakhstan was one of the major sites used by the former USSR for testing nuclear weapons for more than 40 years. Since the early 1990s, agricultural activities have been re-established there by neighbouring collective and private farms. Therefore, it has become important to evaluate the radiological situation and the current and future risk to people living on and using the contaminated area. During the last eight years, GSF has participated in many international projects performed on the STS to evaluate the radiological situation. A large number of soil, vegetation and food samples has been collected and analysed. Internal dose is one of the main components of the total dose when deriving risk factors for a population living within the test site. Internal doses, based on food monitoring and whole body measurements, were calculated for adults and were in the range of 13–500 μSv/y due to radiocaesium and radiostrontium.

INTRODUCTION

Between 1949 and 1989, 456 atomic tests were performed on the Semipalatinsk test site (STS), Kazakhstan.[1)] There were three major testing areas (Fig. 1) within the STS: Ground Zero, where 26 above-ground and 87 atmospheric bomb tests have been performed, the Degelen mountains, where more than 200 underground nuclear explosions occurred, and the Balapan area (Chagan) where 123 underground explosions took place and one excavation explosion creating the "Atomic Lake".[1–3)]

The STS, covering about 18,000 km^2, is located in north-eastern Kazakhstan (77° to 79° E and 49°–51° N). The area is dominated by chestnut and light chestnut soil with localised areas of solonetz (alkali soils) and solonchaks (saline soils). The vegetation of the test site consists of sparsely growing stunted grass, dominated by drought-resistant xerophytic species with a considerable quantity of short-lived spring ephemerals. Agricultural activities on the STS and the surrounding lands are extensive; major landuse is pasture grassland. On the STS, there are several winter and summer huts housing 3 or 4 families. Their main occupation is breeding and maintaining livestock (sheep, horses and private cattle).

Since agricultural activities have been re-established, it has become important to evaluate the current and future risk to those people living on and using the contaminated areas. The major factors which need to be considered are: 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 at present such as ^{60}Co, ^{137}Cs, $^{152/154}$Eu and ^{241}Am.[4,5)] The evaluation of USSR data[5)] 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 localized hot spots surrounding Lake Balapan and Ground Zero of up to 1,850 kBq/m^2, and 15 to 75 kBq/m^2 in the Degelen mountains.[2,3,6)]

Results of gamma spectroscopy and radiochemical analyses of a number of soil and vegetation samples taken on the STS have been published by numerous authors.[4,7–13)] Results of Dubasov *et al*[14)] showed that exposures from inhalation due to the resuspension of radioactive materials are a minor contributor to the internal doses. Therefore, this paper assumes the major exposure pathway to the population living on the STS is via food intake, and inhalation has been ignored. The mean annual external doses to man, 0.6 mSv/y,[15)] have been calculated based on mean area dose equivalent rates monitored in pastures, hay stocks and settlements; internal dose was expected to be much lower.[15)]

The radiological situation on the STS was assessed using

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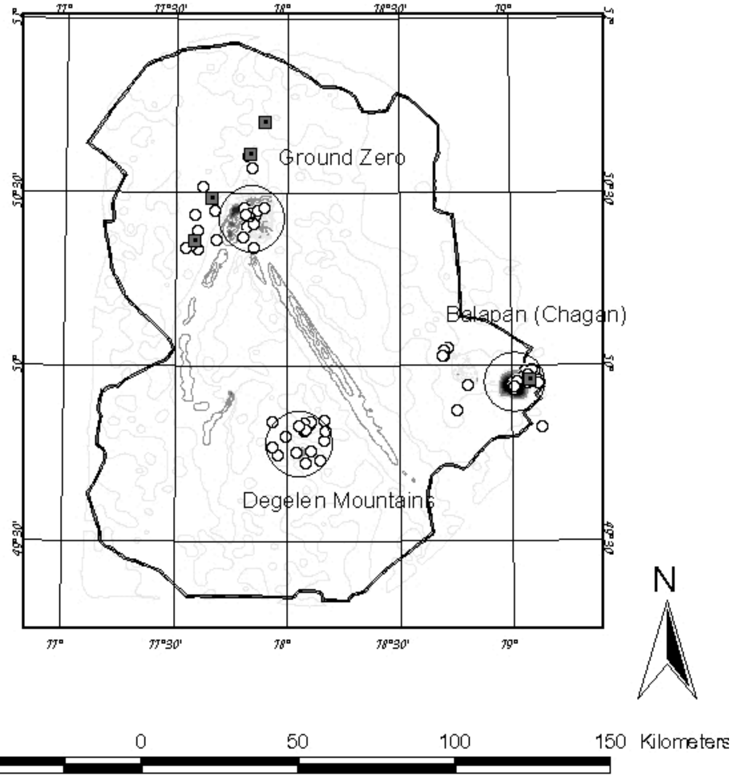


