

External Radiation in Dolon Village Due to Local Fallout from the First USSR Atomic Bomb Test in 1949

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Semipalatinsk/Atomic bomb test/Fallout contamination/External radiation/Dolon.

Dolon village, located about 60 km from the border of the Semipalatinsk Nuclear Test Site, is known to be heavily contaminated by local fallout from the first USSR atomic bomb test in 1949. External radiation in Dolon was evaluated based on recent ¹³⁷Cs data in soil and calculation of temporal change in the fission product composition. After fitting a log-normal distribution to the soil data, a ¹³⁷Cs deposition of 32 kBq m⁻², which corresponds to the 90th-percentile of the distribution, was tentatively chosen as a value to evaluate the radiation situation in 1949. Our calculation indicated that more than 95% of the cumulative dose for 50 y had been delivered within 1 y after the deposition. The resulting cumulative dose for 1 y after the deposition, normalized to the initial contamination containing 1 kBq m⁻² of ¹³⁷Cs, was 15.6 mGy, assuming a fallout arrival time of 3 h and a medium level of fractionation. Finally, 0.50 Gy of absorbed dose in air was derived as our tentative estimate for 1-year cumulative external dose in Dolon due to local fallout from the first USSR test in 1949.

INTRODUCTION

Dolon village, located about 60 km from the border of the Semipalatinsk Nuclear Test Site (SNTS), is known to be heavily contaminated by local fallout from the nuclear weapon tests in SNTS. According to Gordeev *et al.*,¹⁾ more than 99% of radiation exposure in Dolon originated from the first USSR test on August 29, 1949 and an external effective dose of 1,240 mSv was estimated for the people living in Dolon at that time. This fallout dose seemed to be extremely high compared with the case of Nagasaki, the bomb of which was imitated by the first USSR test. In Nagasaki and Hiroshima only nearby areas around the cities were significantly affected by local fallout called “black rain”.²⁾ The reason for the difference between Hiroshima-Nagasaki and the first USSR test was thought to be the difference in the height of burst (HOB). In cases of Hiroshima (HOB=600 m) and Nagasaki (503 m) fireballs did not touch the ground, and debris rose up to high altitude, while the first USSR test

(HOB=30 m) dragged a large amount of soil into the fireball and created a large radioactive plume along the wind direction.³⁾

Since the first expedition to SNTS in 1994, Yamamoto and Sakaguchi have been publishing a series of papers on ¹³⁷Cs and ^{239,240}Pu contamination in soil around SNTS, including the data in Dolon.⁴⁻⁸⁾ In this study, using the soil data in Dolon and calculation of fallout composition, we tried to reconstruct the radiation circumstances at the time of the first USSR test and evaluated the external radiation from the deposited radionuclides.

MATERIALS AND METHODS

Soil contamination data in Dolon

Sakaguchi *et al.*⁶⁾ provided data on ¹³⁷Cs and ^{239,240}Pu in 22 and 10 soil samples, respectively, all from Dolon village. They took cylindrical soil cores of 30- or 100-cm length and 4.7-cm diameter mostly inside Dolon. In addition, data on 27 soil samples, also for ¹³⁷Cs and ^{239,240}Pu, were taken from Gastberger *et al.*⁹⁾ Sampling points by Gastberger *et al.* were pasture or steppe outside Dolon village. Three cores (12- or 14-cm length and 8-cm diameter) at the corner of an approximately 10-m triangle, were taken from each of nine sampling points. In total, 49 and 37 soil data results were used in this analysis, for ¹³⁷Cs and ^{239,240}Pu, respectively.

The relation between ¹³⁷Cs and ^{239,240}Pu contamination in soil samples from Dolon is shown in Fig. 1. Results from

