COMPARATIVE ANALYSIS BETWEEN RADIATION DOSES OBTAINED BY EPR DOSIMETRY USING TOOTH ENAMEL AND ESTABLISHED ANALYTICAL METHODS FOR THE POPULATION OF RADIOACTIVELY CONTAMINATED TERRITORIES

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A comparative analysis of radiation doses determined by tooth enamel electron paramagnetic resonance (EPR) spectroscopy and by an acknowledged analytical method is performed for individual doses and for average doses in population of some settlements of the Bryansk region (Russia), which have been contaminated after the Chernobyl nuclear accident. The analysis is performed for doses in the range of 0–200 mGy for individuals and in the range of 0–50 mGy for the averaged populations. The method of orthogonal distance linear regression is used for the analysis. For both data sets the slopes of the regression line close to unity and the intercept close to zero are obtained, which indicates that doses determined by these two methods agree with each other. The root-mean-square difference between the results of EPR and analytical methods is estimated to be 35 mGy for individual doses and 15 mGy for averaged doses, which is consistent with uncertainty of these methods.

INTRODUCTION

Determination of absorbed radiation doses in the population of territories contaminated as a result of nuclear accidents is necessary to assess the health effects and to plan rehabilitation. In the territories contaminated by the Chernobyl nuclear accident in 1986, typical determined radiation doses in the concerned population were assessed to be in the range of exposure of population to relatively low doses in the range of 0–200 mGy^(1, 2).

At present, in Russia, the main officially accepted method for retrospective dose determination in the population of radioactive contaminated territories is the analytical method⁽³⁾. This method is based on radioactivity measurements in the local environment and the human body of the individual and takes into account the consumption of radioactive products, conditions of work and habitation. The accuracy of this method is limited by the heterogeneity of the radioactive contamination, the uncertainty on the information about the consumption of the radioactive products and other personal information obtained on the basis of questionnaires. Despite the method being officially recognised, it may benefit from continuous verification to refine the applied models related to the specific exposure conditions.

Electron paramagnetic resonance (EPR) dosimetry using tooth enamel is a powerful method for providing information on exposure to ionising radiation many years after the event. This technique is of particular relevance to relatively low-dose exposure or when the results of conventional dosimetry are not available (e.g. in accidental circumstances). The use of EPR

dosimetry, as an essential tool for the retrospective assessment of radiation exposure, is an important part of radioepidemiological studies and also provides data to select appropriate countermeasures based on retrospective evaluation of individual doses^(4–6). The possibility of using this method is limited by the availability of teeth samples, which may only be obtained after removal for medical reasons. Therefore, the main objective in using EPR dosimetry is focused on determining individual doses for limited groups of population, as well as on validation of the doses obtained by the aforementioned analytical method⁽⁷⁾.

Despite the difficulty of collecting teeth samples, a large-scale examination of population in the territories of the Bryansk region of Russia, who were exposed to radioactive contamination, was performed by tooth enamel EPR dosimetry⁽⁶⁾. The obtained average doses over the settlements were compared with the level of radioactive contamination, but not with doses determined by the analytical method.

A comparative analysis of individual doses obtained by EPR and by the analytical method was conducted for the residents of the Zaborie village of Bryansk region with a high degree of pollution^(5, 7). However, the results of this analysis are to be refined using more sophisticated methods.

The aim of this paper is to demonstrate the consistency in the assessed doses using tooth enamel EPR dosimetry and the analytical method in a real situation of population exposed to radiation in contaminated territories after wide-scale radiation accidents. The comparison is performed for individual doses determined by both methods and for average doses of

populations from separate settlements and districts of the south part of Bryansk region, i.e. the most contaminated territories of Russia after the Chernobyl accident. Special attention is paid to the selection of the method for comparing the sets of data in order to find out the exact relationship between the doses obtained by these two methods.

MATERIALS AND METHODS

Description of the data used for analysis

Individual dose estimates

For the analysis of the individual doses, the results of dose determination from both tooth enamel EPR dosimetry and analytical methods in the Zaborie village were taken, according to authors' previous publications^(5, 7). In these publications, the individual doses absorbed in tooth enamel determined by EPR were compared with those determined by calculations based on the internal and external calculated whole-body doses caused by the radioactive contamination of ¹³⁴Cs and ¹³⁷Cs isotopes. For comparison of the results obtained by these two methods, the ordinary linear regression analysis was used. However, in this case both data sets had relatively high uncertainties and therefore such analysis did not result in acceptable parameters for the functional dependence. The summarised list of data based on dose values taken from refs (5, 7), which are used for analysis in the present paper, is given in Table 1.