Fig. 1. STS indicating major tests areas (big circles), investigated winter huts (squares) and soil and plant sampling sites (small circles). Winter huts: 1 – Akzhar collective farm; 2 – Chagan collective farm. Isolines show the results of air-gamma monitoring.[3)]

measurements of radionuclides, activity concentrations in soil and vegetation. The transfer of radionuclides to animal products has been investigated in controlled experiment and in field conditions. Especially attention has been given to horses: the products of horse breeding (milk and meat) play a very important role in the diet of the Kazakh population. Food consumed by the local population was monitored, and a dietary survey and whole body counting were undertaken. Internal doses were calculated from the food monitoring and dietary survey data. Whole body counting was conducted for comparison with the calculated dose.[16)]

MATERIALS AND METHODS

Location

Three sites on the STS were selected for the investigations. Three winter huts of the collective farm of Akzhar* situated close to Ground Zero: Kyzyl Kuduk (50°22'N, 77°35'E), Taktajkol (50°29'N, 77°39'E) and Tulpar (50°37'N, 77°50'E); the collective farm Zavety Iljicha with one winter hut Chagan (49°58'N, 79°05'E), close to Lake Balapan; and an area of the Degelen Mountains (Fig. 1).

Soil and pasture grass samples preparation and measurements

On the pasture areas grazed by the study farms and at the three more highly contaminated sites, Ground Zero, Degelen and Lake Balapan, about 200 soil and vegetation samples have been collected and analyzed for ^{137}Cs and ^{90}Sr, and some of them for $^{238,239,240}Pu$ and ^{241}Am. A standard envelope technique for soil sampling was used in which the sampling pattern is to take 5 sampling points in a 3×3 m^2, comprising 4 points in the corners and one in the center dividing the soil into three layers 1–5, 5–10 and 10–20 cm and bulking soil samples per layer. Vegetation samples were taken over several m^2 above and adjacent to the soil sample area because of the low biomass of plants. All sampling locations were geo-referenced using a global positioning system satellite navigator (Magellan GPS nav 5000dxtm). The samples were air-dried, sieved and homogenized.

Various digitized maps of the Test Site have been prepared, including a sampling map, a soil type map, a radionuclides deposition map etc.

Horses

The population on the STS keeps and breeds animals that are very well adapted to the climatic conditions of the test site. The most widespread are: Dzhabe and Adaev horse races. Kazakhstan horses are kept on pastures all year round; they can also graze through 40 cm of snow cover. Kazakh horses of the Dzhabe type have a high live weight, 400–500 kg. The milk and meat performance of Dzhabe horses is very high: some mares yield up to 20 kg of milk at hand-milking and they fatten quickly. Dzhabe horses are noted for their good meat characteristics: the meat yield at slaughter is 57–60%.

Laboratory experiment

To estimate the transfer of radionuclides to different organs of domestic animals (hens, rabbits, sheep and horses) laboratory experiments were carried out at the Kazakh Agricultural Research Institute (Dr. A. Savinkov). Great importance was attached to the experiment performed with three lactating horses to determine the transfer of ^{137}Cs and ^{90}Sr to meat, milk and inner organs. The duration of the experiment was 90 days. ^{137}Cs and ^{90}Sr activities of 10 kBq respectively, dissolved in water, were applied daily. Two horses received the activity over a period of 30 days, one horse for a period of 90 days. At the end of the 30 day period, the activity measurements in milk continued for a further 2 months in order to observe the decrease and to determine the biological half-lives. The horse, to which the activity was applied over 90 days, was slaughtered and the samples of meat, skin and other organs were collected. All samples were dried and ashed and analysed for ^{137}Cs and ^{90}Sr. The data were used to determine the equilibrium transfer factor and the biological half-life.

Field measurements

Samples of food, such as cow milk, horse milk, milk and meat products, and water used and sold by the local population, were taken directly from the winter-huts area. Samples of meat, bones, skin and inner organs of three horses from the winter-hut of Akzhar farm were taken. Samples were prepared (weighed, dried and ashed). ^{137}Cs gamma spectroscopy and ^{90}Sr analysis were performed at the GSF research center and at the National Nuclear Centre of the Republic of Kazakhstan.

