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Around Semipalatinsk Nuclear Test Site: Progress of dose Estimations Relevant to the Consequences of Nuclear Tests

(A summary of 3rd Dosimetry Workshop on the Semipalatinsk Nuclear Test Site Area, RIRBM, Hiroshima University, Hiroshima, 9-11 of March, 2005)

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Retrospective dosimetry/Semipanalatinsk/Nuclear tests/Health consequences of irradiation.

The paper is an analytical overview of the main results presented at the 3rd Dosimetry Workshop in Hiroshima (9–11 of March 2005), where different aspects of the dose reconstruction around the Semipalatinsk nuclear test site (SNTS) were discussed and summarized.

The results of the international intercomparison of the retrospective luminescence dosimetry (RLD) method for Dolon' village (Kazakhstan) were presented at the Workshop and good concurrence between dose estimations by different laboratories from 6 countries (Japan, Russia, USA, Germany, Finland and UK) was pointed out. The accumulated dose values in brick for a common depth of 10 mm depth obtained independently by all participating laboratories were in good agreement for all four brick samples from Dolon' village, Kazakhstan, with the average value of the local gamma dose due to fallout (near the sampling locations) being about 220 mGy (background dose has been subtracted).

Furthermore, using a conversion factor of about 2 to obtain the free-in-air dose, a value of local dose ~440 mGy is obtained, which supports the results of external dose calculations for Dolon': recently published soil contamination data, archive information and new models were used for refining dose calculations and the external dose in air for Dolon village was estimated to be about 500 mGy.

The results of electron spin resonance (ESR) dosimetry with tooth enamel have demonstrated the notable progress in application of ESR dosimetry to the problems of dose reconstruction around the Semipalatinsk nuclear test site. At the present moment, dose estimates by the ESR method have become more consistent with calculated values and with retrospective luminescence dosimetry data, but differences between ESR dose estimates and RLD/calculation data were noted. For example mean ESR dose for eligible tooth samples from Dolon' village was estimated to be about 140 mGy (above background dose), which is less than dose values obtained by RLD and calculations. A possible explanation of the differences between ESR and RLD/calculations doses is the following: for interpretation of ESR data the "shielding

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and behaviour" factors for investigated persons should be taken into account. The "upper level" of the combination of "shielding and behaviour" factors of dose reduction for inhabitants of Dolon' village of about 0.28 was obtained by comparing the individual ESR tooth enamel dose estimates with the calculated mean dose for this settlement.

The biological dosimetry data related to the settlements near SNTS were presented at the Workshop. A higher incidence of unstable chromosome aberrations, micronucleus in lymphocytes, nuclear abnormalities of thyroid follicular cells, T-cell receptor mutations in peripheral blood were found for exposed areas (Dolon', Sarjal) in comparison with unexposed ones (Kokpekty). The significant greater frequency of stable translocations (results of analyses of chromosome aberrations in lymphocytes by the FISH technique) was demonstrated for Dolon' village in comparison with Chekoman (unexposed village). The elevated level of stable translocations in Dolon' corresponds to a dose of about 180 mSv, which is close to the results of ESR dosimetry for this village. The importance of investigating specific morphological types of thyroid nodules for thyroid dosimetry studies was pointed out.

In general the 3rd Dosimetry Workshop has demonstrated remarkable progress in developing an international level of common approaches for retrospective dose estimations around the SNTS and in understanding the tasks for the future joint work in this direction.

In the framework of a special session the problems of developing a database and registry in order to support epidemiological studies around SNTS were discussed. The results of investigation of psychological consequences of nuclear tests, which are expressed in the form of verbal behaviour, were presented at this session as well.

INRODUCTION

At the last meeting of this workshop, the 2nd Dosimetry Workshop on the Semipalatinsk Nuclear Test Site Area, that was held in 2002 (Helsinki, Finland), it was concluded that there were significant differences in estimates of cumulative dose for areas affected by nuclear tests at the Semipalatinsk Nuclear Test Site (SNTS), depending on the particular method of retrospective dosimetry used. Following this meeting and also a subsequent meeting on the topic held in Hiroshima (in the framework of the 9th Hiroshima International Symposium, 2004), the organization of an international intercomparison of retrospective luminescence dosimetry (RLD) was agreed. This was to be based on the testing of brick samples collected from the village of Dolon' in the Semipalatinsk region of Kazakhstan. Dolon' is the most heavily contaminated inhabited settlement in the region, largely due to the nuclear test of 29 August 1949. The results of this intercomparison were discussed in the framework of the current, 3rd Dosimetry Workshop (Hiroshima, March 2005). Dose estimates obtained by computational modeling, by ESR tooth enamel dosimetry, by the methods of biological dosimetry (chromosome aberrations, T-cell receptor (TCR) mutation frequency) and radioactive contamination data relevant to dose estimations were presented and discussed as well. Different consequences of nuclear tests (radiation effects on the thyroid gland, psychological aspects based on the analysis of verbal data) were reported in a related research activities session. It was concluded at the 3rd Dosimetry Workshop that there is notable progress in retrospective dosimetry around the SNTS: RLD data obtained independently by the Labs in Japan, Russia, USA, Germany, Finland and UK are very consistent with each other and instrumental estimations of external dose in Dolon' village are close to the computed dose values.

RETROSPECTIVE LUMINESCENCE DOSIMETRY SESSION

Laboratories from six countries participated in an international intercomparison of luminescence measurements with samples of brick obtained from four buildings in the settlement of Dolon' Kazakhstan. The primary purpose of the work was to compare determinations of the cumulative absorbed dose, D_T, from a common depth range in the brick and also to examine the cumulative dose as a function of depth from the brick surface to confirm the presence of an external gamma radiation field arising from the decay of artificial radionuclides within fallout products.

