Original Contribution

Fallout from nuclear tests: dosimetry in Kazakhstan

K. Gordeev[1], I. Vasilenko[1], A. Lebedev[1], A. Bouville[2,✉], N. Luckyanov[2], S. L. Simon[2], Y. Stepanov[1], S. Shinkarev[1] and L. Anspaugh[3]

Background and aim of the study

The populations that appear to have been the most exposed to radioactive fallout as a result of nuclear weapons testing at the Semipalatinsk test site (STS) can be divided into two groups. The first group is located in the areas of the Republic of Kazakhstan in the vicinity of the STS and the second group is located in the Altai krai (i.e. Altai region) of the Russian Federation. The purpose of this paper is to estimate doses for the populations of the Republic of Kazakhstan that resided in the vicinity of the STS at the time when nuclear weapons tests were conducted in the atmosphere.

The methodology that was used to estimate doses is based on the radiation measurements that were made after each test. It was developed by joint efforts of the scientists of the Institute of Biophysics and other Institutes of the Ministry of Health of the USSR, biologists and physicists of the STS, as well as of the specialists from other organizations involved in radiation protection problems. That methodology is currently applied to the estimation of doses received by subjects living near the STS, as part of an epidemiological study carried out by the U.S. National Cancer Institute [*1*].

Methodology of dose estimation

The methodology of dose estimation is based on the coupling of data on radiation exposure of the populations of the Republic of Kazakhstan and environmental transfer models. The usable data are maintained in the archives of the Ministry of Defense and of the Ministry of Health, as well as those of other organizations of the Russian Federation that took part in nuclear testing operations at the STS. The most useful data are exposure rates measured along the trajectories of the radioactive clouds. The exposure-rate measurements, which were usually taken aboard low-flying aircraft, were sometimes supplemented with ground-level monitoring. In the archives of the Ministry of Defense of the Russian Federation, the measurement data of exposure rates are presented in different forms:

1. Original measurements with indication of time, location, height above ground surface, and reading of the instrument, and

2. Maps showing isopleths of exposure rates normalized to some definite postdetonation time. In addition, the results of some measurements of radionuclide content in soil, vegetation, grain crops, milk, and other environmental samples are available.

The model used to predict or reconstruct the radiological conditions after each test, in areas where measurements were lacking, requires information on test yield, type and composition of fission material, date and time of explosion, height of radioactive cloud top, height of detonation above ground surface, and average wind speed over the height of the radioactive cloud [2].

The main parameters characterizing the radiological conditions at the location of interest are derived by means of the model:

- Fallout arrival time, H+t (h)
- Duration of fallout Δt (h)
- Fraction of the activity of the radionuclides in fallout assigned to the biologically active particles, defined as those with diameter d $\leq$ 50 µm, $\eta_{d \leq 50}$ (unitless)
- Average concentration of radionuclides in ground air during the time of radioactive fallout $\overline{C}$ $(Bq\ m^{-3})$
- Radionuclide ground deposition density at time H+24 h, $\sigma_{\Sigma,24}$ $(Bq\ m^{-2})$
- Exposure rate at time H+24 h, P_{24} $(mR\ h^{-1})$.

Whenever possible, the values of exposure rate, P_{24}, and of radionuclide ground deposition density at time H+24 h, $\sigma_{\Sigma,24}$, were derived from the available measurements of exposure rate in the location of interest or in its vicinity [3, 4, 5, 6].

The next step in the dosimetry calculation is to take into account the lifestyle and dietary habits of the population groups living at the location of interest:

- Age-dependent number of hours spent outdoors, used to derive the effective doses from external irradiation, and
- Type of milk consumed and age-dependent milk consumption rates, used to derive the thyroid doses from internal irradiation.

For the purpose of determining those tests most likely to have affected the local population, dosimetric calculations were used to classify the 111 atmospheric tests according to whether the estimated effective dose to an adult living off-site at the point of maximum exposure rate during the year following the nuclear explosion would exceed 5 mSv. Eleven events were found to satisfy that criterion and thus to contribute substantially to radiation exposure. They were conducted on 29 August 1949, 24 September 1951, 12 August 1953, 5 May 1954, 30 October 1954, 29 July 1955, 2 August 1955, 16 March 1956, 24 August 1956, 22 August 1957, and 7 August 1962. Important characteristics of those tests are presented in Table 1, while the airmass trajectories of the corresponding radioactive clouds are shown in Fig. 1.