Averaged dose estimates

For the analysis of doses for averaged over settlements, the results of dose determination by EPR in tooth enamel for the population of certain settlements of the Bryansk region were used⁽⁶⁾. Whole-body doses presented in this publication were obtained from

doses in tooth enamel determined by EPR using a conversion coefficient. These results were obtained mainly for teeth collected in the period of 1997–1998 and were not analysed up to date in comparison with calculated doses.

In the present paper, for comparison, calculated doses for the same settlements according to official reference book publications were used^(1, 2). The publications with calculated doses were selected for the periods of dose estimation in 1995 and 2001, which are the closest to the period of teeth sampling for EPR measurements. To obtain calculated doses corresponding to the period of teeth sampling, 1998 yr, the linear interpolation of the time dependence of doses was performed. Dose for the period of 1998 approximately corresponds to the average of doses for 1995 and 2001. In the cited official publications the uncertainties of calculated doses are not presented. The uncertainty of 10 % was prescribed for these doses. Such value follows from the estimation of uncertainties in the mean level of radioactive contamination for settlements^(1, 2) and uncertainties in parameters of the models used for dose reconstruction based on publications^(3, 7, 8).

In the present work, only dose values in the range of low doses up to 50 mGy were used for the analysis, because in this range no countermeasures were applied by the local administration for reduction of the irradiation of the population. Such countermeasures significantly affect the results of dose calculation, but were not taken into account while obtaining the calculated doses presented in the official publications⁽⁹⁾.

The summarised list of data on averaged doses used for the analysis is presented in Table 2.

Method of data analysis

For determining the parameters of the linear dependence in the comparison of the sets of data obtained by EPR and analytical methods, the orthogonal distance linear regression (ODR) method was applied. The principles of this method are described in several publications^(10, 11).

The ODR method is the most appropriate to use in case of a comparison of two data sets both having uncertainties comparable in values. In general, this method minimises the sum of squared distances between the regression line and experimental points weighed by their uncertainties.

$$Q_{\text{ODR}} = \sum_i \left(\frac{\Delta Y_i^2}{U_{Y_i}^2} + \frac{\Delta X_i^2}{U_{X_i}^2} \right),$$

where $\sum_i$ is the summation over all data points; ΔY_i and ΔX_i are vertical and horizontal distances from the experimental point to the regression line; U_{Y_i} and U_{X_i} the uncertainties in Y_i and X_i , reciprocal values of which produce the weighting factors.

Table 1. Individual doses in tooth enamel determined by the analytical method (D_{cal}) and those determined by the EPR dosimetry (D_{EPR}) for inhabitants of the Zaborie village^(5, 7).

Personal IDN	D_{cal}	Er	D_{EPR}	Er
1	111	22	106	26
2	111	27	120	28
3	150	32	83	23
4	150	32	114	26
5	36	11	77	35
6	188	50	203	30
7	120	27	138	29
8	159	47	112	28
9	176	45	170	32
10	100	28	52	29

Er , uncertainty. All values are given in mGy.

Table 2. Average doses at different settlements and districts, determined by EPR, D_{EPR} (based on an earlier study⁽⁶⁾) and doses determined by analytical method, D_{cal} , according to official data (based on earlier publications^(1, 2)) in different years for settlements of the Bryansk region contaminated after the Chernobyl accident.

Territory name	D_{cal} 1995 (1)	D_{cal} 2001 (2)	D_{cal} 1998	Er	D_{EPR}	Er	n
<i>Gordeevski district</i>	34	45	40	4	29	4	226
Gordeevka	40	52	46	5	51	9	34
Tvorishino	31	44	38	4	51	14	15
Strugova Buda	26	35	31	3	23	25	10
<i>Klintsy</i>	12	23	18	2	28	12	150
<i>Klintsovski district</i>	30	40	35	4	30	8	114
Smortova Buda	23	28	26	3	40	16	16
Smolevichi	11	16	14	2	40	16	16
Gulevka	19	29	24	2	19	16	11
<i>Zlynkovski district</i>	41	55	48	5	50	8	104
Zlynka	31	40	36	4	28	7	28
Vyshkov	39	54	47	5	71	13	25
<i>Krasnogorski district</i>	39	52	46	5	36	7	36
Krasnaya Gora	11	29	20	2	6	8	26
<i>Klimovski district</i>	16	21	19	2	12	7	34
<i>Uncontaminated territories</i>	0	0	0	0	1	4	64

Er , uncertainty. All values are given in mGy; n , number of EPR dose measurements used for averaging.

