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ESR dosimetry study of population in the vicinity of the Semipalatinsk Nuclear Test Site

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A tooth enamel electron spin resonance (ESR) dosimetry study was carried out with the purpose of obtaining the individual absorbed radiation doses of population from settlements in the Semipalatinsk region of Kazakhstan, which was exposed to radioactive fallout traces from nuclear explosions in the Semipalatinsk Nuclear Test Site and Lop Nor test base, China. Most of the settlements are located near the central axis of radioactive fallout trace from the most contaminating surface nuclear test, which was conducted on 29 August 1949, with the maximum detected excess dose being 430 ± 93 mGy. A maximum dose of 268 ± 79 mGy was determined from the settlements located close to radioactive fallout trace resulting from surface nuclear tests on 24 August 1956 (Ust-Kamenogorsk, Znamenka, Shemonaikha, Glubokoe, Tavriya and Gagarino). An accidental dose of 56 ± 42 mGy was found in Kurchatov city residents located close to fallout trace after the nuclear test on 7 August 1962. This method was applied to human tooth enamel to obtain individual absorbed doses of residents of the Makanchi, Urdzhar and Taskesken settlements located near the Kazakhstan–Chinese border due to the influence of nuclear tests (1964–1981) at Lop Nor. The highest dose was 123 ± 32 mGy.

Keywords: ESR dosimetry; tooth enamel samples; Semipalatinsk Test Site

INTRODUCTION

Semipalatinsk is a well-known region of Kazakhstan because of the presence of the Semipalatinsk Nuclear Test Site (SNTS) and its close proximity to China, where the Lop Nor test base is situated. In the period from 1949 to 1962 125 nuclear tests (including 25 near-surface nuclear tests) were conducted at the Ground Zero technical site in the SNTS. The date of 29 August 1949 represents the first nuclear explosion, which contaminated a huge territory northeast from the epicenter with radioactive fallout. The radioactive dust cloud was transferred by the wind and its gradual precipitation formed several radioactive fallout traces [1–3]. There are no data describing the dynamics of the precipitation of the dust from the radioactive cloud onto the region adjacent to the SNTS. It is a very complicated procedure to reconstruct the individual and collective radiation doses received by the local population.

On 24 August 1956, the 28th nuclear explosion took place with a 27-kiloton total yield, which contaminated a huge territory to the east of the hypocenter and near Ust-Kamenogorsk city with radioactive fallout [4, 5]. Reconstruction of individual and collective doses received by the local population is a sophisticated procedure combining data of the radioactive fallout levels, individual doses measured by ESR, doses reconstructed from retrospective area dosimetry and the individual behavior of inhabitants.

The Lop Nor nuclear weapons test base is located in the Malan, Xinjiang Autonomous region of China. China conducted 45 nuclear tests at Lop Nor, including 22 atmospheric and surface tests between 1964 and 1981. According to Gusev *et al.* [6] about half of the 22 tests were surface tests. In this paper the estimates of total external gamma dosage from the main dose-forming explosions (1966, 1967 and 1973) were 371 mGy, 334.6 mGy and 284 mGy for the populations of the Makanchi, Urdzhar and Taskesken settlements, respectively. These are possible doses for the exposed territories of the population. The model [7] used for dose calculation accounts for the time of explosion and behavior of the population depending on season.

ESR dosimetry is one of the most useful tools for such dose reconstruction [8]. This method can determine radiation doses retrospectively even > 40 years after the exposure event. ESR measures the amount of stable radicals created by radiation exposure in tooth enamel. The purpose of this study is to combine the data from previous studies to obtain more comprehensive conclusions.

MATERIALS AND METHODS

From 2000 to March 2005, 97 teeth samples were extracted on the basis of medical indications from adult residents of Dolon, Mostik and Bodene villages, located near the radioactive fallout trace formed as result of the most hazardous nuclear test of 1949 [9, 10], and from Kurchatov City and Semipalatinsk City, which are located 70–150 km from SNTS [11]. In 2008 and 2009, 88 teeth samples were extracted for medical reasons from adult residents of Ust-Kamenogorsk city and the Znamenka, Glubokoe, Tavriya, Gagarino and Shemonaikha settlements [12, 13]. For the period from 2008 to 2009, 30 teeth samples were extracted on the basis of medical indications from adult residents of Makanchi, Urdzhar and Taskesken villages, which are located 100–200 km from the Kazakhstan–Chinese border [14, 15]. Eight teeth were collected as controls from the population of Kokpekty village (400 km east of the test site), which was not subjected to any radioactive contamination. All samples were measured in the previous studies.