At the 3rd Dosimetry Workshop on the Semipalatinsk Nuclear Test Site Area[1)] the description of the samples and sampling procedure, and the outcome of the luminescence measurements were presented and discussed during the Retrospective Luminescence Dosimetry session.[2,3,4,5)] The purpose of this part of the summary is to provide a brief overview of the outcome.

The following authors contributed to the session in five presentations (speakers underlined):

1. V. Stepanenko, M. Hoshi, A. Sakaguchi, M. Yamamoto, K. Apsalikov, B. Gusev, T. Kolizshenkov and H. Jungner;[2)]
2. H. Sato, M. Hoshi and J. Takada[3)] (Japan);
3. S. Simon, S. McKeever, M. Blair and A. Bouville[4)]

(USA);
4. H. Göksu, V. Stepanenko, I.K. Bailiff and H. Jungner,[5] (European supported measurement group: GSF, Germany; MRRC, Russia; Durham University, UK; Helsinki University, Finland);
5. L.Heide, S. Bauer, A. Galheimer, D. Gusev, B. Groshe[6] (Federal Office for Radiation Protection, Gemany).

In this summary we refer to five papers[4,7,8,9,10] that contain descriptions of sampling and brick samples and results of the experimental work relevant to international intercomparison and to presentation[6] with the results of RLD from bricks, which were not included in the intercomparison.

Methodology of RLD

Thermoluminescence (TL) and optically stimulated luminescence (OSL) techniques were applied to quartz grains extracted from various depths in each brick to determine the total cumulative absorbed dose, D_T. The latter is the sum of dose contributions[10] from both natural and artificial radionuclides in the vicinity of the sampling location:

$$D_T = D_X + D_{BG}, \quad (1)$$

where D_X and D_{BG} are the cumulative absorbed doses due to artificial and natural lithogenic radionuclides respectively.

In three papers[8,9,10] the external nature of the irradiation due to gamma rays from artificial radionuclides was verified by the measurement of depth-dose profiles. To produce these profiles, the cumulative dose due to natural background radiation, D_{BG}, was assessed, based on the age of the building and, assessment of the concentrations of radionuclides of lithogenic origin within the bricks and the surrounding environment and estimated dose rates, or based on measurements made in the deep shielded layers behind the external surface of the bricks. Tentative values of cumulative absorbed dose since the onset of the delivery of fallout, D_X, were calculated using Eqn. 1. Göksu *et al.*[8] estimate the cumulative absorbed doses in air in the reference location, ${}_{RL}D_X$, using a conversion factor estimated on the basis of previous work.[10]

In addition to results for samples distributed for this intercomparison, reference is made to relevant results from samples that were collected in 1999 from Dolon' village and studied as part of EU-supported research.[10]

The samples[2,7]

Whole bricks were obtained for the intercomparison by a team of specialists from Kazakhstan and Japan during September and October 2002. Four bricks were taken from three selected buildings located in the southeastern part of Dolon' village; they were the School (1 brick), the Small Church (1 brick) and the Large Church (2 bricks). It should be noted that all samples were taken from buildings, which are located relatively close to each other in the village.[7,11] Slices cut from these bricks were then distributed between six laboratories in Finland, Germany, Japan, Russia, UK and USA for luminescence measurements. The distribution of all samples was completed during June, 2003.

Photographic records of the sampled buildings, their geographic coordinates and available ^{137}Cs soil contamination data near the sampled buildings were presented.[7,11] It should be noted that between 1997 and 1999 brick samples had been taken from the Large Church by specialists from the European Supported Measurement Group (Durham University, GSF, University of Helsinki, MRRC of RAMS) and by scientists from IRBM (Hiroshima University), the results from which have been published.[10,12,13]

Details of the handling of the samples following extraction, including marking of the orientation, packaging and transfer from Semipalatinsk, Kazakhstan, to MRRC of RAMS, Obninsk, Russia were described.[2,7] At MRRC (Obninsk, Russia) each brick was cut under red light into seven slices using a low speed water-lubricated diamond saw; the cuts provided each laboratory with slices containing the front and back surface of the brick to enable depth-dose measurements to be performed. The orientation of the bricks was marked on each slice. The samples and documentation were transferred to the University of Helsinki by car and thence onwards to each participating laboratory. At this stage it was not revealed that two bricks had been taken from the same wall (The Large Church). One slice from each brick, (a total of four slices) were retained in Obninsk for reference purposes. Consequently each laboratory was provided with one cut slice taken from each of the four bricks collected at different locations.

Japanese Laboratory[9]

The results of dose estimations by RLD method using four bricks extracted in Dolon' village for international intercomparison were reported as a depth-dose profiles in the bricks. The description of the thermo-luminescence (TL) method was presented. The natural background dose was estimated for each brick using estimated dose rates and information about the ages of the bricks. The fallout dose values obtained after subtraction of background dose at the depth of 10 mm from the front surfaces of the bricks at specific locations were estimated to be in the range from 217 mGy to 309 mGy (the averaged value over four bricks is equal to 249 ± 45 mGy).

National Cancer Institute/Oklahoma State University (USA)[4]

Dose estimates were obtained using OSL signals. The background dose was determined by measurements made in the layers from 95–105 mm behind the external surfaces of the bricks. The dose from radioactive fallout was estimated by the difference between the absorbed dose within the layer of 5–15 mm below the surface and the dose at 95–105 mm.

The mean local dose (averaged over 4 brick samples) from fallout was estimated to be 210 ± 120 mGy for 10 mm depth in the bricks (with a range of 170–310 mGy).