Food sample preparation and measurements

Thirty samples of the main food products of local origin (cow milk, horse milk, meat, milk products etc.), consumed by local inhabitants, were collected at the selected sites during two summer expeditions. The samples were homogenized, weighed, ashed and analysed for ^{137}Cs (Canberra gamma spectrometry system using Ge detectors with an efficiency of 30–50% in a 3 g tube geometry for 590,000 sec). Radiochemical procedures for ^{90}Sr and ^{239,240}Pu were conducted according to standard techniques in the laboratory.[17)]

Dietary survey questionnaire

During the expedition in 1999, a dietary survey was performed at the selected sites. (111 adults were questioned in the age range 30–65 years). The questionnaire was developed in the Institute of Radiation Hygiene, St. Petersburg, Russia, and was previously used in the Chernobyl affected area.[18)] This questionnaire was modified for Kazakh climatic, traditional and cultural conditions. The major components of the questionnaire were: personal data (name, date of birth, body mass etc), a survey of the dietary patterns, including the quantity of the consumed products, and also their source (private production, market or state shops) and results of measurements of ^{137}Cs content in the body.

Internal dose calculation

The average internal effective daily whole body dose, D(T), (Sv/d) due to ^{137}Cs and ^{90}Sr was calculated from measured activity concentrations in food and average intake rates representative for the inhabitants of the STS.

Whole body counting and internal dose calculation

The measurements of body burden were performed with a portable single channel spectrometer SKIF-3 with a 63x63 mm NaI(Tl) crystal, developed and constructed in the Institute of Radiation Hygiene, St. Petersburg, Russia. The minimum detectable activity depends on the background of the whole body counter and the detection efficiency for a given phantom. In our case the minimum detectable activity was about 700 Bq of ^{137}Cs content in the body.[16)]

RESULTS AND DISCUSSION

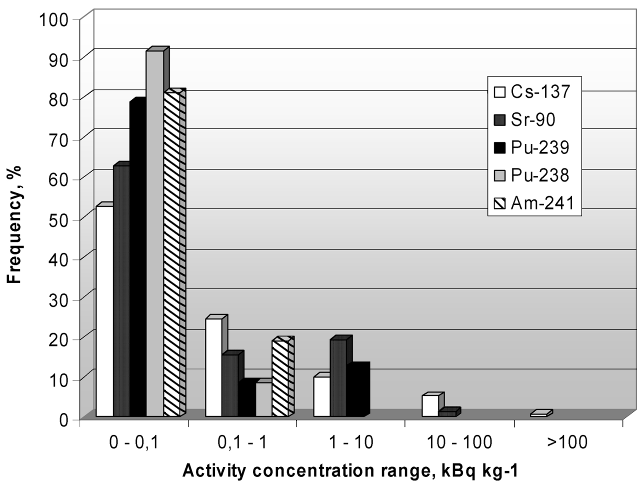
^{137}Cs and ^{90}Sr contents in soil and vegetation

A summary of measured activity concentrations of different radionuclides for 0–20 cm soil and vegetation samples from all sampled areas is given in Bq/kg-dw (dry weight) in Fig. 2 a and b respectively. The measured highest values occurred at Ground Zero followed by the other two technical areas (10–711000 Bq/kg of ^{137}Cs, 10–6000 Bq/kg of ^{90}Sr). The pasture areas were both less heavily contaminated than the technical areas (3–400 Bq/kg of ^{137}Cs, 10–120 Bq/kg of ^{90}Sr). There was a highly heterogeneous pattern, with considerable variation in the radionuclide measurements at each site.[19)]

Vegetation samples were taken at the same sampling sites as the soil samples, and also showed a large variation in contamination values. The range of activity concentrations of ^{90}Sr in vegetation samples taken from Ground Zero was 450–3700 Bq/kg-dw; from Degelen 9–9390 Bq/kg-dw; and from the farm pastures, 0–2083 Bq/kg-dw (Chagan) and 9–412 Bq/kg-dw (Akzhar).

Radionuclide transfer to horse milk

The maximum activity concentration of ^{137}Cs in horse milk was found to be 100 Bq/L.[24)] On the basis of a daily activity intake of 10 kBq/d, an equilibrium transfer coeffi-



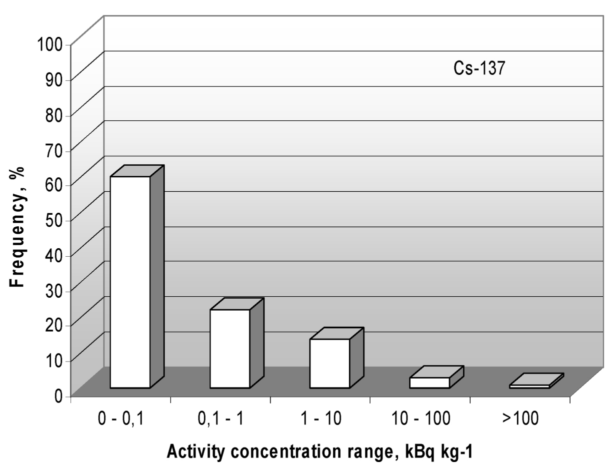


Fig. 2. Frequency distribution of radionuclide activity concentration in soil (a) and vegetation (b) samples from different areas on the STS.

