

Width and Center-axis Location of the Radioactive Plume That Passed Over Dolon and Nearby Villages on the Occasion of the First USSR A-bomb Test in 1949

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Semipalatinsk/Atomic bomb test/Radioactive plume/Fallout contamination/Dolon.

In relation to the efforts to reconstruct the radiation dose in Dolon village, which was affected by the first USSR atomic bomb test in 1949 at the Semipalatinsk nuclear test site, the width and the center-axis location of the radioactive plume were investigated based on the soil contamination data around Dolon and the nearby villages. Assuming that the radioactive plume passed over along a straight line from the ground zero point to this area, the spatial distributions of soil contamination were plotted as a function of the perpendicular distance from the supposed center-axis of the plume. In total 83 and 52 soil contamination data were available for ¹³⁷Cs and ^{239,240}Pu, respectively. The plotted distribution formed a peak-like shape both for ¹³⁷Cs and ^{239,240}Pu. A Gaussian function drawn so as to envelop the points plotted for ^{239,240}Pu indicated that the central part of the radioactive plume passed over the residential area of Dolon with a σ value of 1.5 km. Additional soil contamination data around Dolon and other villages are necessary for more detailed discussion.

INTRODUCTION

Nuclear weapon tests by the former USSR at the Semipalatinsk Nuclear Test Site (SNTS) in Kazakhstan caused a vast amount of radioactive contamination around the site.¹⁾ Dolon village is known as one of the most contaminated villages by radioactive fallout around SNTS.^{2,3)} It is also known that the contamination in Dolon was mainly caused by the first Soviet Atomic Bomb Test on August 29, 1949.⁴⁾ Recently various efforts have been made to estimate radiation dose to inhabitants who were living in Dolon at the time of the first test. Gusev *et al.*⁵⁾ and Stepanov *et al.*⁶⁾, both using the radiation survey data taken just after the test, calculated external gamma-ray dose in air in Dolon of 2 Gy and 1.9 Gy, respectively. Takada *et al.*⁷⁾ evaluated gamma-ray dose in air of about 1.4 Gy based on TL measurement of a brick sample taken from a church in Dolon, while Bailiff *et al.*⁸⁾ obtained a dose value in air of 0.475 Gy from TL measurement of

brick samples taken from the same church. Simon *et al.*⁹⁾ summarized the situation of dose assessment in Dolon, pointing out various discrepancies in dose estimation for the village among investigators.

The 3rd Dosimetry Workshop on SNTS was held at Hiroshima University in March 9–11, 2005.¹⁰⁾ Through the discussion at the workshop, it was pointed out that a single survey measurement was used for Dolon in the dose calculations both by Gusev *et al.*⁵⁾ and by Stepanov *et al.*⁶⁾: a dose rate of 33 $\mu\text{R s}^{-1}$ (119 mR h⁻¹) was recorded on September 5, 1949, one week after the first test, at a point 1.5 km northwest from the border of Dolon, and kept in a military archive of USSR.¹¹⁾ Interesting results of an international intercomparison program of TL measurement, in which five laboratories from different countries have participated, were presented at the workshop. The TL measurement of four brick samples from three buildings in Dolon has shown a good agreement among the participating labs and indicated that about 0.5 Gy of external radiation in air was plausible due to fallout from SNTS.

In relation with the discrepancy between dose calculations by Gusev *et al.*⁵⁾ and Stepanov *et al.*⁶⁾ and the result of the TL intercomparison, a possible explanation was given by Stepanenko *et al.*¹²⁾ at the workshop. They suggested that the width of the radioactive plume from the first USSR test was so narrow that only the edge part of the radioactive plume passed over the area of Dolon. In order to check this expla-

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nation, we analyzed the spatial distribution of ^{137}Cs and $^{239,240}\text{Pu}$ contamination in soil samples around Dolon and near villages as a function of distance from the supposed center-axis of the radioactive plume from the first USSR test.

MATERIALS AND METHODS

Beginning from the first expedition to SNTS in 1994, Yamamoto and Sakaguchi have been continuing a series of field expeditions around STNS.^{13–17} A lot of soil contamination data of ^{137}Cs and $^{239,240}\text{Pu}$ have already been published, including for Dolon, Cheremushki, Mostic and Budene villages, which are considered to have been affected by the first USSR test in 1949. Together with the results of soil contamination data, the precise coordinates of points where samples were collected were obtained by GPS (Global Positioning System) and are provided in their papers.^{14,15,17} Gastberger *et al.*¹⁸ also reported soil contamination of ^{137}Cs and $^{239,240}\text{Pu}$ in Dolon along with GPS coordinates.