European supported Measurement Group[5)]

The dose estimations, performed using TL and OSL techniques, were obtained independently by four laboratories: GSF-Forschungszentrum für Umwelt und Gesundheit (Institut für Strahlenschutz, Germany), MRRC of RAMS, Obninsk (Russia), the University of Durham (UK) and the University of Helsinki (Finland). The variance of dose for various sections of the same brick measured by four laboratories was found to be about ±10%, and within these limits no systematic difference between OSL and TL determinations was found. After subtraction of the estimated value of D_{BG}, the fallout dose at a depth of 10 mm from the brick surface was estimated to be 204 ± 15 mGy where this represents the mean value of the four intercomparison bricks in Dolon' (with a dose range of 190–222 mGy for 10 mm depth in the different bricks).

The summary of the results obtained is presented in Table 1.

Table 1. Estimation of accumulated dose in brick at 10 mm depth averaged over four samples from three locations in Dolon' (background dose is subtracted).

RLD method of dose estimation	Dose in the brick, mGy	Reference
TL	249 ± 45	Sato *et al*. (Japan)[9)]
TL/OSL	204 ± 15	Göksu *et al*.[8)] (UK, Germany, Russia, Finland)[*)]
OSL	210 ± 120	Simon *et al*. (USA)[4)]

*) – averaged over 4 labs: Durham University (I. Bailiff *et al*., UK); GSF (Y. Göksu *et al*., Germany), MRRC (V. Stepanenko *et al*., Russia); Helsinki University (H. Jungner *et al*., Finland).

It should be noted that according to the report of Heide *et al*.[6)] (presented by B. Groshe) the RLD doses were estimated by TL measurements (fine grain technique) in brick samples from Dolon' village (former Church) and from Semipalatinsk city. The highest registered dose was 500 mGy.

Conclusion

The values of D_T obtained independently by all participating different laboratories from six countries for the common depth of 10 mm in the brick are in good agreement for all four samples, with the average value of the local gamma dose due to fallout (near the sampling locations) being about 220 mGy.

It should be noted that although the purpose of the intercomparison was to compare values of the total cumulative dose, D_T, sufficient data are available to produce tentative estimates of the cumulative gamma dose in brick due to fallout, D_X.

The results are consistent as well with a recently published determination of fallout dose for a brick sampled from one of the locations in Dolon' (Large Church) included in the intercomparison.[10)]

Furthermore, using a conversion factor of about 2 to obtain the free-in-air dose,[4,10)] a value of local dose ~440 mGy is obtained, which supports the recent results of external dose calculations for Dolon' (about 500 mGy of external dose in air).[11,14,15)]

ESR DOSIMETRY WITH TOOTH ENAMEL SESSION

The main subject of the ESR session was dose determination using the ESR tooth enamel dosimetry method for residents in the vicinity of the Semipalatinsk nuclear test site. Results of methodical investigations aimed on improvement of the accuracy of the ESR dosimetry method and results of bio-dosimetry (FISH chromosome painting method) in comparison with results of the ESR dosimetry were also presented in some reports. In total, eight reports were presented at the session.

One of the main topics in the session was ESR dose determination for residents of the area adjacent to the trace of radioactive fallout resulted from the most contaminating nuclear test of 1949. These are the settlements of Dolon', Mostik and Bodene of the Semipalatinsk region, Kazakhstan. These settlements are located at a distance of about 100 km northeast from the test site. Dolon' is located close to the centerline of the radioactive fallout trace, Bodene and Mostik, about 10 km away from the axis.

Results of ESR dose measurements for Dolon' (22 samples) and Mostik (17 samples) are presented in the report of A. Ivannikov *et al*.[16)] Results for Dolon' (4 samples), Bodene (19 samples) and a control territory of the Kokpekty district (4 samples) were presented in the report of K. Zhumadilov *et al*.[17)] These results are given in the corresponding papers in this issue. Excess doses caused by technogenic radiation, were obtained from experimental absorbed doses after subtraction of contribution of natural background radiation during the period after enamel formation.

In the course of discussion, results of excess dose determination by the ESR method for 9 samples from Dolon' were presented by S. Simon from the National Cancer Institute (NCI, USA). These results are given in Table 2. Birth years of tooth donors were not given. It was known only that they have enamel formed before 1949, and for obtaining excess doses, the contribution of the natural background dose was subtracted from the experimental adsorbed doses as estimated according to an average age of tooth enamel of 63 yrs and an annual dose of 1.0 mGy yr^{-1}.

Table 2. Results of excess ESR dose measurements for Dolon' population presented by S. Simon. (NCI, USA). All teeth formed before 1949.

N	1	2	3	4	5	6	7	8	9
Tooth position	6–8	6–8	4–5	4–5	6–8	1–3	6–8	1–3	4–5
Excess dose (mGy)	125	118	77	45	141	66	156	308	58

Results of ESR dose measurements for inhabitants of some settlements in the Semipalatinsk region were presented in the report of S.Pivovarov.[18] Among them there are results for Dolon' and Mostik (Table 3). For Dolon', 6 samples measured were collected from persons with birth years 1967–1983; doses absorbed in enamel are in the range from 0 to 540 ± 200 mGy. For Mostik, 2 samples were measured; doses obtained were 800 ± 300 mGy (1930 birth year), and 580 ± 200 mGy (1951 birth year). Unfortunately, only one of these samples is a testament to the test of 1949 (the sample belongs to a person from Mostik born in 1930). Results were also presented for another district subjected to radiation after the later tests (Maisk settlement): 8 samples in total were measured; doses were in the range from 0 to 960 ± 250 mGy for persons of 1947–1962 birth years. For Sarjal settlement (22 samples), the bulk of doses are in the range from 0 to 540 mGy, one dose is of 1200 mGy. Results of chromosome aberration analysis are also presented for the same persons from Sarjal, and no correlation with ESR doses was observed. Ages of tooth donors and errors of dose determination are not reported for this settlement, which caused difficulty on analytical assessment of these results.

