Estimations of Radiation Risk for the Population of Contaminated Territory of Belarus

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Abstract

Accumulated doses for adult residents of contaminated regions of Belarus were calculated for different periods after the Chernobyl accident. The average dose during the period of 1986-2001 was evaluated to be 50 mSv and 39 mSv in the southern and the eastern contaminated regions of Belarus, respectively. Data obtained were used to evaluate the excess of the relative risk of cancer mortality for adult residents of contaminated regions in terms of Two Defence Reactions (TDR) model developed on the basis of modern results of radiobiological investigations. The results show that the excess of the relative risk (ERR) of cancer mortality as a result of the Chernobyl accident is about 5–6% during the whole life. The results were compared with risk values estimated in the framework of the 1990 Recommendation of the ICRP. The ERR values obtained in terms of TDR model is about six times larger than values calculated on the basis of ICRP recommendations.

Introduction

The radionuclides released during the Chernobyl accident contaminated large areas in the southern and the eastern parts of Belarus. At the present time more than 200 000 people live in regions where the level of ^{137}Cs deposition density is higher than 185 kBq/m^2. According to dose assessments [1, 2], radiation exposure of the population of the contaminated territory is characterized by low dose distribution. Doses (without the thyroid doses) received by the majority of people in the first decade after the accident were smaller than permissible dose limit for life — 70 mSv. Note that doses from external and internal exposure in the first decade are equal to about 60% and 90% of doses for life, correspondingly (see [3]).

To evaluate risks of damage at low doses an extrapolation of high dose results to low dose ones is implemented. At present the non-threshold linear theory is most often, as well as officially, used to make evaluation of radiation risks. However, experimental data accumulated during the last years show evidence against the linear extrapolation of high dose effects to low dose range (see [4, 5] and references therein). In this connection it is of interest to evaluate radiation risk for the population of the contaminated regions of Belarus by using dose-effect relationship based on recent data on radiation-induced effects. The present work gives radiation risk estimations obtained by using nonlinear dose-effect relationship derived in terms of the Two Defence Reactions (TDR) model [6] developed on the basis of modern results of radiobiological investigations. The calculation results are compared with the risk values estimated in the framework of the 1990 Recommendation of the ICRP [7].

Methods and Materials

Accumulated doses for adult residents of contaminated regions of Belarus

Estimation of radiation risk requires the knowledge of accumulated dose for residents of contaminated regions. An expression for evaluation of the average accumulated dose for adult residents of n-th settlement is written

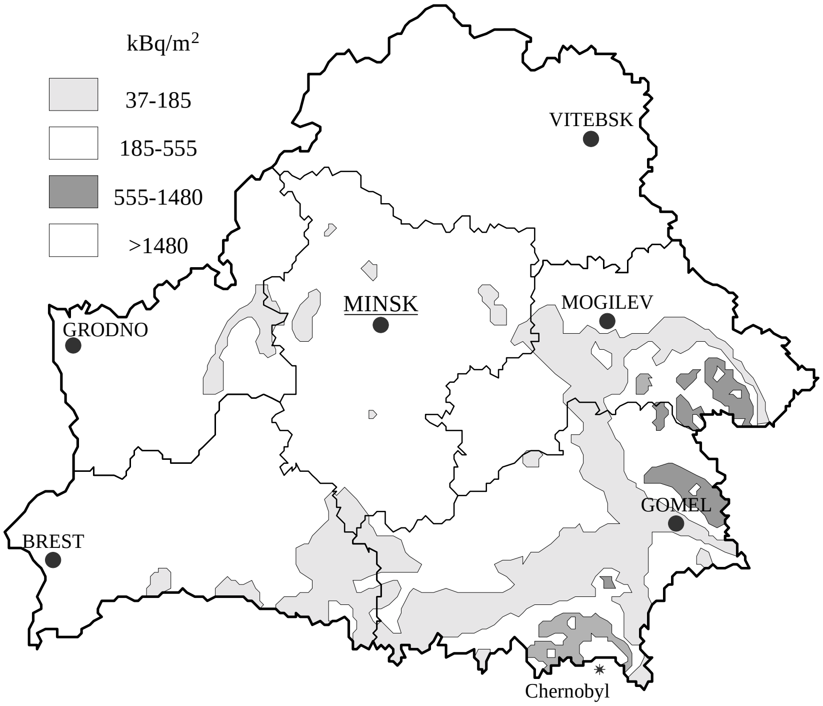

Figure 1: Belarus territory contamination with ^{137}Cs.