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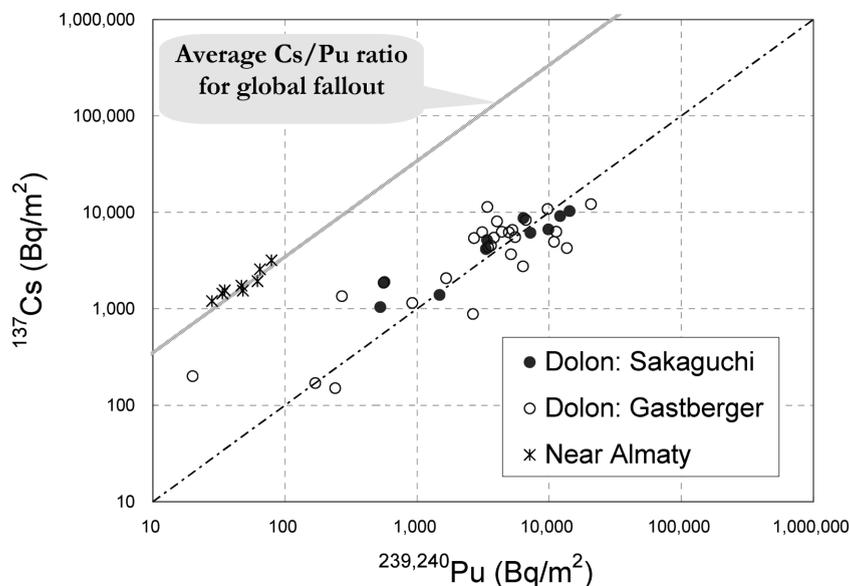


Fig. 1. The relation between ^{137}Cs and $^{239,240}\text{Pu}$ contamination in soil samples from Dolon and near Almaty.

eight soil samples⁷⁾ taken in 2000 near Almaty about 1,000 km south from SNTS, where local fallout from the test site can be neglected, are also plotted in Fig. 1. Considering that the current average level of global fallout for $^{239,240}\text{Pu}$ is 40 – 120 Bq m^{-2} , the $^{239,240}\text{Pu}$ contamination in Dolon is very high, while the ^{137}Cs level in Dolon is similar to the usual level in Japan (3,000 – 8,000 Bq m^{-2}).⁵⁾ Therefore, a unique feature of soil contamination in Dolon is a very low ratio (1.3 ± 0.8) for $^{137}\text{Cs}/^{239,240}\text{Pu}$, compared with the ratio of Almaty soil (39 ± 5). The latter ratio corresponds to a ratio (34 ± 4) reported for the global fallout.⁵⁾ It was assumed in this study that the average of eight soil samples taken near

Almaty could be used as the global fallout level in Dolon. The log-linear histogram of ^{137}Cs levels in Dolon is shown in Fig. 2 after subtracting 1,900 Bq m^{-2} , the average of the eight Almaty samples.

Fallout composition and gamma-ray dose from the fallout deposition

A data file, the JNDC FP Nuclear Data Library, was obtained from the Japan Atomic Energy Research Institute (JAERI).¹⁰⁾ It contains FP (fission product) information such as fission yields, decay modes and constants, and branching ratios for 1,227 nuclides whose atomic numbers range from 66 to 172. Using this FP file as the input data, an Excel Visual Basic program (FPCOMP.xls) was developed to calculate the temporal change of FP composition after the nuclear explosion. Because most radionuclides in the FP file have very short half-lives in comparison with the fallout arrival time (around 3 h) in Dolon after the explosion, only 29 radionuclides, excluding rare gas species, were selected as possible candidates that could significantly contribute to external radiation in Dolon. According to the observation of atomic bomb tests at the Nevada test site, USA,¹¹⁾ off-site contribution of neutron-capture nuclides such as ^{56}Mn and ^{60}Co was reported to be rather small compared with FP nuclides. So neutron-capture nuclides were not considered in this study.

Dose rate conversion coefficients from a unit density on the ground of each radionuclide (Bq m^{-2}) to the absorbed dose in air at 1 m above the ground ($\mu\text{Gy h}^{-1}$) were calculated using the assumption of an infinite plane model on the ground and published gamma-ray emission data.¹²⁾

When we assume that fallout radionuclides stay on the ground without migration, the dose rate at time t after the