A summary of the results for the settlements in the vicinity of the trace of the nuclear test of 1949 (Dolon', Mostik, Bodene) is presented in the histogram distributions in Fig. 1. The reasons of anomalous high doses obtained for Mostik reported by Ivannikov[16] and Pivovarov[18] for persons with enamel formed before 1950 and for younger persons reported by Pivovarov[18] are not clear. Probably, other extra effects, in addition to effects of contamination by the nuclear test of 1949 may cause these high doses, and these results need special analysis. To exclude artifacts connected with the ESR method application, these high doses may be explained by the effects of medical X-ray examination, or by being in places with high radioactivity. For understanding the reason of appearance of these high doses, additional information about the behaviour of the teeth donors in the radioactive contaminated territory is necessary.

A bimodal distribution is observed for the Dolon' population group with enamel formed before 1950 (Fig. 1a). It may be explained by supposing that only part of population was exposed in 1949–1950. During this period after the nuclear test of 1949, the major contribution to the dose accumulated, because of decay of radionuclides in the fallout trace. Probably, only part of the population of this area was subjected to irradiation. This accords with the high heterogeneity of contamination caused by the narrow width of the radioactive trace (Stepanenko *et al.*,[11] Imanaka *et al.*[19]). Part of the distribution from 250 to 450 mGy may be attributed to the exposed population ($<D_{ex}>$ = 354 ± 27 mGy). Part of the distribution (below 200 mGy) represents a population slightly exposed in 1949–1950 ($<D_{ex}>$ = 67 ± 8 mGy). The population of Bodene and Mostik with enamel formed before 1950 (Fig. 1b, $<D_{ex}>$ = 38 ± 13 mGy) and the younger population group (Fig.1c, $<D_{ex}>$ = 32 ± 8 mGy) possess lower doses, which indicate that they were not exposed in the given period.

The results of ESR dosimetry may be compared with the results of dose reconstruction by other methods. In earlier publications (see for example the previous Helsinki Dosimetry Workshop[20]) external dose estimations ranging from 1000–2200 mGy were given for Dolon' based on dose reconstruction models using archival records of exposure rates in September 1949. According to results presented in the present Workshop, the calculated doses were revised because of refining the location of the radioactive trace and modification of the models.[11,14,15] New retrospective luminescence dosimetry (RLD) data were presented during this workshop as a part of the international intercomparison of the RLD method.[2–9] The value of external dose in the air for

Table 3. Results of determination of absorbed doses in enamel by ESR for Dolon' and Mostik from report of S. Pivovarov.[18]

N	1	2	3	4	5	6	7	8
Residence	Dolon'	Dolon'	Dolon'	Dolon'	Dolon'	Dolon'	Mostik	Mostik
Birth year	1983	1947	1949	1964	1956	1955	1930	1951
Tooth position	7	6	6	7	6	8	5	6
Total dose, mGy	550	500	560	370	< 100	< 100	800	580
SD, mGy	150	150	200	200	100	100	300	200

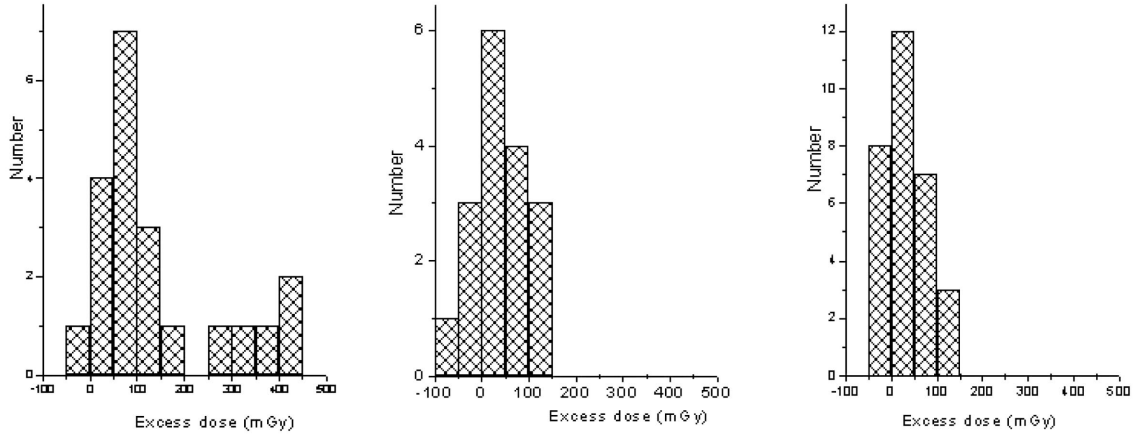

Fig. 1. Histogram distributions of EPR excess doses: (a) For residents of Dolon' only, enamel formation before 1950 (N = 21, <Dex> = 138 ± 39 mGy): distribution of low doses – in the range below 200 mGy (N = 16, <Dex> = 67 ± 12 mGy); distribution of high doses – in the range of 250–450 mGy (N = 5, <Dex> = 362 ± 32 mGy). (b) For residents of Bodene and Mostik, enamel formation before 1950 (N = 17, <Dex> = 38 ± 13 mGy). (c) For residents of Dolon', Bodene, Mostik, enamel formation after 1950 (N = 30, <Dex> = 32 ± 8 mGy).

Dolon' village was estimated by different methods (calculations and RLD) to be in the range of 300–770 mGy.[11,14,15,2–9] Therefore, high ESR doses for Dolon' attributed to the exposed population group are very close to the results of other methods. Slightly lower ESR doses may be caused by that part of time in the period after the test when the inhabitants of Dolon' were sheltered in their houses. An additional reason for the difference – possible relocation of the persons from contaminated territory. Such a kind of combination of "shielding and behaviour" factors was discussed and estimated in the report of Stepanenko *et al.*[11] by comparison of calculated doses with doses obtained by ESR tooth enamel dosimetry.