$$D_n(\Delta t = t_f - t_i) = \sum_{t=t_i}^{t_f} d(t) S_n(t), \qquad (1)$$

where Δt is the time period after the accident (t_i=1986), $S_n(t)$ is the mean ^{137}Cs deposition density in the n-th settlement; d(t) is average annual dose of adult population exposure normalized to ^{137}Cs deposition density. Note that according to measurement results the concentration of ^{137}Cs activity in organism of adult inhabitants is in average about 1.5 times larger than that in organism of children of 10-15 years old [8]. As a consequence, radiation doses for adult population are higher than doses for children. Estimations of $S_n(t)$ were obtained by using of empirical data on ^{137}Cs deposition density in settlements [2]. Values of the average annual normalized dose d(t) for $t_f \leq 1995$ were taken from [9], and the sum of two exponents was used for fitting and extrapolating these data for $t_f > 1995$.

The distribution of ^{137}Cs deposition density as of 01.01.1995 on the territory of Belarus is shown in Fig. 1. One can see that the contaminated territory consists of the southern and the eastern regions (spots). It is necessary to note that the regions mentioned above are characterized by different values of normalized dose d(t). The southern spot, closely situated to Chernobyl NPP, includes the Belorussian Polesie area, where coefficients of ^{137}Cs transfer from soil to agricultural plants are several times larger than the coefficients obtained for other contaminated regions. Therefore the doses from ^{137}Cs perroral intake and respectively normalized average annual dose for residents of the southern contaminated region are larger than doses in the eastern region (see [9]).

Taking into account the mentioned dose difference, calculations of accumulated dose $D_n(\Delta t)$ were carried out separately for adult residents of the southern and eastern contaminated regions. Values of the accumulated dose $D_n(\Delta t)$ estimated for the case of ^{137}Cs deposition density $S_n(t)$ = 370 kBq/m^2 are shown as example in Fig. 2. Dash line corresponds to the accumulated dose calculated by multiplying Δt by constant value of the permissible annual dose of exposure for population (1 mSv per year) (see [7]). According to Fig. 2, doses accumulated by inhabitants of the eastern and the southern contaminated regions during the first five years after the accident are about 5 and 10 times higher, correspondingly, than

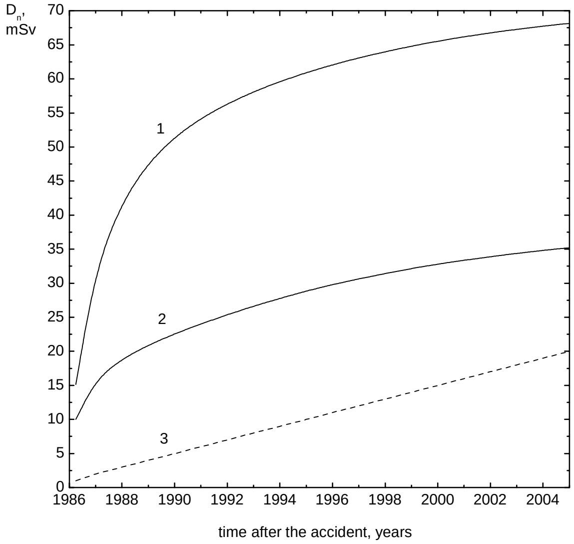

Figure 2: Accumulated doses D_n for residents of the southern (1) and the eastern (2) regions with ^{137}Cs deposition density $S_n(t)$ = 370 kBq/m^2. Dash line (3) corresponds to the permissible annual dose: 1 mSv [7].

permissible level 5 mSv; doses for the 15 years period are about 2(4) times higher than permissible level 15 mSv.

The results show that about 80% of dose accumulated for the 15-years period were taken during the first five years after the accident. It means that the intensity of exposure in first years after the accident was several times higher than permissible level.