Enamel was mechanically separated from dentine using hard alloy dental drills and diamond saws. Dentins were removed carefully with cooling water in order to prevent the sample from heating, which can induce an additional ESR signal and significantly change the shape of the signal [8]. Tooth enamel was crushed with cutting pliers to chips 0.5–1.5 mm in diameter. Two samples were prepared from the buccal and lingual parts of each tooth.

The measurements were carried out in the X-band on the ESR spectrometer JEOL JES-FA100 at a stabilized room temperature of 21°C. The spectrometer was equipped with a high Q-factor cylindrical TE_{011} cavity model ES-UCX2. The spectrum recording parameters were the same as previously published [16]. Especially designed computer software was used for spectra processing and dose estimation [17].

For all the samples, excess doses were calculated with the following equation:

$$D_{ex} = D_{en} - TA \times D_b$$

Where D_{en} = dose calculated by automatic program, in mGy;

TA = tooth enamel age (years); and

D_b = background dose, 0.8 mGy/year [2, 3].

Uncertainty of dose determination (*Er*) was determined based on a semi-empirical formula used in a previous publication [3].

RESULTS AND DISCUSSION

The doses for the residents of Semipalatinsk City and Kurchatov City were included in this report from the published data [18]. The experimentally determined dose was considered to consist of two contributions: the dose from the natural radiation background accumulated during the lifetime of the tooth enamel and the dose received as a result of nuclear tests (excess dose). The latter is the subject of the interest for present dose reconstruction. First, the intensity of the radiation-induced signal (RIS) was converted into a dose absorbed by enamel D_{en} (expressed in mGy) calibrated using a ^{60}Co γ source. Second, excess dosage in enamel was determined by subtraction of the contribution of the natural background radiation during the enamel's lifetime after its formation from the absorbed dose in enamel.

For some doses, negative values were obtained. This is because the measurements were performed near the threshold of sensitivity of the method. It is natural that some of the values become negative according to their statistical distribution determined due to experimental errors. The negative doses are probably the result of underestimation of uncertainty of the dose assessment.

The average excess doses for enamel formed before and after 1949 for Dolon, Mostik and Bodene villages and for Semipalatinsk and Kurchatov cities are shown in Table 1. The value of the average dose for Semipalatinsk City is close to the average results of Dolon village [11]. One of the explanations for this is the person tested worked in a place located close to SNTS, and another explanation that they were born in a village that was affected by fallout from the test site. The bulk of the excess doses are near the sensitivity threshold of the method.

For the control samples excess doses are from –66 ± 39 up to 24 ± 39 mGy; for Dolon they are from –74 ± 38 up to 440 ± 106 mGy; for Mostik from –64 ± 32 up to 119 ± 51 mGy; for Bodene from –50 ± 38 up to 356 ± 58 mGy; for Kurchatov from –47 ± 85 up to 56 ± 42 mGy; and for Semipalatinsk City from 0 ± 46 up to 268 ± 79 mGy. Low

Table 1. Information about samples from vicinity of the Semipalatinsk Nuclear Test Site

Settlement	Number of teeth samples	Enamel formed before 1949	ESR average excess dose with enamel formation before 1949 (mGy)	ESR average excess dose with enamel formation after 1949 (mGy)
Dolon	38	17	141 ± 37	25 ± 11
Mostik	23	12	19 ± 15	44 ± 14
Bodene	20	9	74 ± 40	17 ± 10
Semipalatinsk	9	4	145 ± 68	74 ± 35
Kurchatov	7	5	11 ± 20	9 ± 27
Total	97	47	–	–

Table 2. Information about tooth samples from the settlements located close to radioactive fallout trace as a result of surface nuclear tests on 24 August 1956 at the Semipalatinsk Nuclear Test Site

Settlements	Number of teeth samples	Archival dose (mSv) [19]	ESR average excess dose (mGy)	ESR maximal excess dose (mGy)
Znamenka	9	25	41 ± 46	268 ± 79
Glubokoe	14	10–15	36 ± 31	83 ± 29
Tavriya	10	10–15	17 ± 36	54 ± 34
Ust-Kamenogorsk	30	80	20 ± 25	120 ± 35
Gagarino	10	10–15	–24 ± 33	47 ± 34
Shemonaikha	15	0.1	17 ± 37	110 ± 37
Kokpekty	8	<0.1	0.01 ± 33	24 ± 39

doses were found for the group with enamel formed after 1962, the end of the atmospheric nuclear tests. The dose values for the group with enamel formed before 1962 are consistent with estimations based on the official registered data indicating high levels of fallout in the period 1949–1962. The experimentally measured individual doses are comparable with data of dose reconstruction, which were given in previous publications [8, 9]: about 500 mGy for Dolon.