Other factors affecting the results of the method were also presented by Pivovarov *et al.*[18] A high variation of enamel sensitivity (ESR signal dose response) was noticed for the samples investigated (35% mean square deviation). It was indicated that the sensitivity is correlated with enamel density (which varied in the range of 2.3–2.9 g cm^{-3}). No correlation of the sensitivity with age of tooth donors was detected. It was indicated that sensitivity is reduced after chemical treatment by acidic liquids (dry wine, acetic, lactic acids). It should be noted that in the literature concerning ESR dosimetry (see for example IAEA Technical Document[21]) there are no indications of such a high variation of sensitivity dependent on tooth enamel density. A high reduction of enamel sensitivity was detected only for samples prepared from caries-damaged teeth by dissolving dentin using intensive ultrasonic treatment in concentrated alkaline solution. In the work reported, samples were prepared by a mechanical method, and according to information from the author, no special check was performed to test thoroughness of removal of dentin from enamel after sample preparation. It is not excluded therefore, that variation of enamel density and, consequently, variation of sample sensitivity is caused partially by presence of remnant dentin and caries-damaged enamel in the samples. Sensitivity variation is a very important point at ESR dosimetry, and this matter should be further investigated. Methods of control of quality of sample preparation should be developed and applied, and also variation of enamel density and enamel sensitivity should be investigated more deeply.

In the report of Romanyukha *et al.*,[22] problems of application of methods of individual dose reconstruction (ESR and FISH) to population in the vicinity of the SNTS is discussed. It is pointed out that ESR gives smaller dose values in comparison with results of dose reconstruction by other methods, such as model dose reconstruction based on the exposure rates measurements in the period of tests and thermoluminescent dosimetry, especially for Dolon'. It is suggested that reasons of these discrepancies may be that either methods of individual dose reconstruction (ESR and FISH) underestimate doses, or the model dose reconstruction methods overestimate doses received by the population. Probable reasons of underestimation by ESR and FISH are that people available now for collection of samples are not representative because they received lower than average doses, or for other statistical reasons, or because problems occurred at sample collection, such as residents with high doses had died already, etc. However, after revision of dose reconstruction results as was reported in the present workshop, good agreement of dose reconstruction results with ESR doses is observed. In any case, the analysis presented in this report and its recommendations should be taken into account when

organizing collection of teeth samples for ESR dosimetry.

In the report of Skvortsov *et al*,[23] experience of the application of the ESR dosimetry method to wide-scale dosimetric inspection of populations is summarized. The main aspects of applying this method to the population in the vicinity of the SNTS are analyzed basing on the experience obtained applying this method in other radiation accidents. It was noted that radioactive contamination was highly irregular and existed for a relatively short period after tests. Therefore, during analysis of results it is important to take into account migration of tooth donors in the period of tests and the period of enamel formation. That can be determined from the age of the persons and the type of teeth collected. Special efforts should be taken when converting absorbed doses in enamel to effective doses. For that, it is necessary to take into account real radiation fields acting in the period of tests basing on the isotope content in the environment and in the human body together with its dynamic change. Besides, possible unique of tooth enamel properties in this geographic region, such as radiation sensitivity, line shape variation of the native signal and of the radiation-induced signal in enamel should be taken into account for correct dose determination.

In the report of Toyoda *et al*.,[24] some results of methodical investigations are presented concerning the possibility of using analysis of radioactive isotopes incorporated by mammals in the Semipalatinsk region and study of mammal teeth for retrospective local dose assessment. Conditions of enamel sample preparation from cow teeth were investigated in order to improve sensitivity of the ESR dosimetry method. It was shown that treatment by alkaline solution leads to decreasing the native signal in enamel attributed to the organic component, and there are some optimal conditions of sample treatment, which leads to increased sensitivity when using enamel. The possibility of determination of radioactive isotopes is demonstrated using the example of ^{90}Sr in cow teeth taken in South Ural region, Russia.

In the second report of Pivovarov *et al*.,[25] some results of investigation of soil samples from the SNTS are presented. It is pointed out there is a high concentration of paramagnetic centers in the soil. The authors use this parameter for estimation of dose burden on soil in the southeastern direction from the SNTS. At distances from 0 to 100 km from the test area, doses based on concentration of paramagnetic centers in flint were estimated to be in the range of 6 to 18 kGy. These doses are too high to be explained as induced by radiation from radioactive traces after the tests. Probably, the high concentration of paramagnetic centers is caused by admixture in the soil of particulate matter fallen out from the radioactive cloud, in which a high concentration of paramagnetic centers is formed near the center of explosion, and then transported to the place of precipitation.

In the report of Sevan'kaev *et al*.[26] (presented by I. Khvostunov), method aspects of the application of ESR-dosimetry and biodosimetry (FISH chromosome painting method) for retrospective dose estimation were discussed. Using the example of persons subjected to overexposure as a result of nuclear accidents in Chernobyl in 1986 and in nuclear submarines during the years 1961–1985, it was shown that results of ESR dosimetry correlate with results of biodosimetry and results of dose reconstruction based on dosimetry records.

Interesting data were presented in the paper of Tanaka *et al*. (RIRBM, Japan).[27] The influence of the X-ray baggage scan on the ESR signal in tooth enamel samples transported form Kazakhstan to Japan via Korean Incheon Airport (which is the typical route of sample transportation) was investigated. It was concluded in this study that the effect of X-ray scanning is negligible for the results of ESR dosimetry using tooth enamel samples from residents near the SNTS. These data are important for interpretation of dose estimations by the ESR tooth enamel dosimetry method.

Conclusion

The reports presented during this session have demonstrated the notable progress in application of ESR dosimetry with tooth enamel to the problems of dose reconstruction around the Semipalatinsk nuclear test site. At the present moment, dose estimates by the ESR method have become more consistent with calculated values and with retrospective luminescence dosimetry data. For interpretation of ESR data the shielding and behaviour factors for investigated persons should be taken into account.