Estimation of doses for population groups in Kazakhstan

Settlements of interest: location and population habits

On the basis of the analysis of the radiological conditions in the Semipalatinsk Oblast as a result of nuclear testing and after taking into account the opinion of the specialists of local medical facilities, eight settlements (see Table 2) were selected by the U.S. National Cancer Institute for the purpose of an epidemiological study [*1*]. The locations of the eight settlements, which are believed to include those sites in which the highest levels of exposure occurred, as well as other sites where radiation exposure was very low, are given in Table 2 and are shown in Fig. 1.

The eight settlements listed in Table 2 can be divided into two groups: northeastern and southern, differentiated according to the prevalent nationality of the inhabitants, the northeastern group being mainly of Russian descent, and the southern group being mainly of Kazakh descent. Lifestyle and dietary parameters that impact the dose estimates were collected or estimated for the two population groups. With respect to external irradiation, the lifestyle parameters that are important are the average time spent outdoors and the type of residence. With respect to internal irradiation of the thyroid, the consumption rate of cow's milk is the most important dietary parameter.

The northeastern group of settlements is located in the northern part of the Semipalatinsk Oblast on the northern bank of the Irtysh river, close to the Altai region of Russia. Five settlements are in this group: Dolon, Bolshaya Vladimirovka, Kanonerka, Novopokrovka, and Korostelevskii. The populations of those villages are primarily Russian and have specific life-style and dietary habits of that nationality. In addition, there is a small percentage of Germans, whose life-style and diet are close to those of Russians. They typically lived in wooden houses that afforded little protection from the gamma radiation emitted from the radioactive cloud or from the activity deposited on the ground. For Russian settlements, the ratio of the outdoor and indoor exposure rates is taken to be 1 for the gamma radiation emitted from the radioactive cloud and 3 for the activity deposited on the ground. Also, the residents of Russian settlements typically drank cow's milk. Age-dependent values of the average time spent outdoors and of consumption rate of cow's milk for the inhabitants of Russian settlements are provided in Table 3.

The other (southern) group of settlements is located in the steppe part of northern Kazakhstan and includes Kaynar, Sarzhal, and Kara-Aul, typical villages with primarily Kazakh populations and with life-style and dietary habits typical of that population. One of the main differences between Russian and Kazakhs is that the Kazakhs drank horse's milk instead of cow's milk. In addition, they usually lived in adobe (mud) houses, which afforded more protection from outdoor gamma radiation than the wooden houses inhabited by the Russians. For Kazakh settlements, the ratio of the outdoor and indoor exposure rates is derived from measurements to be 2.5 for the gamma radiation emitted from the radioactive cloud and 13 for the activity deposited on the ground. Age-dependent values of the average time spent outdoors and of consumption rate of horse's milk for the inhabitants of Kazakh settlements are listed in Table 3.

Radiological conditions in the settlements of interest

The first step of the dosimetry modeling was to characterize the fallout radiation field in the settlements of interest for each test that contributed to the radiation exposure there. The methodology that was used for that purpose is described in [*2*]. The characteristics of fallout (time of arrival, duration of fallout, fraction of the activity of the radionuclides in fallout assigned to the biologically active particles with diameter $d \leq 50$ μm, average activity concentration in ground-level air during the radioactive fallout,

ground deposition density at time H+24 h, and external gamma-exposure rate at H+24 h) were measured or estimated for each settlement and each significant test. The results are presented in Table 4.

In a second step, the concentrations of ^{131}I and of ^{133}I in the type of milk predominantly consumed in each of the eight settlements were estimated using the methodology described in [2]. In these calculations, it is assumed that dairy animals were on pasture during a time period of a few weeks after each test and that only milk of local origin was consumed. Under those conditions, the contributions of other foodstuffs e.g., leafy vegetables or meat, to the thyroid doses from internal irradiation are minor; hence, they have not been considered in this paper. Estimates of radioiodine concentrations in milk in each of the villages following the most important tests are presented in Table 5.

