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External Doses of Residents near Semipalatinsk Nuclear Test Site

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Accumulated external radiation doses of residents near the Semipalatinsk nuclear test site of the former USSR are presented as a results of study by the thermoluminescence technique for bricks sampled at several settlements in 1995 and 1996. The external doses that we evaluated from exposed bricks were up to about 100 cGy for resident. 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

A total of 459 nuclear tests were conducted by the former Union of Soviet Socialist Republics (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[1)].

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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 USSR2,3) 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 bombs4,5), 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)6) but also in prolonged exposure to natural radiation, which is used in dating7). Moreover, this technique was applicable for dosimetry studies of radioactive fallout as shown in studies of the Chernobyl accident8,9).

MATERIALS AND METHODS

We sampled bricks from the surfaces of the walls of buildings mainly in two settlements that we focused on near the SNTS10). One was in Semipalatinsk City, which is the largest settlement near the test site, and is 100 km 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 populations2). 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 30 m above the ground during rain11). 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 Village2,3). 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 described5,12). The quartz inclusion method was applied to sample preparations12). The surface of brick samples was removed with a thickness ranging from 5 to 10 mm. The next 20 mm 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 ∞ 25 ∞ 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 grains 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 10 cm thick Pb shielding box with N_2 gas5), and beta counting on the surface of a brick sample by a 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.

RESULTS

The results of TLD for bricks are summarized in Table 1. 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).

Table 1. TL brick doses near the Semipalatinsk nuclear test site

	GPS Coordinates		Brick Dose^a (cGy)			
Settlement	N	E	D_{TL^*}	D_{BG}	D_{F^*}	D_{FS}
DOLON	50°39.37´	79°19.06´	79 ± 9	27 ± 6	52 ± 10	71 ± 14
Izvyestka	50°37.41´	78°51.45´	36 ± 7	12 ± 2	24 ± 7	30 ± 9
Chagan	50°36.08´	79°12.48´	33 ± 6	12 ± 2	21 ± 6	25 ± 7
Semipalatinsk						
S1	50°24.30´	80°15.35´	53 ± 9	24 ± 5	29 ± 10	36 ± 12
S2	50°24.08´	80°14.39´	43 ± 7	9 ± 2	34 ± 7	48 ± 8
S3	50°23.53´	80°15.14´	50 ± 8	15 ± 3	35 ± 9	49 ± 13
S4	50°23.11´	80°14.33´	19 ± 3	15 ± 5	4 ± 6	6 ± 8
S5	50°23.50´	80°12.07´	8 ± 1	13 ± 5	< BG	< BG
S6	50°27.34´	80°12.26´	9 ± 1	20 ± 6	< BG	< BG

$^a D_{TL^*}$: actual readings by a TLD device for brick samples,

D_{BG}: natural background dose accumlated in the brick (see text for detail),

D_{F^*}: dose due to redioactive cloud and fallout which is given by Eq. 2; DF* = DTL*−DBG,

D_{FS}: dose at the surface of building wall given by Eq. 1; DSF = DF*/Tav, where T_{av} is a transmission coefficient, i.e., 0.7 (see text for detail).

The method of external dose estimation from TLD doses for brick is summarized here (Table 2). The external dose of free space in air (D_{AirF}) 1 m above the ground surface 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$^{13)}$. 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.

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

Table 2. Evaluation of external dose of residents near the Semipalatinsk nuclesr test site

	External Dose Reported values[a] (cSv)		Present data[b] (cGy)	
Settlement	TS	GU	D_{AirF}	D_{Ext}
Dolon	107	217	142	99
Tchagan	—	54	50	35
Izvyestka	—	—	60	42
Semipalatinsk city	0.4	—		
S1			84	59
S2			94	66
S3			98	69
S4			10	7
S5			< BG	—
S6			< BG	—

[a] TS: dose reported by Tsyb et al (1989)[2)], GU: those reported by Gusev (1993)[3)].

[b] D_{AirF}: external dose of free sapace in air which is given by an equation; $D_{AirF} = 2 \times D_{FS}$,

D_{Ext}: external dose of residents given by; $D_{Ext} = 0.7 \times D_{AirF}$

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.

Fission products of Sr-91 (9.5 h: half-life), Sr-92 (2.7 h), Zr-97 (16.9 h), Ru-105 (4.4 h), I-132 (2.3 h), I-133 (20.8 h), I-134 (52.6 m), I-135 (6.6 h), La-140 (40.3 h) and La-142 (1.6 h) as gamma emitters are the main sources of radioactivity of the external dose on residents more than several tens of km from the test site, from the half-life point of view. The effective energy of gamma rays from them is estimated to be 810 keV by weighted average of each gamma ray energy by its dose (3 h~7 d) and gamma ray intensity per decay. The difference of transmission coefficient between the 810 keV gamma ray and 662 keV Cs-137 gamma ray, which is estimated to be 10%, is acceptable in the present dosimetry study.