DOSE ESTIMATIONS BY CALCULATIONS/ RADIOACTIVE CONTAMINATION SESSION

Radioactive Contamination data

Results of the estimations of radioactive contamination in the vicinity of Semipalatinsk nuclear test site and within the SNTS were presented in the following three reports: Yamamoto *et al*.,[28] Semioshkina *et al*.,[29] Sakaguchi *et al*.[30]

Data of Yamamoto *et al*.:[28]

- Vertebral bone samples were collected at autopsy from more than 100 residents; $^{239+240}$Pu concentrations were estimated as not markedly high (being mainly due to the global fallout) in comparison with reported data from other countries.
- The levels of ^{238}U activity were found to be several times higher than the levels of plutonium activity and a marked disequilibrium was observed for ^{234}U/^{238}U activity ratios.

Semioshkina *et al*.[29] data:

- Information about ^{137}Cs, ^{90}Sr contamination of soil, vegetation, horse milk and meat within the SNTS in connection with an assessment of current internal dose was presented. Whole body counting was conducted for comparison with

the calculated dose.
- The data obtained are important in order to evaluate the current and future risk to the people, who are living on and using the contaminated areas.

Sakaguchi *et al*. data[29]:
- ^{137}Cs and $^{239+240}$Pu soil contamination in Dolon', Mostik, Cheremushki and Budene settlements was estimated; the locations of the soil sampling spatial points were determined by GPS.
- Contamination data are very detailed and are in agreement with available published data.
- Soil contamination data in combination with GPS data are very useful for external dose calculation, especially in Dolon' village, which is the subject of RLD International Intercomparison.

It should be noted that interesting quantitative methodology for estimation of ^{90}Sr concentration in teeth samples was demonstrated by Tieliewuhan *et al*[31] using cow teeth samples taken from South Ural (Russia) radioactive contaminated region. This report was presented in the frame of a "Related research activity session". The Imaging Plate (IP) technique which uses the Monte Carlo code (MCNP) to convert IP response to ^{90}Sr concentration with varied thickness of the standard source has been proposed in this study. The estimated specific activity in teeth samples was equal to 0.11–0.12 Bq/g. This technique can be used for interpretation of the ESR tooth enamel data - accounting for additional irradiation of teeth by internal beta irradiation from ^{90}Sr.

Dose estimations by calculations

Results of external dose calculations in the vicinity of SNTS were presented in the following reports:

Imanaka *et al*.,[14] Gordeev *et al*.[32] (presented by S. Shinkarev), Simon *et al*.,[15] Stepanenko *et al*.[11] and Orlov *et al*..[33]

The methodology of estimation of exposure to the thyroid was presented by S. Shinkarev in the report of Gordeev *et al*.[34] This methodology is not related to the matter of external dose estimations, but it should be noted that further development and application of this methodology is very important for dosimetric support of epidemiological studies of thyroid diseases in the vicinity of the SNTS.

Imanaka *et al*.[14] data:
- The estimation of the external accumulated dose for Dolon' village was performed on the basis of available ^{137}Cs soil contamination data by calculations of the input to dose from 29 gamma-emitting radionuclides from ^{239}Pu fission and by calculation of temporal change in the fission product composition.
- External dose in the air of about 500 mGy for Dolon' village was evaluated as a probable value as a result of the fallout from the 29 August 1949 test.

Gordeev *et al*.[32] data:
- In the frame of an analysis of 111 tests conducted at SNTS, special attention was given to Dolon' village and to the 29 August 1949 test;
- The method of external dose calculation on the base of archival exposure rate data was described;
- Absorbed dose in the air presumably associated with the axis of radioactive trace near Dolon' village can be estimated as about 2300 mGy on the base of the data, which are presented in the report.

S. Simon *et al*.[15] data:
- A joint U.S./Russian methodology of external dose estimates based on the exposure rate functions derived from U.S. nuclear test U.S. data (TRINITY test) was described.
- In the case of 29 August 1949 test the average external dose for a person in Dolon' is estimated to be about 500 mGy, which agrees much better with the reported ESR and RLD data.

Stepanenko *et al*. data and Orlov *et al*. data:[11,33]
- Spatial distributions of soil contamination by ^{137}Cs (89 sampling points in total) and $^{239+240}$Pu (76 points in total) near and within Dolon' village were analyzed. An essential exponential decrease of contamination was found in Dolon' village: the distance of a half reduction of maximum soil contamination is about 0.87–1.25 km (in a northwest-southeast direction from the supposed centreline of the radioactive trace, orthogonal to the centreline).
- The gradient of external dose along Dolon' from northwest to southeast direction was estimated:[11]

a) On the base of archival exposure rate data the absorbed dose in the air, associated with the supposed position of the centreline of radioactive trace near Dolon' is equal to 2260 mGy;
b) Local doses near the RLD sampling points (at a distance of 1.82 km from the supposed centreline of the trace orthogonal to the trace to the southeast direction in the village) were calculated to be in the range 466–780 mGy (averaged value: 645 ± 70 mGy), which is comparable with RLD data.

- A comparison of the computed mean dose in the settlement with dose estimates by ESR tooth enamel dosimetry makes it possible to estimate the "upper level" of the "shielding and behaviour" factor in dose reduction for inhabitants of Dolon' village which was found to be 0.28 ± 0.068.[11]

The summary of external dose estimations in the air in Dolon' village is presented in Table 4.

As a result of discussions between participants of this session the following general conclusions were made.

Table 4. Results of calculations of external dose in Dolon' village by different methods.