A satellite photo of Dolon and other villages is shown in Fig. 1 together with the supposed center-axis of the radioactive plume. The position of the center-axis was suggested by Kazakhstan scientists who accompanied our soil sampling around SNTS. The number of data used in the present analysis is shown in Table 1. Positions of all soil samples are plotted in Fig. 2. The origin of the coordinate axes is set at ground zero of the first USSR test (50° 26' 11" N, 77° 48' 39" E).¹³ The center-axis of the plume was assumed to be a straight line from ground zero to the middle point among four sample points (No.14–No.17 in Fig.1 in the paper by Sakaguchi *et al.*¹⁵) over which the plume is considered to have passed. Judging from Fig. 1 of Sakaguchi *et al.*,¹⁵ the center-axis of the radioactive plume went across 1–2 km north-west of the residential area of Dolon, which coincides with the position reported at the March workshop in Hiroshima.

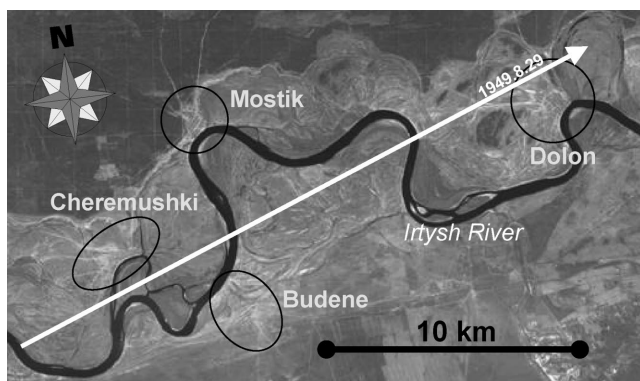


Fig. 1. Satellite photo and location of Dolon, Mostic, Cheremushki and Budene villages. The white arrow indicates the trace of the center-axis of the radioactive plume. The photo was obtained from Earth Remote Sensing Data Analysis Center (<http://www.gds.aster.ersdac.or.jp/>)

Table 1. Number of soil data used in the present study.

Village	Number of soil data ^a		References
	^{137}Cs ^b	$^{239,240}\text{Pu}$	
			Gastberger (2001) ¹⁸ c
Dolon	51 (16)	39	Yamamoto (1999) ¹⁴ Sakaguchi(2004) ¹⁵
Cheremushki	14 (6)	4	Sakaguchi(2005) ¹⁷
Mostic	7 (4)	4	Yamamoto (1999) ¹⁴ Sakaguchi (2005) ¹⁷
Budene	12 (6)	5	Sakaguchi (2005) ¹⁷
Chagan	1 (0)	1	Yamamoto (1999) ¹⁴
Total	85 (32)	53	–

^a; Since some samples of the Yamamoto and Sakaguchi group were not measured for Pu, there are differences of sample numbers between ^{137}Cs and $^{239,240}\text{Pu}$.

^b; () indicates the number of data less than 0 when 1,900 Bq m^{-2} for global fallout is subtracted.

^c; From Gastberger *et al.*,¹⁸ 27 data in Dolon are used for ^{137}Cs and $^{239,240}\text{Pu}$.

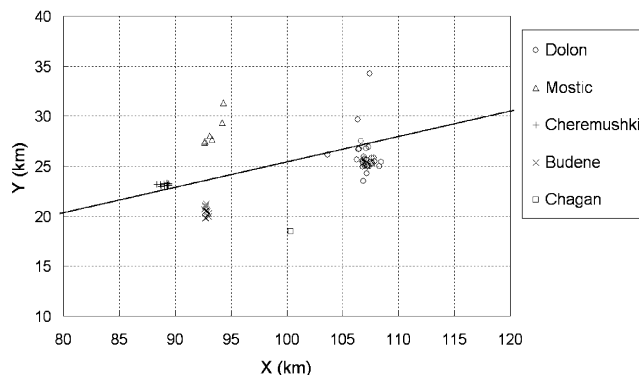


Fig. 2. Sample position and the centerline of the radioactive plume. X- and Y- axes correspond to East-West and North-South directions, respectively. The origin of coordinates is the ground zero of the first USSR test.