Using assessments of $D_n(\Delta t)$ and the population data of settlements, distributions of accumulated doses for Δt = 5, 10, 15 years were deduced for adult residents of the southern and the eastern regions where the level ^{137}Cs contamination is more than 37 kBq/m^2 (see Fig. 3). Note that the percentage of adult population in settlements was supposed to be constant for the period under consideration. The number of them are 103,680 and 153,380 in the southern and the eastern regions, respectively (see [2]). According to calculation results, average values of the accumulated dose for residents of the southern region are about 30% higher than those for the eastern region. As it is shown in Fig. 3, the dose accumulated during ten-years and fifteen-years periods following the accident are about 20% and 25% larger than dose for the first five-years period, correspondingly. In the second five-years period the average annual increase of the dose was about 1.3 mSv/y. During the third 5-years period the dose increase rate was about two times smaller: 0.6 mSv/y.

Dose-effect relationship and radiation risk estimation in terms of model of Two Defence Reactions

Dose-effect relationship (DER) is the basis of radiation risk evaluation. Presently the official form of DER is the linear non-threshold (LNT) relationship, which was accepted by UNSCEAR [10] and ICRP [7]. It is the foundation for all present-day norms, standards and rules of radiation safety. In the formulation of UNSCEAR, the main merits of LNT hypothesis are its simplicity and agreement with most concepts and numerical data. At the same time modern results of epidemiological observations and radiobiological researches show difference between a variety of DERs obtained for stochastic radiobiological effects at low dose range (see, for example [11]). The epidemiological data of the survey of Japanese survivors cohort prove the non-linear dependence of the excess of the relative risk on dose at low range [12, 13]. It is very likely that DER depends on kind of radiation damage, type of biological

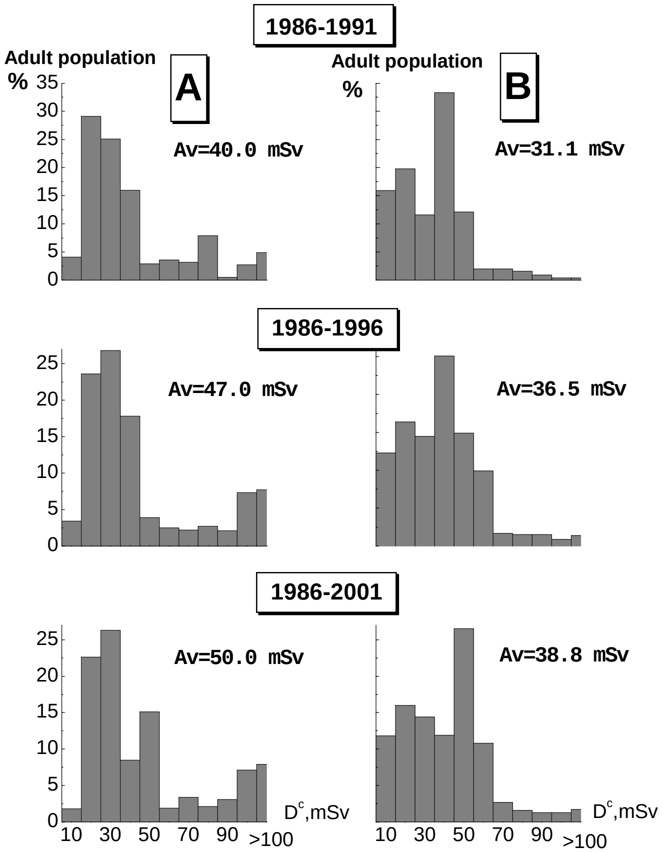

Figure 3: Distributions of accumulated doses for adult residents of the southern (A) and the eastern (B) contaminated regions.

object and exposure conditions.

In this paper the Two Defence Reactions (TDR) model [6] was used for radiation risk assessment. The basis of the choice are the results of the observations of low dose radiation damages in cells of different biological objects: HT29 human lines [14], V79 Chinese hamster lines [11] and root meristem of barley grains [15]. The results obtained in the above mentioned works show nonlinear increase of damage with dose growth (see Fig. 4–7). Data presented in these figures were treated in the framework of TDR model [16]. According to the results, TDR model satisfactorily describes DERs for considered biological objects.

