Radiation Exposure on Residents due to Semipalatinsk Nuclear Tests

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Accumulated external doses of residents near the Semipalatinsk nuclear test site are presented as a results of study by the thermoluminescence technique for bricks sampled at several settlements in 1995 and 1996. A way of external dose reconstruction of residents from the brick dose are discussed. The external doses that we evaluated from exposed bricks were up to about 100 cGy for residents in Dolon Village. The external doses at several points in the center of Semipalatinsk City ranged from a background level to 60 cGy, which was remarkably high compared with the previously reported values based on military data.

INTRODUCTION

Dose values of radiation exposure on residents far from hypocenter of nuclear explosion due to the radioactive fallout are not clear comparing with direct exposures of gamma ray and neutrons from the epicenter of explosion such as those in Hiroshima and Nagasaki A-bombs. This paper present a way of external dose reconstruction and data in case of residents around nuclear weapon test site of the former Union of Soviet Socialist Republics (USSR)[1)].

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 Defense Department of the former USSR[3, 4)] did not involve direct experimental data concerning the effective equivalent dose. They just measured some doses for particular settlements after some nuclear explosions. These did not indicate an integrated dose of the residents of all the explosions.

The technique of thermoluminescence dosimetry (TLD), which had been successfully applied in dosimetry for the Hiroshima and Nagasaki atomic bombs[5, 6)], enabled us to evaluate the accumulated external gamma ray doses of all the nuclear explosions at specific places in 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 dating[8)]. Moreover this technique was applicable for dosimetry studies of radioactive fallout as shown in studies of the Chernobyl accident [9, 10)].

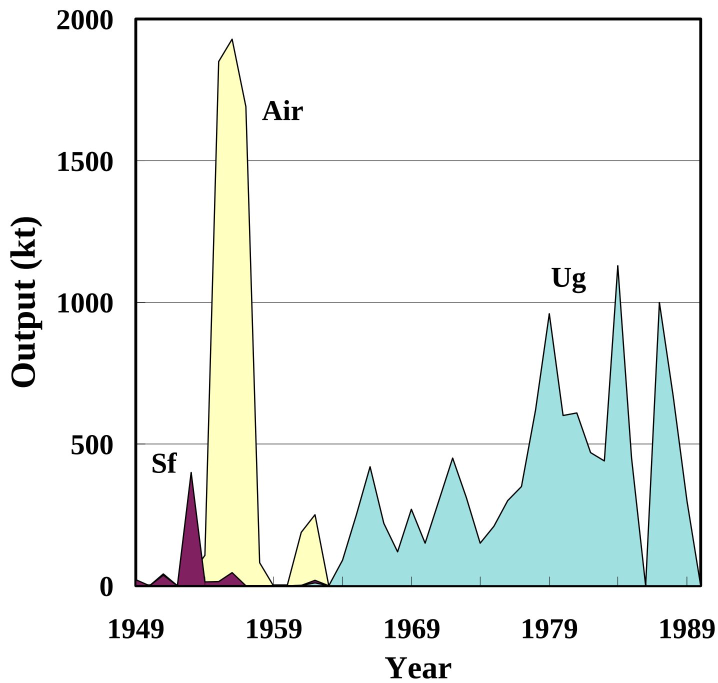

Fig.1. Chronological graph of Semipalatinsk nuclear tests for air (Air), surface (Sf) and underground (Ug) explosions respectively.

Photo 1. Field mission 1995. Atomic Lake, hydrogen bomb 240 kt 15 Jan. 1965 (upper). Dolon

Village (Lower left). Chagan station (Lower right).

SAMPLING AND MEASUREMENTS

In 1995 and 1996 we sampled bricks from the surfaces of the walls of buildings mainly in two settlements that we focused on near the SNTS[11)]. One was in Semipalatinsk City which is the largest settlement near the test site, and is 100km far from the boundary of the SNTS. The population was 116 – 191 thousand between 1949 and 1963. The total dose for the population reported by the former USSR, which is 0.56 cSv, is quite obscure compared with that of the other settlements with smaller populations[3)]. The other is Dolon Village, and it was part of a fallout area of the first atomic explosion on August 29th 1949. The explosion test was undertaken 30m above the ground during rain[12)]. Therefore, although the output, which was estimated to be equivalent to 20 kt of TNT, was not so large, the amount of local radioactive fallout was thought to be large. Total doses of 160 and 447 cSv were reported for Dolon Village [3, 4)]. Each coordinate of the sampling sites was measured by 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)]. The surface of brick samples was removed with a thickness ranging from 5 to 10 mm. The next 20mm of the brick was used for sample preparation. 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)