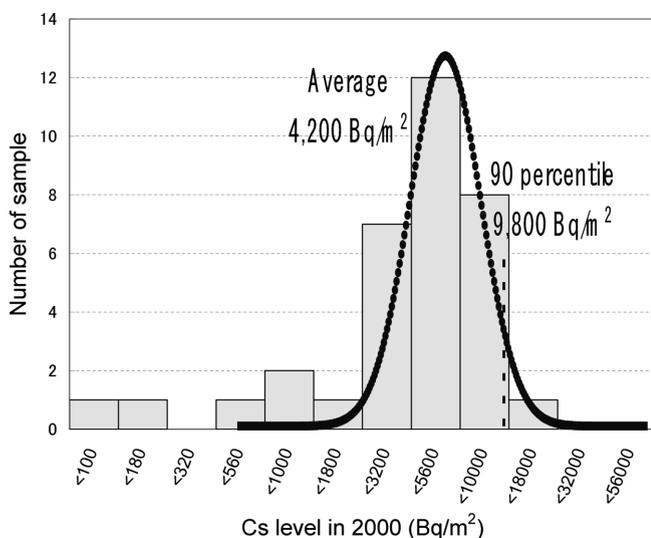


Fig. 2. Log-linear histogram of ^{137}Cs level in soil sample from Dolon. A value of 1,900 Bq m^{-2} is subtracted as the background from global fallout.

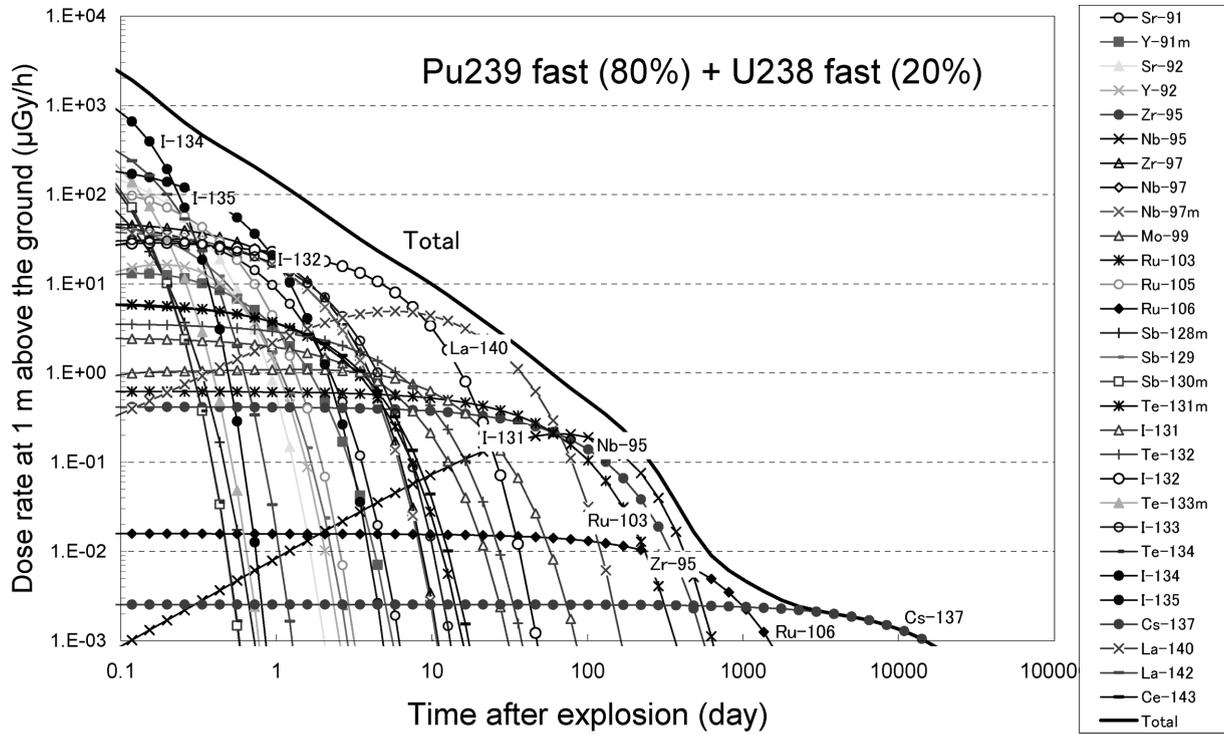


Fig. 3. Temporal change of gamma-ray dose rate in air from deposited radionuclides on the ground, normalized to the initial contamination containing 1 kBq m^{-2} of ^{137}Cs without fractionation.