cient to milk of 0.012 d /kg was estimated. The biological half-life was approximated by a sum of two exponential functions. The best fit was achieved for half-lives of 3 and 40 days with fractions of 0.7 and 0.3, respectively.

The transfer of ^{90}Sr in horse milk was lower than that of ^{137}Cs. The activity concentration of ^{90}Sr reached a maximal value of 20 Bq/L after approximately 20 days. The estimated equilibrium transfer coefficient was found to be 0.0022 with a biological half-life of 3.5 days. In our case the slow component (100 days) couldn't be fully observed in this short time (90 days). Analysis of organ samples of the third horse showed maximum values of ^{137}Cs and ^{90}Sr activity concentration in the spleen (10.9 Bq/kg) and in bones (39.9 Bq/kg) respectively. The activity concentrations of both radionuclides for other organs were lower.

Dose assessment

Most of the population living on the STS is of Kazakh nationality with a rather uniform consumption of a nutrient-poor diet. It consists mainly of meat, bread, noodles, and milk products, whereas vegetables and fruits are consumed in small quantities and only during the summer months. Usually in November one or two horses (depending on family size) are slaughtered (approximately 180 kg edible meat per animal), which supplies the family with meat up to May of the following year. In May, sheep are slaughtered. This continues according to need during the summer and autumn period. Kazakh people do not drink fresh milk (adults), but prefer to eat and drink milk products such as water diluted thick soured milk (ayran), fermented horse milk (kumys), and fresh processed cheese (kurt).

Measurements of ^{137}Cs and ^{90}Sr activity concentrations in food produced at the two farms Akzhar and Zavety Iljicha on the STS were carried out.[16)]

Based on these data (food monitoring + consumption habits) a preliminary dose assessment was carried out as described in Semioshkina *et.al.*[16)] The maximum annual internal effective doses for adults were estimated to range from 13 to 50 µSv/y for ^{137}Cs and from 30 to 500 µSv/y for ^{90}Sr. The results and derived doses of the whole body measurements are given in Table 1 and confirm the calculated ingestion doses for ^{137}Cs. Despite rather limited data and a low number of ^{90}Sr measurements for the important food products, the estimated internal doses due to ^{90}Sr are higher than those due to ^{137}Cs. The probable reason is much lower transfer of ^{137}Cs from soil to plant due to very high exchangeable potassium content in soil.[21)]

CONCLUSIONS

The dose from ingestion (internal exposure) due to ^{137}Cs and ^{90}Sr and from external exposure for the population living on the STS is low. But the relatively high dose contribution due to ^{90}Sr needs to be investigated in more detail. Therefore, countermeasures to protect the population from enhanced radiation exposure at the STS are currently not necessary, provided the inhabitants are warned about some very localized hot spots that should be fenced to restrict entry by humans or grazing animals.

When evaluating the general radiological situation of the STS, exposures to other radionuclides need to be addressed. Available data for alpha emitters such as $^{238/239/240}$Pu and ^{238}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, for example, at Ground Zero or close to Lake Balapan.[10,20,21)] Even though external exposures in this case can be neglected, ingestion of contaminated foodstuffs and inhalation of resuspended material may lead to high internal doses. This needs to be addressed and investigated in more detail in the future.

Finally it should be noted that available information about heterogeneity of fallout following nuclear test in

Table 1. Measured whole body burdens and estimated doses of selected population groups (WBC – Whole Body Counting)

Site	Number of measured people	Number of people with WBC value above detection limit	WBC (maximum value), Bq	Max dose from ^{137}Cs estimation based on WBC, µSv/y	Max dose estimation based on consumption, µSv/ y	
					^{137}Cs	^{90}Sr
Akzhar	Male (26)	1	1200	60	50	310
	Female (33)	1	1100	56	40	30
Chagan	Male (19)	6	1400	42	13	100
			1200	58	50	350
			1100	47	32	70
			900	33	37	500
			810	40	48	270
			810	21	14	130
	Female (25)	1	800	26	13	125

STS[6,7,8,10,2022,23)] should be taken into account for interpretation of published and current dose estimates.

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