We measured the in situ gamma ray dose rate at the surface of the sampling point by using a pocket survey meter (Aloka PDR-101), in which a CsI(Tl) (20 x 25 x 15 mm) detector is installed. We used these data for estimation of natural gamma ray exposure for bricks in TLD analysis. The beta ray internal dose rate for quartz grain in the brick was measured for each brick sample in the laboratory. We applied measurement of sandwiching CaSO4:Dy TL powder between two disks of brick samples, which were stored in a 10cm thick Pb shielding box with N_2 gas [6)], and beta counting on the surface of a brick sample (ZnS(Ag) plastic scintillator (Aloka TCS-35, active area, 72 cm^2). The former is for the absolute value and the latter is for the 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 negligible by etching the surface of quartz. The age of the brick was assumed to be the same as the age of the building.

TLD ON BRICK SAMPLES

The results of TLD for bricks are summarized in Table 2. The number of samples from a building at each location is one in the present report. The bricks were obtained from the outer surface of the buildings. The number of brick buildings was very limited, especially in the village (usually one).

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

The D_{SF} 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.

$$D_{SF} = D_F^* / T_{av} \quad (1)$$

Actually we applied the transmission coefficient (T_{av}: 0.8~0.7) of bricks for gamma ray of Cs-137 to the estimation that had been measured for each sample.

Table 1. Data of γ rays from main fallout activities for residents

Nuclied	Half Life	Dose contribution (%) t=3h-7d	γ energy (keV)	γ yield/decay	e*y (keV)
Sr-91	9.5h		750	0.231	173
			1024	0.335	343
		3.63	912	0.566	516
Sr-92	2.7h	3.26	1384	0.9	1246
Zr-97	16.9h	8.08	734	0.931	683
Nb-97	72.1m	6.51	658	0.983	647
Ru-105	4.44h		317	0.117	37
			469	0.175	82
			676	0.167	113
			725	0.49	355
		4.72	619	0.949	587
I-132	2.3h		523	0.161	84
			630	0.137	86
			668	0.987	659
			773	0.762	589
		17.42	693	2.047	1419
I-133	20.8h	6.85	530	0.863	457
I-134	52.6m		595	0.114	68
Xe-134			622	0.106	66
			847	0.954	808
			884	0.653	577
			1073	0.153	164
		6.13	850	1.98	1683
I-135	6.6h		1132	0.225	255
			1260	0.286	360
		11.39	1204	0.511	615
La-140	40.3h		329	0.207	68
			487	0.459	224
			816	0.236	193
			1596	0.954	1523
		4.77	1081	1.856	2007
La-142	1.55h		641	0.525	337
			2398	0.164	393
			2543	0.112	285
		3.64	1267	0.801	1015

Fission products of Sr-91, Sr-92, Zr-97, Ru-105, I-132, I-133, I-134, I-135, La-140 and La-142 as gamma emitters are the main sources of the radioactivity of the external dose on residents more than several tens of km from the test site, from the half-life point of view. Data on each nuclide are listed in Table 2 [15, 16]. Weighted mean values of γ energy for each nuclide are calculated from γ rays with intensity more than 10% per decay. 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.

D_F* can be expressed by the following equation:

$$D_F^* = D_{TL}^* - D_{BG} \qquad (2)$$

where D_{TL}* and D_{BG} are the raw value of dose in the brick and natural background dose, respectively. Maximum correction of the measured D_{TL}* values for supralinearity was –7%.