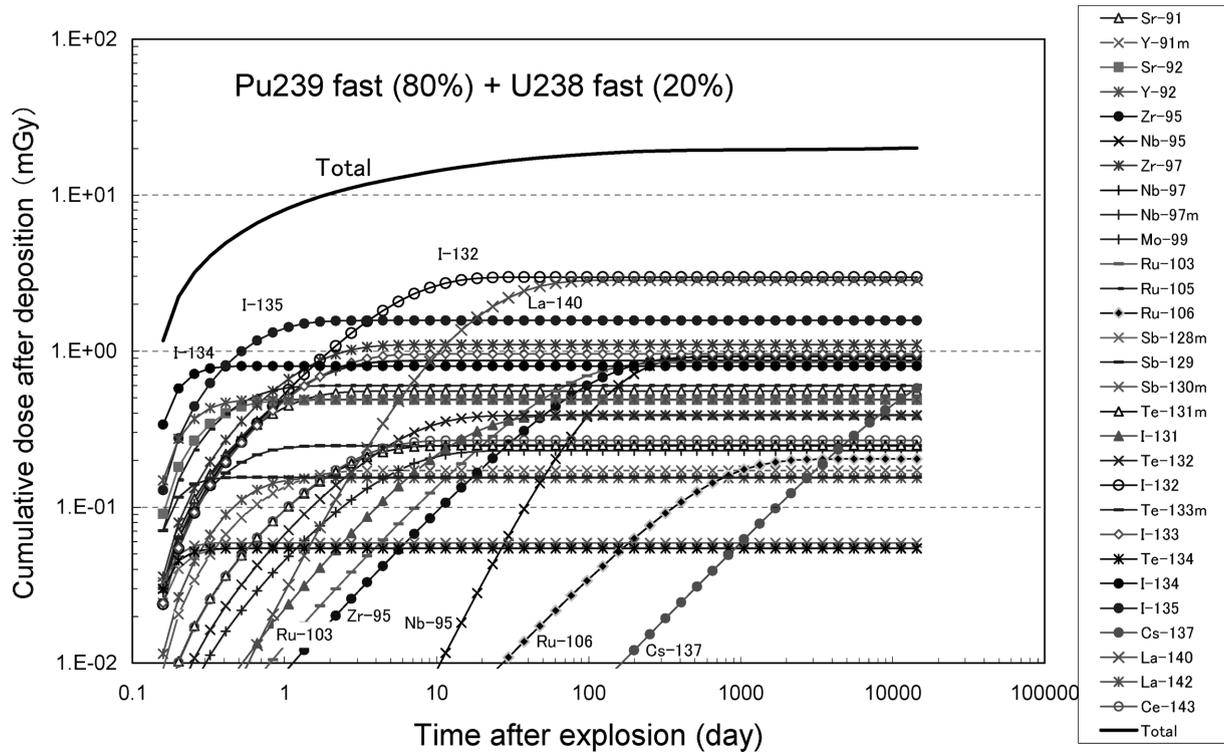


Fig. 4. Cumulative dose after the deposition, normalized to the initial contamination containing 1 kBq m^{-2} of ^{137}Cs . The arrival time is 3 h and fractionation is not considered.

explosion is expressed with the following equation;

$$d(t) = \sum_i k_i \cdot w_i \cdot f_i(t) \cdot a_{Cs}(t) \quad (1)$$

where, $d(t)$: absorbed dose rate in air at 1 m above the ground at time t , $\mu\text{Gy h}^{-1}$;

$a_{Cs}(t) = a_0 e^{-\lambda(t-t_d)}$; ^{137}Cs density on the ground at time t , Bq m^{-2} (a_0 ; initial ^{137}Cs deposition, λ ; decay constant, t_d ; time of deposition after explosion);

$f_i(t)$: activity ratio at time t of radionuclide i to ^{137}Cs in a mixture maintaining the same composition as FP;

w_i : fractionation factor for radionuclide i , indicating divergence of fallout composition from FP composition at the time of deposition, $0 \leq w_i \leq 1$;

k_i : dose rate conversion coefficient per unit density of gamma-ray emitting nuclide i on the ground, $(\mu\text{Gy h}^{-1})/(\text{Bq m}^{-2})$.