RESULTS AND DISCUSSION

The contamination distribution of ^{137}Cs and $^{239,240}\text{Pu}$ are plotted in Fig. 3 as a function of perpendicular distance from the supposed center-axis of the radioactive plume. Plus value of X-ordinate corresponds to the southern side from the plume center-axis. In Fig. 3(a), a value of 1,900 Bq m^{-2} of ^{137}Cs is subtracted from all data as the contribution from the global fallout, while in Fig. 3(b) the global fallout of $^{239,240}\text{Pu}$ is not subtracted because it is negligibly small compared with the measured values around Dolon. A global fallout value for ^{137}Cs of 1,900 Bq m^{-2} is obtained from the average

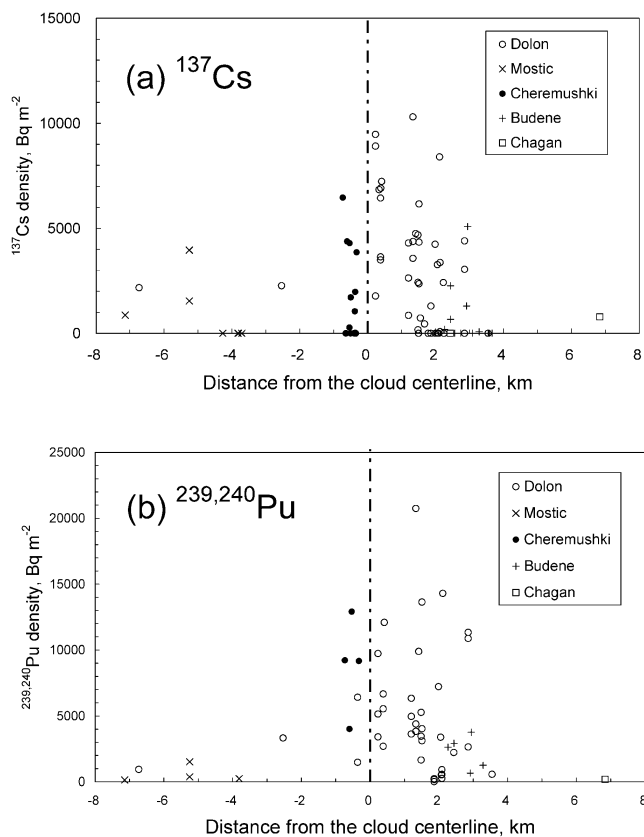


Fig. 3. Distribution of soil contamination around the supposed center-axis of the radioactive plumes for ^{137}Cs (a) and $^{239,240}\text{Pu}$ (b). $X = 0$ is set to the center-axis and $X > 0$ corresponds to the southern side of the radioactive plume. Minus values after subtracting $1,900 \text{ Bq m}^{-2}$ for ^{137}Cs global fallout are set to be 0 in (a). Global fallout for $^{239,240}\text{Pu}$ isotopes are neglected in (b). All activities are at the time of measurements, not decay-corrected after deposition.

of the soil samples taken near Almaty,¹⁶⁾ around 1,000 km south from Semipalatinsk, where fallout from STNS can be neglected.

The envelope of plotted data in Fig. 3 seems to form a peak-like shape both for ^{137}Cs and $^{239,240}\text{Pu}$, the center position of which is 1–2 km south from the presumed center of the plume. Considering that the radioactive fallout from the first USSR test was deposited more than 50 years ago, other than physical decay of radionuclides, the current distribution of radioactive contamination is reflecting various factors such as migration into soil, washing out, resuspension, human activities and so on.^{15,18)} Although it is extremely difficult to quantify the effects of these factors, it seems to be acceptable to assume that large values in the distribution are more likely to keep the original circumstances of fallout contamination than small values.

Therefore, based on an assumption that the original shape of the fallout distribution was Gaussian-type around the center line of the radioactive plume, a Gaussian curve was drawn so as to envelop the points plotted for $^{239,240}\text{Pu}$ in Fig.