Initial results

External effective doses and internal thyroid doses for the residents of the settlements of interest in the Republic of Kazakhstan

Using the data on the radiological conditions and on the lifestyle and dietary habits of the population in the settlements, effective doses from external irradiation and thyroid doses from internal irradiation have been estimated. Both the external and the internal doses are age-dependent. Doses were calculated for people who were adults at the time of the tests (i.e., born before 1930), as well as for 1-year-old children at the time of the first test (i.e., born in 1948).

The thyroid doses from internal irradiation were calculated for:

- Inhalation intake of ^{131}I, ^{133}I, and ^{135}I, and
- Ingestion intake with milk of ^{131}I and ^{133}I.

The values of the thyroid dose coefficients were taken from [7].

The estimated doses, assuming that no countermeasures were taken, are presented in Table 6. In fact, countermeasures were only taken for test no. 4, which occurred on 12 August 1953, and affected only the populations of Sarzhal and of Kara-Aul:

- The residents of Sarzhal and their cattle were evacuated to non-exposed areas before the detonation of event 4 occurred. Those residents returned to Sarzhal 16 days after the event.
- The residents of Kara-Aul were hurriedly evacuated a few hours after the arrival of the radioactive cloud in their settlement. However, out of the 1,620 residents of Kara-Aul, 191 adults were left behind in order to guard the properties of the residents. Those residents were also evacuated at a later time. All residents returned to Kara-Aul 10 days after the event. Table 6 also presents dose estimates for the evacuated residents of Sarzhal and Kara-Aul.

This method was also used by Gordeev [8] to calculate thyroid doses for inhabitants of other settlements in Semipalatinsk oblast. For example, thyroid doses for 1-year-old children were estimated to be 25.7 mGy for residents of Semipalatinsk city, while for Znamenka, thyroid doses for 1-year-olds were estimated to be 380 mGy for Kazakh children and 160 mGy for Russian children [8].

Problems, limitations and potential solutions

1. The dose estimates presented in this paper should be considered as preliminary reconstructions. Efforts are under way to assess their validity and improve them where possible. On-going activities include a detailed comparison of the environmental transfer models used in Russia and in the U.S., as well as the estimation of external doses from EPR measurements in teeth taken from local residents and thermoluminescence measurements in bricks obtained from local buildings.

2. The upper ranges of estimated doses are about 1 Sv (effective doses) from external irradiation and about 2 Gy (thyroid doses) from internal irradiation. However, there is not yet validation of these estimates by physical measurements.

3. Effective doses from external irradiation are expected to be reliable where based on measurements of exposure rates after each test. The limiting factor, however, is the sparseness of such data. Uncertainty of external doses to residents is mainly due to lack of knowledge about the number of hours spent outdoors each day among different age groups.

4. Thyroid doses from internal irradiation due to the consumption of milk contaminated with ^{131}I and ^{133}I are difficult to estimate reliably because they cannot be confirmed by any present-day measurement. Moreover, the dose estimates depend on highly uncertain parameters, including the fraction of fallout debris intercepted by plants, the solubility of fallout of different particles sizes and at different locations, transfer coefficients for different types of dairy animals, and the origin and amount of milk consumed by each person.

5. Intakes via consumption of foodstuffs other than milk are likely to provide small contributions to the internal thyroid dose.

Future plans

The dose estimates presented in this paper relate to unspecified residents of the settlements that are considered. In order to estimate the thyroid doses to the specific individuals who are members of the epidemiological study undertaken by NCI, account should be taken of the residence histories of those individuals, as well as of their personal life-style and dietary habits, especially with regard to the type and amount of milk consumed. This effort is under way.

It is also important to note that it would be highly desirable to confirm the validity of the dose estimates presented in this paper. It is for that purpose that it is planned to conduct a detailed comparison of the environmental transfer models used in Russia and in the U.S. and that EPR measurements in teeth taken from local residents and thermoluminescence measurements in bricks obtained from local buildings are being envisaged.

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