An example of dose rate change is plotted in Fig. 3, assuming an initial deposition of 1 kBq m^{-2} of ^{137}Cs and $w_i = 1$ (no fractionation). The $f_i(t)$ value depends slightly on the type of fission reaction. Referring to the values of the Nagasaki bomb,¹³⁾ a combination of 80% production by ^{239}Pu fast fission and 20% by ^{238}U fast fission was used to calculate $f_i(t)$ values in this study.

The cumulative dose in air $D(t)$ was calculated by integrating eq (1) for the time period from t_d to t ;

$$\begin{aligned} D(t) &= \int_{t_d}^t d(t) dt \\ &= \sum_i k_i \cdot w_i \int_{t_d}^t f_i(t) \cdot a_{Cs}(t) dt \end{aligned} \quad (2)$$

Assuming $t_d = 3 \text{ h}$, an example of cumulative dose calculation is shown in Fig. 4 by integrating dose rates in Fig. 3. From the results in Fig. 4, a cumulative dose of 20.1 mGy was obtained for 50 y after an initial deposition containing 1 kBq m^{-2} of ^{137}Cs . It is noted here that 82.3 and 96.0% of this dose were delivered within 1 month and 1 year, respectively.

Although it is certain that there was some gamma-ray dose from radionuclides within the plume, it is not evaluated in this study because the contribution of direct gamma-ray from the passing plume to cumulative dose is considered to be rather small compared with that from deposited nuclides.¹⁴⁾

RESULTS AND DISCUSSION

Referential value of ^{137}Cs deposition in Dolon

As shown in Fig. 2, a log-normal distribution was applied to the ^{137}Cs data in Dolon, neglecting small values less than 1 kBq m^{-2} . A good fit was obtained with a geometric mean of 4.2 kBq m^{-2} and a geometric SD factor of $10^{0.23} = 1.7$. Considering that the current ^{137}Cs level reflects various factors such as migration into soil, washing out, re-suspension,

human activities and so on, we assumed that large values in the distribution were more likely to reflect the original level of fallout contamination than small values. So, we tentatively chose the 90th-percentile value of the log-normal distribution, 9.8 kBq m^{-2} as our preferred value of ^{137}Cs deposition in Dolon, which corresponds to 32 kBq m^{-2} at the time of the first USSR test in 1949.

Dependency of cumulative dose on arrival time

Dolon village is located 110 km from the ground-zero of the first USSR test. Two values of wind speed, 47 and 60 km h^{-1} at the time of the experiment have been reported so far,^{1,15)} which correspond to arrival times of 2.3 and 1.8 h, respectively, if the radioactive plume traveled in a straight line from the ground-zero to Dolon. Considering that these wind speeds were very fast and were given as average values up to high altitude (6 km),¹⁵⁾ it is reasonable to assume that wind speed near the ground surface was somewhat less and the deposition happened a little later than these arrival times. So we calculated cumulative doses for three arrival times: 2, 3 and 4 h after the explosion. Resultant values of the cumulative dose for 50 y were calculated to be 22.3, 20.1 and 18.7 mGy, respectively, for arrival times of 2, 3 and 4 h, being normalized to the initial contamination containing 1 kBq m^{-2} of ^{137}Cs . Finally, an arrival time of 3 h is taken as representative in this study and the uncertainty of cumulative dose relating to arrival time is considered to be about 10%.

Effects of fractionation

In the process forming a radioactive plume after a nuclear explosion, refractory FP elements tend to solidify faster and deposit earlier than volatile FP elements. Therefore the refractory fraction in the radioactive plume tends to decrease

Table 1. Refractory index for 29 radionuclides used in the present study

Nuclides	Refractory index
^{91}Sr , ^{91}Y , $^{91\text{m}}\text{Y}$	0.2
^{92}Sr , ^{92}Y	1
^{95}Zr , ^{95}Nb , $^{95\text{m}}\text{Nb}$	1
^{99}Mo , $^{99\text{m}}\text{Tc}$	1
^{106}Ru	0
^{131}Sb , ^{131}Te , $^{131\text{m}}\text{Te}$, ^{131}I	0.1
^{132}Te , ^{132}I , $^{132\text{m}}\text{I}$	0
^{134}Te , ^{134}I , $^{134\text{m}}\text{I}$	0
^{137}Cs	0
^{140}Ba , ^{140}La	0.3
^{141}La , ^{141}Ce	0.7
^{144}Ce , ^{144}Pr , $^{144\text{m}}\text{Pr}$	1