Method of dose estimation	Distance from the trace	Dose	Reference
Russian archive exposure rate data	On the trace – 0 km	2300 mGy	Gordeev *et al*.[32]
^{137}Cs in soil and fission products	Average in the village	~ 500 mGy	Imanaka *et al*.[14]
U.S. TRINITY test dose rate function	Average in the village	~ 500 mGy	Simon *et al*.[15]
Russian archive exposure rate and gradient of ^{137}Cs and $^{239+240}$Pu soil	On the trace – 0 km	2260 mGy	Stepanenko *et al*.[11]
contamination in the village	In the village – 1.82 km from the trace	645 ± 70 mGy	Stepanenko *et al*.[11]

General Conclusions:
- New soil contamination data are extremely useful for more correct dose calculation.
- New calculations of external dose in Dolon' village, which were provided by different independent groups (about 0.5 Gy), are in much better agreement with instrumental dose estimates by RLD and ESR methods.
- More detailed further investigations of soil contamination in the vicinity of SNTS are very desirable.

BIOLOGICAL DOSIMETRY ("CHROMOSOME SESSION")

There are two reports, which were presented in the framework of this session: by Tanaka *et al*. (IES, Japan)[35] and by Chaizhunosova *et al*.[36] Two additional reports relevant to biological dosimetry were presented by Takeichi *et al*.[37] and Taooka *et al*.[38] in the setting of a "Related research activity session".

In the study of Tanaka *et al*.[35] a higher incidence of unstable-type chromosome aberrations and micronucleus in lymphocytes were found in residents of the exposed areas (Dolon', Sarjal, Kaynar) in comparison with an unexposed area (Kokpekty). According to the authors' suggestion one of the possible explanation of this finding is the internal irradiation of the body by long-lived radionuclides in contaminated territories.

The Chaizhunusova *et al*. study[36] was performed among populations in Dolon' and Chekoman villages. The village of Chekoman is considered to be relatively less affected by radiation than Dolon'. The life styles of the residents are similar in both villages. Analyses of chromosome aberrations in lymphocytes collected from the residents of the two villages were performed by the FISH technique. The results obtained showed that the average frequency of stable translocations for the Dolon' group was significantly greater that of the Chekoman group. The elevated level of stable translocations with the Dolon' residents corresponds to a dose of about 180 mSv, which is quite close to the results of ESR tooth enamel dosimetry for the population of this village.

Chromosomal studies in peripheral lymphocytes from 63 residents with ages of 52–63 years near the Semipalatinsk nuclear test site, were performed by Takeichi *et al*.[37] in 2001–2002. A higher rate of chromosome aberrations was observed in the two contaminated villages, Dolon' and Sarjal, compared with the control village, Kokpekti. The same was found for apparent nuclear abnormalities (ANA) of thyroid follicular cells (studied in 30 out of 63 residents, who were examined for chromosome aberrations). The high rate of ANA in thyroid cells in parallel with the high rate of chromosome aberrations in peripheral lymphocytes among the same subjects in Dolon' and Sarjal, may suggest that some late radiation effects were induced in the residents near the SNTS after the nuclear explosion tests. A relationship of frequency of cells with radiation induced chromosome aberrations and the previously estimated exposure dose was observed. This study may be the first to report late radiation effects on thyroid follicular cells, based on information on lymphocyte chromosome aberrations in the area near the SNTS. The higher frequencies of lymphocyte chromosome aberrations in Dolon and Sarjal indicate a significant radiation exposure and at the same time late radiation effects were induced in the thyroid follicular cells in the residents near the SNTS. The analysis of ANA in thyroid cells may also be able to be one of the methods of biological dosimetry in this area.

Taooka *et al*.[38] reported the first evidence of increased T-cell receptor (TCR) mutations in peripheral blood from radiation-exposed residents in Dolon' and Sarjal in comparison with the control group (Kokpekti). According to the authors, the TCR mutation assay appeared to be a useful biological dosimeter even 40 years after radiation exposure. This may be the result of the presence of long term internal exposure.

ESTIMATION OF CONSEQUENCES OF NUCLEAR TESTING ("RELATED RESEARCH ACTIVITIES SESSION")

One of the papers presented in this session (Zhumadilov,[39] Semipalatinsk State Medical Academy) was devoted to application of ultrasound devices with high resolution and cytopathological investigation of thyroid lesions for identification of particular morphological types of thyroid nodules among exposed and non exposed populations living around the Semipalatinsk nuclear test site in order to estimate relationships between specific types of nodules and radiation dose. It was pointed out that considering specific morphological types of thyroid nodules would be interesting and possibly more informative for investigation of the radiation induced consequences of nuclear tests and for thyroid dosimetry studies in so far as the radiation risk for thyroid nodules is higher than the radiation risk for radiation thyroid cancer.

Two reports in this session were devoted to the current status and problems of developing of a database (Katayama *et al*.[40]) and registry (Apsalikov *et al*.[41]) in order to support epidemiological studies around the SNTS.

According to the paper of Katayama *et al*.[40] there are two major problems in order to achieve the principal aim – to conduct comprehensive epidemiological research. The first is to overcome the gap between the number of registrations in the developing database and the number of data entries in the INCO-COPERNICUS database. Otherwise it is difficult to prove the accuracy and reliability of data needed for epidemiological research. The second problem is to establish a special committee of statisticians and epidemiologists to conduct the research project from a long-term perspective and carry out the collection of data effectively.

In the presentation of Apsalikov *et al*.[41] the current status of SNST Kazakhstan registry construction was reported. The developing of this registry is being performed in collaboration with the specialists from Hiroshima University and RERF. It was pointed out that special attention should be paid to creating individual dosimetry systems to support epidemiological studies.

In the course of the same session two reports were devoted to investigation of psychological consequences of nuclear tests, which are expressed in the form of verbal behaviour: Kawano *et al*,[42,43] and Matsuo *et al*.[44]

These studies do not seem directly related to the health effects of ionising radiation, but are quite important for widening of understanding of the influence produced by nuclear tests and large-scale radiation accidents on the quality of human life. Another important aspect of these studies is the following: verbal behaviour can be an indicator (witness) of psychological stress, which results in health consequences.