The distances on which the minimisations are performed are shown in Fig. 1 by vectors. Their orientations are defined by the ratio of the uncertainties in the X and Y coordinates of the experimental points. In the case of equal uncertainties for X and Y , these vectors are orthogonal to the regression line, which gives the name for this method.

In the case of the ordinary regression method, the sum of squared differences between the point and the regression line weighted by their uncertainties in the direction of Y or X coordinates is minimised:

$$Q_Y = \sum_i \frac{\Delta Y_i^2}{U_{Y_i}^2} \text{ in the case of ordinary regression of 'Y on X' (LR} Y_X \text{);}$$

$$Q_X = \sum_i \frac{\Delta X_i^2}{U_{X_i}^2} \text{ in the case of ordinary regression of 'X on Y' (LR} X_Y \text{).}$$

These are the limiting cases of ODR at relatively small uncertainties in X and Y coordinates, respectively. In the case of LR Y_X , it is supposed that error in the X coordinate is negligible, and minimisation is performed in the direction of Y axis, and in the case of LR X_Y in the direction of X axis.

The ODR method is realised by minimisation of Q_{ODR} by the parameters of regression line and coordinates of the intercept of the distance vectors with the line. A non-linear least square method is commonly used for such minimisation (the Levenberg–Marquardt method). For realisation of the ODR

Figure 1. Demonstration of the principles of the ODR method. Directions in which minimisation is performed are presented by vectors with orientation defined by the ratio of uncertainties in X and Y coordinates.

method in the present work, as well as the ordinary regression, the statistical pack *IGOR Pro 6* (Wave Metric Inc.) was used, in which the algorithm described in refs (10, 11) is applied.

RESULTS AND DISCUSSION

The results of comparison of the individual doses are presented in Fig. 2. The slope value obtained by ODR is very close to unity and the value of intercept is close to zero. This means that doses determined by EPR and calculated doses are consistent with each other. The scattering of the main part of experimental

Figure 2. Results of analysing the relation between individual doses determined by the tooth enamel EPR method and by the analytical method using different linear regression methods: LR Y_X , ordinary regression Y on X ; LR X_Y , ordinary regression X on Y ; ODR, orthogonal distance regression; S_X , S_Y , S_{ODR} , residual sums of the regressions, respectively. Parameters of the regression lines with their uncertainties given in parenthesis are presented on the plot panel.

points from the line determined by ODR is close to their estimated uncertainties as shown in Table 1, which indicate the correct estimation of these values.

Parameters of regression lines determined by LR Y_X and LR X_Y are essentially different from each other. Their slopes are significantly different from unity and their intercepts are different from zero. This indicates the incorrectness of using these methods, since the uncertainties of both sets of data are approximately equal.

The root-mean-square of differences between the results of the two methods is equal to 35 mGy. This value results from the cumulative uncertainties of the EPR doses and the calculated doses and consistent with the uncertainties on data presented in Table 1. Residual sums characterising the quality of regression lines are presented on the plot panel and they are close to the root-mean-square difference.

The results of comparison of the doses determined by EPR and the calculated doses averaged over settlements are presented in Figure 3. Similar to the results for the individual doses, the regression lines obtained by LR Y_X and LR X_Y are significantly different from each other and significantly different from unity. The parameters of the regression line obtained by ODR (the slope very close to unity and intercept close to zero) indicate very close consistency of the doses obtained by EPR and analytical methods in the analysed dose region. The intercept value obtained by all three methods is close to each other because of the high statistical weight of dose for uncontaminated territory. This is resulted from low uncertainty of EPR

Figure 3. Results of analysing the relation between averaged over settlements doses determined by the tooth enamel EPR method and by the analytical method using different linear regression methods. Notations are the same as in Figure 2.

doses because of large number of measurements performed for this territory.

Differences between the averaged over the settlement doses obtained by EPR and by the analytical methods are characterised by root-mean-square difference of 15 mGy. This value is consistent with estimations of uncertainties of data presented in Table 2.

CONCLUSIONS

Doses obtained by the tooth enamel EPR spectroscopy method and by the analytical method for the population of radioactive contaminated territories were compared with the use of the orthogonal distance linear regression analysis. As a result of such analysis, the regression line is obtained having the slope close to unity and the intercept close to zero. The ordinary linear regression analysis is not applicable in this case as both sets of data obtained by the two methods, which were used for comparison, have relatively high and comparable uncertainties.

The root-mean-square difference between dose obtained by the EPR dosimetry and by the analytical methods is found to be 35 mGy for individual doses and 15 mGy for average doses. These values are consistent with estimated uncertainties of doses obtained by these two methods.

The results of analysis indicate the consistency of doses obtained by the two methods, validate both methods and verify the reconstructed doses.

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