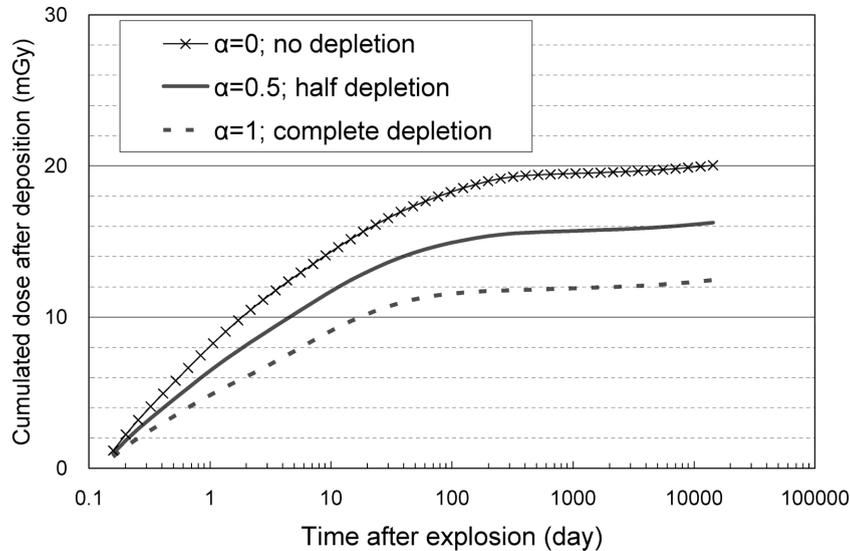


Fig. 5. Dependency of cumulative dose on depletion factor, α . $\alpha = 1, 0.5$ and 0 corresponds, respectively, to the maximum (no refractories present), medium (half refractories present) and minimum (all refractories present) level of fractionation.

gradually with distance from the ground-zero. This phenomenon called fractionation is expressed by w_i in eq (1).

Fractionation has been intensively investigated through nuclear experiments carried out both in the Nevada test site¹¹⁾ and SNTS¹⁶⁾. According to the work by Hicks,¹¹⁾ whether FP will act as refractory or volatile is determined by its state at 20 s after detonation when vaporized FP material begins to solidify. In the decay chain of one particular mass number, the fraction that exists as refractory elements 20 s after detonation will continue to behave as refractory after that time, while the residual fraction behaves as volatile. Therefore, the refractory index r_i , indicating the refractory fraction of nuclide i at 20 s after detonation, was calculated with the FPCOMP.xls program. The results are summarized in Table 1. Behavior of the refractory part in radioactive plume is described using a depletion factor α ($0 \leq \alpha \leq 1$): $\alpha = 0, 0.5$ and 1 means, respectively, no depletion, half depletion and complete depletion of the refractory part before the deposition. Therefore, the value of w_i in eq (1) is described by the following relation:

$$w_i = 1 - \alpha \cdot r_i \quad (3)$$

In Fig. 5 three cases of cumulative dose are shown for various depletion factors: $\alpha = 0, 0.5$ and 1 , assuming arrival time of 3 h. Values of cumulative dose for 1 y are obtained to be 19.3, 15.6 and 11.4 mGy for $\alpha = 0, 0.5$ and 1 , respectively, normalized to the initial contamination containing 1 kBq m^{-2} of ^{137}Cs . Based on observation around the Nevada test site, Hicks reported fractionation such that half of the refractory components were present in the off-site fallout within 160 miles from ground zero¹¹⁾. So, assuming $\alpha = 0.5$, a value of 15.6 mGy is adopted in the present study as a 1-

year cumulative external dose per 1 kBq m^{-2} of initial ^{137}Cs deposition in Dolon. In Fig. 6 our calculation of the dose rate from local fallout in Dolon during the critical period of dose accumulation is compared with the results of a similar calculation by Hicks¹⁷⁾ for the Trinity test, the first USA atomic bomb in New Mexico on July 16, 1945. A very good agreement between the two curves is seen in Fig. 6.