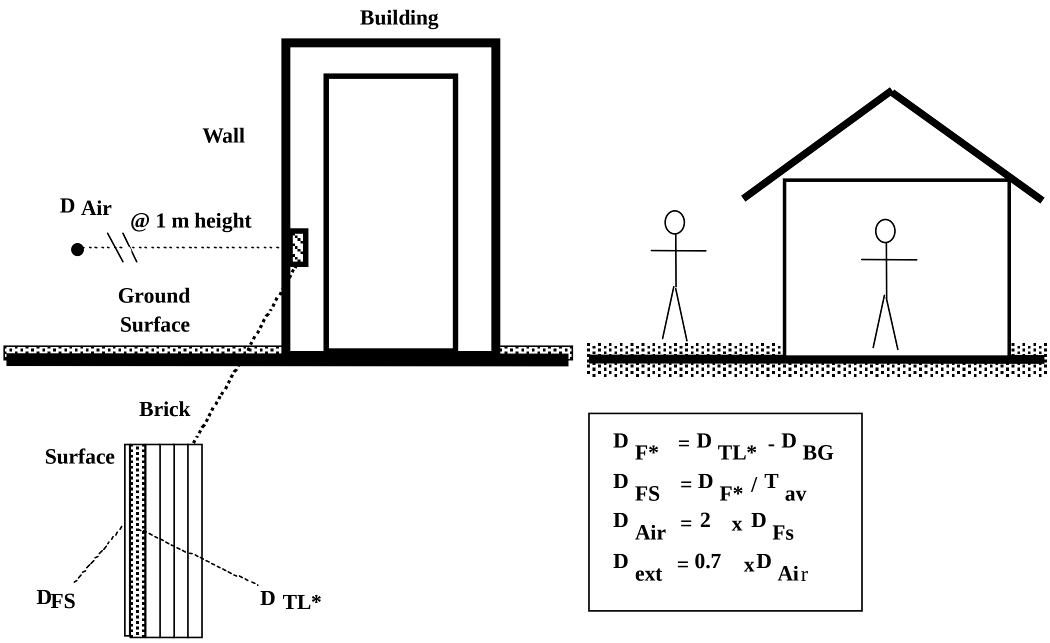

Fig. 2. Schematic illustration of dose reconstruction of residents from brick TLD measurements.

EXTERNAL DOSES OF RESIDENTS

The external dose (D_{Ext}) for people is somewhat less than D_{AirF} since people are not always outside. The radiation level indoors is less than that outdoors. The ratio (D_{Ext} /D_{AirF}), 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 not taken for radiation protection of residents for most of the explosions. Therefore, D_{Ext} /D_{AirF} is likely to be about 0.7. Therefore, we estimated D_{Ext} by

$$D_{Ext} = 0.7\ D_{AirF} \qquad (3)$$

The external doses are summarized with previously reported values in Table 2. The present results of external doses at small settlements such Dolon and Chagan are well 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 100cGy.

On the other hand the external doses at several points in Semipalatinsk City were remarkably high (~ 60cGy as D_{Ext}) compared with the previously reported value, which was 0.4 cGy. Such a large discrepancy may require 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 explosion from a viewpoint of the radioactivity release to the environment. 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 240kt at a depth of 100m, 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.

Table 2. **Doses near Semipalatinsk nuclear test site**

	GPS Coordinates		Brick Dose (cGy)				External Dose Reported (cSv)		External Dose Present (cGy)	
Settlement	N	E	D_{TL*}	D_{BG}	D_{F*}	D_{SF}	TS	G	D_{AirF}	D_{Ext}
Dolon	50 39.37	79 19.06	79 ± 9	27 ± 6	52 ± 10	71 ± 14	107	217	142	99
Izvyestka	50 37.41	78 51.45	36 ± 7	12 ± 2	24 ± 7	30 ± 9	–	–	60	42
Chagan	50 36.08	79 12.48	33 ± 6	12 ± 2	21 ± 6	25 ± 7	–	54	50	35
Semipalatinsk							0.4	–		
S1	50 24.30	80 15.35	53 ± 9	24 ± 5	29 ± 10	36 ± 12			72	50
S2	50 24.08	80 14.39	43 ± 7	9 ± 2	34 ± 7	48 ± 8			96	67
S3	50 23.53	80 15.14	50 ± 8	15 ± 3	35 ± 9	49 ± 13			98	69
S4	50 23.11	80 14.33	19 ± 3	15 ± 5	4 ± 6	6 ± 8			12	8
S5	50 23.50	80 12.07	8 ± 1	13 ± 5	< BG	< BG			<BG	–
S6	50 27.34	80 12.26	9 ± 1	20 ± 6	< BG	< BG			<BG	–

$D_{F*}=D_{TL*} - D_{BG}$: Dose in the brick due to the radioactive cloud and fallout

D_{TL*} : Dose in the brick

D_{BG} : Natural background dose in the brick

$D_{SF} = D_{F*} / T_{av}$: Dose at the surface of the wall

T_{av} is transmission coefficient evaluated by gamma ray of Cs-137

TS: Tsyb (1989) G: Gusev (1992)

D_{AirF} = 2 x D_{SF} : External dose of free space in air

D_{Ext} = 0.7 x D_{AirF}: External dose for resident

Additionally, the amount of military data on Semipalatinsk City, that were available for dose reconstruction, was extremely limited in the calculation of Stepanenko [3]. Therefore, there must be great uncertainty in the previously calculated doses. 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 points in the center of the city were between 50 and 69 cGy. These are larger than those in other parts of city. We also note such a dose distribution around Dolon. The distance between Dolon and Chagan is within 15 km. Such local difference on dose 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.

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