3(b). The result is shown in Fig. 4. The parameters of the Gaussian distribution were determined by the author's inspection: the center location and the σ value of the distribution are 1.1 km and 1.5 km, respectively. This σ value is exactly the same as the estimate reported by Stepanenko *et al.*¹²⁾ at the March workshop, which corresponds to a FWHM (Full Width at Half Maximum) of 3.5 km. Very similar results were obtained when a Gaussian distribution was applied to the ^{137}Cs data in Fig. 3(a). The FWHM value of 3.5 km seems to be extremely small, considering the distance of about 110 km between the ground zero and Dolon. According to the book about U.S. nuclear tests by Glasstone and Dolan,¹⁹⁾ the radius of stabilized cloud formed by a 20 kton nuclear explosion of low air burst is evaluated to be about 1.5 km. Considering that an energy yield of 22 kton was reported for the first USSR test at SNTS,¹⁾ there was almost no dispersion of the radioactive plume for this test during the travel from ground zero to the Dolon area. The weather condition, in particular a very high wind speed (60 km h^{-1}) at the time of the explosion,¹¹⁾ is considered to be the main reason for such a narrow plume width.

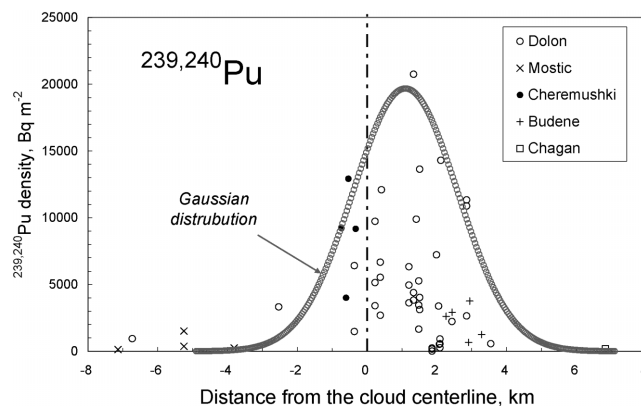


Fig. 4. Gaussian function enveloping $^{239,240}\text{Pu}$ distribution. The centerline position and the σ value of the function are chosen as 1.1 km and 1.5 km, respectively.

A Gaussian distribution shown in Fig. 4 indicates a hypothesis that the real center of the radioactive plume passed over about 1 km south of the supposed centerline in Fig. 2. In this case, the central part of the plume is suggested to have passed over Dolon, which leads to the result that the dose discrepancy between dose calculations (about 2 Gy) and TL measurements (about 0.5 Gy) cannot be explained by the center-axis location of the radioactive plume.

Bailiff *et al.*,⁸⁾ however, gave a discussion supporting the hypothesis that the residential area of Dolon was at the edge part of the plume, citing several reports on ^{137}Cs contamination in soil around Dolon. Stepanenko *et al.*¹²⁾ also argued that, based on an analysis of the Soviet archive data and recent soil contamination data, the central axis of the trace was at 1.6 km north from the border of Dolon.

As can be seen in Fig. 2, the number of sample points used in our analysis for the area to the north outside Dolon are rather more scarce than for within the residential area. A joint effort is being discussed with Russian scientists to include the Soviet archive data in the present analysis after the detailed data has been obtained from the archive. Therefore, there remains a possibility that the entire picture of the contamination distributions in Figs. 3 and 4 may change when more data has been added, in particular for the area to the north outside Dolon. It should also be noted that a straight line from ground zero was assumed for the radioactive plume transport in the present study. If there was significant curvature or turbulence during the plume transport to Dolon and nearby villages, a simple interpretation of the contamination distribution in Figs. 3 and 4 becomes difficult.

The present study clearly shows that a valuable information can be obtained by combining different works^{14,15,17,18} using GPS coordinates of sample location. However, in order to discuss more details about the width and the center location of the radioactive plume over Dolon, additional soil contamination data are needed, as well as the exact information on the ground survey point in 1949. It is also considered that an analysis of ⁹⁰Sr contamination in soil would provide useful information on these issues.

CONCLUSION

In relation to the efforts to estimate radiation dose to inhabitants in Dolon, the width and the location of the radioactive plume that is believed to have passed over Dolon and nearby villages were discussed based on ¹³⁷Cs and ^{239,240}Pu contamination data. The following was obtained from a preliminary analysis:

- The soil contamination data are found to be useful for discussing the width and the location of the radioactive plume that passed over Dolon.
- An analysis of the contamination distribution in the present study suggests that the radioactive plume passed just over Dolon with a width (FWHM) of around 3.5 km.
- Additional systematic data is necessary to obtain a conclusion about the width and the center location of the plume.

A systematic soil sampling to investigate the width and the center-axis location of the plume is planned around Dolon and nearby villages in the next expedition of the Yamamoto group. This is scheduled for autumn of 2005.

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