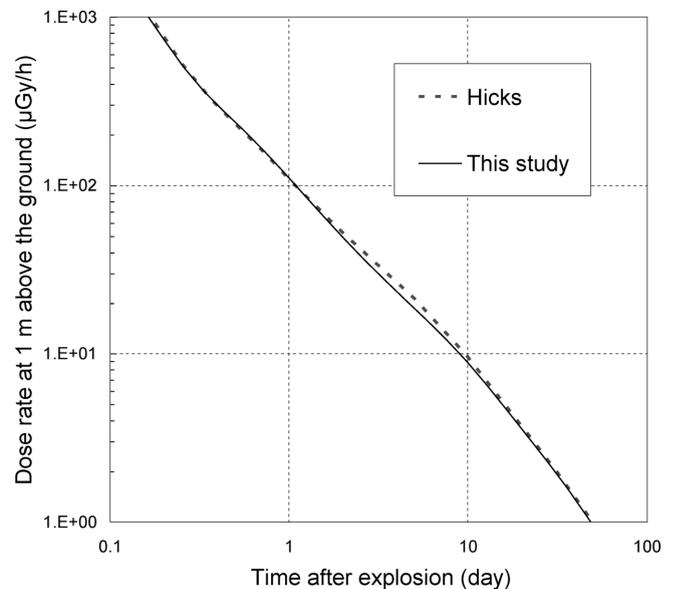


Fig. 6. Comparison of dose rate calculation from local fallout between the present study for the first USSR test and Hicks' work for the first USA test, Trinity. Both curves are normalized to the unit initial contamination containing 1 kBq m^{-2} of ^{137}Cs .

Table 2. Estimates of dose rate and cumulative dose to air in Dolon by local fallout from the first USSR atomic bomb test: fallout arrival time = 3 h and depletion factor = 0.5.

	Time after explosion						
	3 hour	1 day	1 week	1 month	1 year	5 year	50 year
Dose rate, $\mu\text{Gy h}^{-1}$	48,000	3,600	420	66	0.78	0.089	0.026
Cumulative dose, mGy	0	206	350	436	498	505	523

External radiation in Dolon

From the discussion above, the radiation situation in Dolon in 1949 can be described as follows. The radioactive plume of the first USSR test in SNTS arrived at Dolon about 3 h after the explosion. The radiation level must have increased suddenly with the arrival of the radioactive plume, ^{137}Cs deposition from which is supposed to have been 32 kBq m^{-2} . As shown in Table 2, a dose rate of 48 mGy h^{-1} was estimated from the gamma-ray emitting nuclides on the ground at the time of deposition. The dose rate from deposited nuclides decreased rapidly with time after deposition. It is noted that less than 5% of the cumulative dose for 50 y would be delivered after 1 y.

Thus, 0.50 Gy of absorbed dose in air is obtained as the 1-year cumulative external dose in Dolon from the fallout by the first USSR atomic bomb test in 1949. Recently Bailiff *et al.*¹⁴⁾ estimated an absorbed dose in air of $0.475 \pm 0.110 \text{ Gy}$ based on TL measurement of brick samples taken from the building of old church in Dolon. Although our value is consistent with Bailiff *et al.*'s, it should be kept in mind that our estimate directly depends on the assumption about the initial ^{137}Cs deposition, the applicability of which has to be studied in more detail.

CONCLUSION

External radiation in Dolon due to local fallout from the first USSR atomic bomb test in 1949 was evaluated by combining the recent ^{137}Cs data in soil and a calculation of temporal change of FP composition. A value of 32 kBq m^{-2} was tentatively chosen as a value of ^{137}Cs deposition in Dolon from the first USSR test. Cumulative dose to air for 1 y after the deposition, normalized to the initial contamination containing 1 kBq m^{-2} of ^{137}Cs , was calculated to be 15.6 mGy , assuming a fallout arrival time of 3 h and medium level of fractionation. Thus, 0.50 Gy to air was obtained as our tentative estimate for the 1-year cumulative external dose in Dolon from the first USSR atomic bomb test in 1949.

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