This 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 [13)]. Then, $D_F{}^*$ 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 about 7%.

DISCUSSION

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[14)] or 0.65[15)] 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_{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 100 cGy.

On the other hand, the external doses at several points in Semipalatinsk City were remarkably high (~ 60 cGy 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[16)]. 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. In Sakha, where twelve underground nuclear explosions were conducted between 1974 and 1987, two of them were actually accidental surface explosions[17)]. In the SNTS, an explosion of a hydrogen bomb on 15 January 1965 was classified as underground in the Russian report[1)], although the explosion, which had an output of 240 kt at a depth of 100 m, made a crater on the ground surface[10)]. Such a nuclear explosion should be classified as surface explosion[18)]. 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 were available for dose reconstruction was extremely limited in the calculation of Stepanenko[2)]. 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, as shown in Fig. 1. We also note such a 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

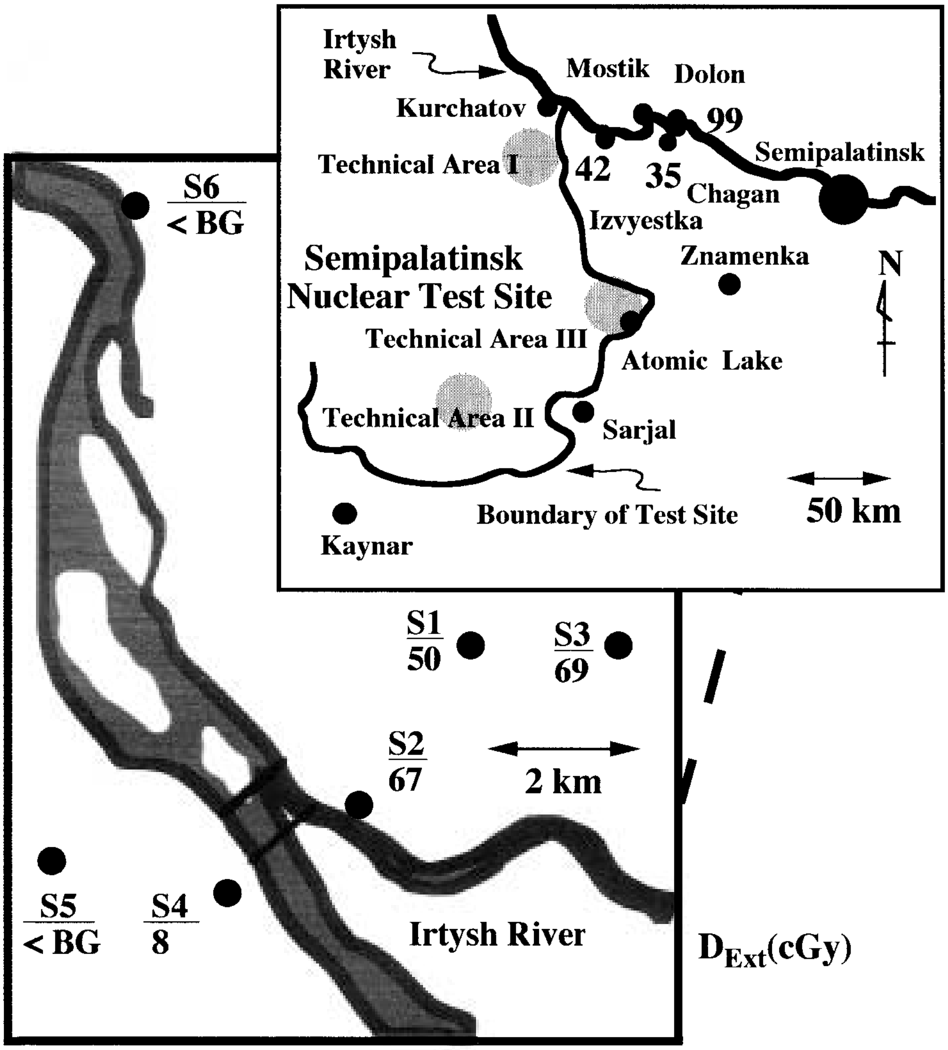

Fig. 1. Dose map of external exposure D_{Ext} for residents around the Semipalatinsk nuclear test site. Each numeral on the map indicates the external dose, D_{Ext}, in cGy.

more measuring points in the future.

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