For Tavriya and Gagarino villages all the studied samples had been formed before the date of the nuclear test. For other settlements, teeth samples were divided into two groups: those formed before and after the nuclear explosion. Low excess doses have been found for Gagarino and Tavriya residents, while the highest excess dose has been determined for Znamenka, Shemonaikha and Ust-Kamenogorsk residents (Table 2). Given the small number of teeth samples investigated, the deduced doses should not be seen as representative of the whole population in the selected villages. The maximum dose obtained for samples from Shemonaikha was not expected, due to its large distance from the radioactive trace, but may be due to radioactivity released by some of the uranium enterprises located there. The maximum dose obtained for Znamenka village [18] confirms that this village is located close to a radioactive trace. The other settlements included in the study also have uranium enterprises, except for Tavriya and Gagarino, where agriculture is prevalent. Average excess doses in the latter two settlements are consistent with estimations based on the official registered data indicating high levels of fallout in the period 1949–1962 [19].

The individual excess dose determinations and archival external dose estimations [20] of villages influenced by the Lop Nor nuclear test site are shown in Table 3. The average excess dose for Makanchi is 62 ± 28 mGy. For Urdzhar, the average excess dose is 64 ± 30 mGy. For Taskesken, the average excess dose is 49 ± 27 mGy and for Kokpekty village, the average excess dose is 0.01 ± 33 mGy. The average excess doses for the investigated settlement are higher than for the control village.

The dose values are consistent with estimations based on the official registered data indicating high levels of fallout in the period 1966–1981 [20]. This dose estimation is an estimation of external dose only. Some of the differences between the ESR dose estimation and archival data can be explained by shielding factors (staying inside the house) and behavior factors (resident's location during the tests and migration).

According to a previous study [6] the populations of Makanchi, Urdzhar and Taskesken were not heavily exposed by the Chinese test site or the Semipalatinsk test

Table 3. Archival data [20] of external dose estimation [6] and results of the study of the Lop Nor nuclear test site influence to the Makanchi, Urdzhar and Taskesken settlements [15]

#	Date of explosions	External dose (mGy)		
		Makanchi	Urdzhar	Taskesken
1[a]	28.12.1966	4.07	3.63	3.03
2[a]	17.6.1967	143.0	129.0	109.0
3[a]	27.6.1973	224.0	202.0	172.0
4	ESR max excess dose	123 ± 32	118 ± 32	107 ± 31
5	ESR average excess dose	62 ± 28	64 ± 30	49 ± 27

[a] The data correspond to the archive [20].

site. Some results of this study are consistent with archival data [19]. Retrospective analyses were made of the formation of the radiation situation in the population points of the south-east district of the Semipalatinsk region as a result of nuclear weapons testing. In Table 3, data of dose estimations from 1966, 1967 and 1973 are shown. The territories of the Makanchi, Urdzhar and Taskesken districts were contaminated by local radioactive fallout from atmospheric and surface explosions conducted at the Lop Nor test site. This was confirmed by the appearance of freshly produced fission products, particularly iodine radioisotopes, ^{90}Sr and others in the environment.

CONCLUSION

This study contains the results of ESR dosimetry estimation of the exposed population in the Semipalatinsk region. Higher average excess doses were determined in Dolon and Semipalatinsk for residents whose tooth enamel was formed before 1949. Results of dose estimation from Dolon samples are in agreement with the fact that this village is located closer to the axis of the radioactive trace. A result from Semipalatinsk needs special investigation. The dosimetry investigation of Kurchatov city residents needs additional study, owing to an insufficient number of samples. Compared with samples from Kokpekty village, which were chosen as controls, higher average excess doses were obtained for Znamenka, Ust-Kamenogorsk city and Shemonaikha. This is in agreement with the fact that Znamenka village and Ust-Kamenogorsk city are located close to the axis of the radioactive trace, but Shemonaikha is located about 70 km from it. It is necessary to note that the investigated area is well known for its active uranium processing plant. This may explain why higher values have also been found for samples from Shemonaikha. At Tavriya and Gagarino no uranium enterprises exist and, accordingly, the measured doses are consistent with the independent estimates of external doses from the fallout that can be found in the literature.

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