The studies were conducted using questioning of radiation exposed individuals in the vicinity of the Semipalatinsk nuclear test site, Kazakhstan. The responses of 706 persons were collected in 10 affected settlements and in one control (not affected) village. The total number of collected testimonies was 468.

The paper of Kawano *et al*.[42] focused mainly upon responses to the questions concerning the experiences of the nuclear tests. The paper touched upon their concrete direct experiences of 'flash,' 'bomb blast,' 'heat,' 'rain' and 'dust'. It also discussed distinct experiences in Semipalatinsk such as evacuation, through the additional use of their testimonies. The paper also mentioned that there was a close similarity in their experiences (memory) between Semipalatinsk and Hiroshima/ Nagasaki as far as those direct experiences are concerned. Another paper of Kawano *et al*.[43] attempted to clarify health effects and mental problems among inhabitants by using their questionnaire surveys. The data in Semipalatinsk have been compared with the results obtained in a similar survey conducted by Hiroshima and Nagasaki cities. The paper of Matsuo *et al*.[44] conducted a principal component analysis of concepts by using the words which occurred most frequently in the testimonies. The paper showed a provisional, tentative overall image (perception or memory) of the experiences of nuclear tests at Semipalatinsk nuclear test site.

DISCUSSION AND MAIN CONCLUSIONS

Any epidemiological investigation of the consequences of large-scale irradiation of population needs uniform and valid methods of radiation dose estimation.

Because of limited application of experimental methods (for example, insufficient number of samples etc.) only one approach is able to be uniform for all investigated subjects – it is dose estimation based on corresponding dosimetric models.

On the other hand the dose calculations according to these models are subject to significant uncertainties in settlements where the distribution of radioactive fallout was heterogeneous, being based largely on sparse monitoring data gathered following the radiation accident or nuclear test.

This is the reason why instrumental methods of retrospective dosimetry (like RLD, ESR with tooth enamel, biological dosimetry) are very important for validation and verification of computed dose values. Nevertheless the results of experimental dose estimates needs verification as well because discrepancies between different laboratories are possible.

The 3rd Dosimetry Workshop in Hiroshima (2005) is an example where all of these aspects of dose reconstruction were discussed and summarized. The main results of the Workshop are the following.

The results of the international intercomparison of the RLD method for Dolon' village (Kazakhstan) were presented at the Workshop and good concurrence between dose esti-

mations by different laboratories from 6 countries (Japan, Russia, USA, Germany, Finland and UK) was pointed out. The accumulated dose values in brick for the common depth of 10 mm depth obtained independently by all participating laboratories were in good agreement for all four brick samples from Dolon' village, Kazakhstan, with the average value of the local gamma dose due to fallout (near the sampling locations) being about 220 mGy (background dose has been subtracted).

Furthermore, using a conversion factor of about 2 to obtain the free-in-air dose, a value of local dose ~440 mGy is obtained, which supports the results of external dose calculations for Dolon': recently published soil contamination data, archive information and new models were used for refining dose calculations, and the external dose in air for Dolon village was estimated to be about 500 mGy.

The results of ESR dosimetry with tooth enamel have demonstrated the notable progress in application of ESR dosimetry to the problems of dose reconstruction around the Semipalatinsk nuclear test site. At the present moment, dose estimates by the ESR method have become more consistent with calculated values and with RLD data, but differences between ESR dose estimates and RLD/calculations data were noted. For example mean ESR dose for eligible tooth samples from Dolon' village was estimated to be about 140 mGy (above background dose), which is less than dose values obtained by RLD and calculations. A possible explanation of the differences between ESR and RLD/calculation doses is the following: for interpretation of ESR data the "shielding and behaviour" factors for investigated persons should be taken into account. The "upper level" of the combination of "shielding and behaviour" factors of dose reduction for inhabitants of Dolon' village of about 0.28 was obtained by comparing the individual ESR tooth enamel dose estimates with the calculated mean dose for this settlement.

The biological dosimetry data related to the settlements near SNTS were presented at the Workshop. A higher incidence of unstable chromosome aberrations, micronucleus in lymphocytes, nuclear abnormalities of thyroid follicular cells, T-cell receptor mutations in peripheral blood were found for exposed areas (Dolon', Sarjal) in comparison with unexposed ones (Kokpekty). The significant greater frequency of stable translocations (results of analyses of chromosome aberrations in lymphocytes by the FISH technique) was demonstrated for Dolon' village in comparison with Chekoman (unexposed village). The elevated level of stable translocations in Dolon' corresponds to a dose of about 180 mSv, which is close to the results of ESR dosimetry for this village. The importance of investigating specific morphological types of thyroid nodules for thyroid dosimetry studies was pointed out.

In the framework of a special session the problems of developing a database and registry in order to support epidemiological studies around SNTS were discussed. The results of investigation of psychological consequences of nuclear tests, which are expressed in the form of verbal behaviour, were presented at this session as well. The main conclusions of these investigations are the following: people tend to attribute their health and mental problems to the nuclear test; current stress and a wish to abolish nuclear weapons are two essential trends, which are expressed in a form of verbal behaviour.

In general the 3rd Dosimetry Workshop has demonstrated remarkable progress in developing an international level of common approaches for retrospective dose estimations around the SNTS and in understanding of existing problems:

- The RLD method was discussed in a framework of international intercomparison and good concurrence between dose estimations by different laboratories from 6 countries was pointed out.
- The results of ESR dosimetry with tooth enamel were compared with RLD data and possible explanation of the differences was found (shielding and behaviour factors).
- Recently published soil contamination data, archive information and new models were used for refining dose calculations.
- Both RLD and ESR dosimetry methods were used for verification of dose calculations and results of comparisons showed increased consistency between experimental dose estimates and dose values calculated by models.

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