The TDR model is based on the assumption that the cell response to irradiation is regulated by constitutive and adaptive mechanisms. On the level of organism the response of the immune system to irradiation also consists of two components: innate and adaptive. The defence reaction at the organism level acts in addition to the cell level defence. The differential equations describing interaction of two components of defense system are similar for both the cell and the organism levels. Curves in Fig. 4–7 are obtained through the fitting procedure of observed DERs by using the function found by solving the TDR model equations.

Taking into account the results of TDR model application for description of DERs, the excess of the relative risks (ERR) for the population of the contaminated regions of Belarus was estimated on the basis of this model and on the dose distributions given in Fig. 3. The ERR for the group of N residents is

$$ERR_N = \frac{\sum_i ERR_i N_i}{\sum_i N_i} = \frac{\sum_i ERR_i N_i}{N}, \qquad (2)$$

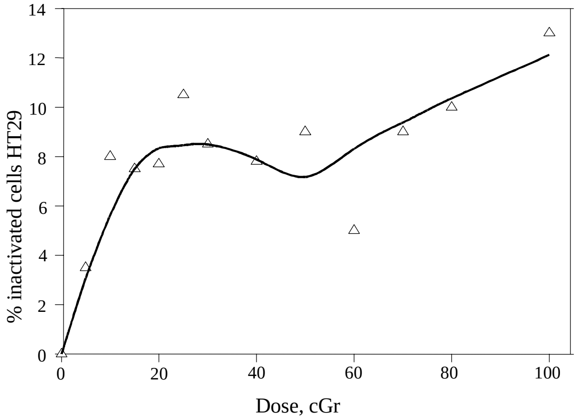

Figure 4: Dependence of the yield for human tumor inactivated cells of HT29 line on X-ray dose [14].

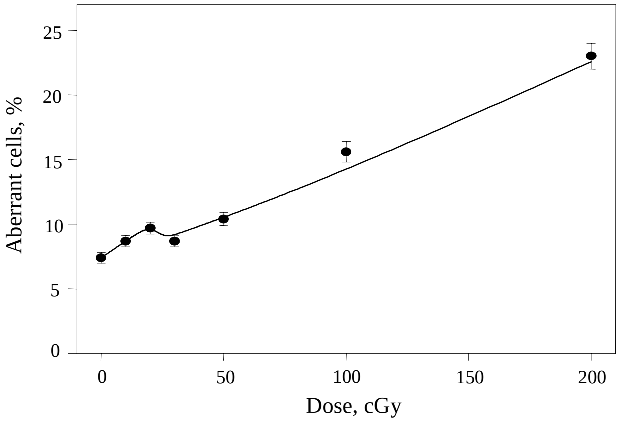

Figure 5: Dependence of the frequency of Chinese hamster cells with chromosome aberrations on γ-radiation dose from ^{60}Co [11].

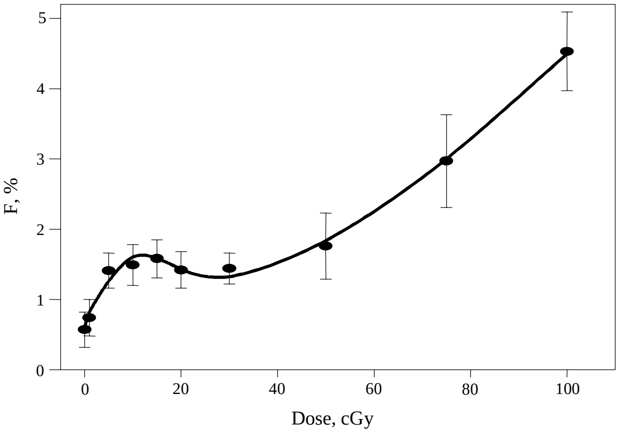

Figure 6: Dose-effect relationship in root meristem cells of barley grains. F - output of aberrant cells [15].

where ERR_i is the excess of the relative risk for i-th subgroup of residents irradiated with the dose H_i. According to the TDR model,

$$ERR_i = \frac{(1-W_c)(1-f_i)}{W_c}, \qquad (3)$$

where W_c is the spontaneous risk of mortality from cancer without irradiation (background), accepted to be 0.28 [12], and function f_i is determined as:

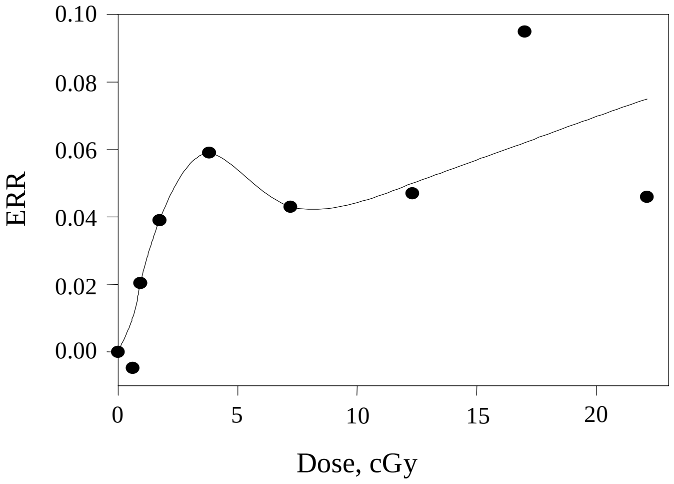

Figure 7: Excess of the relative risk (ERR) of mortality from all cancer other than leukemia for Japanese A-bomb survivors (men) who were 20-40 years old at the time of bombing [6].

$$f_i = \exp(-\mu_n H_i) + \frac{\nu\mu_n}{\mu_n - \mu_a}\{\exp[-\mu_a(H_i - H_t)] - \exp[-\mu_n(H_i - H_t)]\}, \tag{4}$$

with $(H_i\text{-}H_t) \geq 0$ (see [6]).

The model parameters μ_n, μ_a, ν, H_t are found from the best description of empirical risk data by the TDR model. Parameters μ_n and μ_a characterize two types of defence (response) reaction of biological objects: constituent (or innate) and adaptive (or inducible) radiosensitivities, correspondingly. The parameter ν characterizes capabilities of the adaptive protective mechanism. The dose H_t is the threshold of inducible reparations action. Various ranges for the mentioned characteristics are considered in [16].

Epidemiological data for adult survivors of Hiroshima and Nagasaki, who were 20–40 years old at the time of atomic bombing [4], were treated in the framework of TDR model for evaluating the model parameters. The fitting results of ERR of mortality from all types of cancer except leukaemia for Japanese survivors are presented in Fig. 7. One can see that the magnitude ERR is characterized by non-linear growth at low dose range. The behavior of ERR is similar to the dose-effect relationships observed in cells (see Fig. 4–6).

Results and Discussion

Obtained model parameters were used for the assessments of ERR of cancer mortality for the adult residents of the contaminated regions of Belarus on the basis of accumulated doses $D_n(\Delta t)$. The results of calculation of the excess of radiation risk for residents of the southern and the eastern regions are presented in the Table 1 in comparison with the values obtained in the framework of ICRP recommendations.

The results show that excess of the relative risk of cancer mortality for the adult residents of contaminated regions of Belarus as a result of Chernobyl accident is about 5–6% during the whole life. The main contribution to ERR was provided by the doses accumulated during the first five years after the accident; further increase of ERR is 10–15%. The difference between ERR values predicted for the southern and the eastern contaminated regions is smaller than 10%. ERR values obtained in terms of TDR model is about six times larger than values calculated on the basis of ICRP recommendations [7].

On the basis of the ERR assessments obtained in terms of TDR model the average annual excess of cancer mortality for adults can be estimated as $6\% / 50 \text{ years} \cong 0.1\,\%$ in a year. As the excess of cancer mortality is proportional to excess of cancer morbidity the average annual excess of cancer morbidity is expected about 0.1%. Statistical data on cancer incidence in Belarus for the period 1991-2000 (see [17])

Table 1: The excess of the radiation risk (ERR) for the residents of the southern (A) and the eastern (B) regions.

	Model	Period after the accident, years			
		5	10	15	20
A	TDR	0.0554	0.0590	0.0610	0.0620
	ICRP 1990	0.0093	0.0106	0.0112	0.0113
B	TDR	0.0504	0.0553	0.0578	0.0582
	ICRP 1990	0.0077	0.0087	0.0092	0.0093

show that the average annual excess of cancer morbidity among adult residents of contaminated regions is about 1.2%. Note that the same excess of cancer morbidity was observed for uncontaminated regions. So according to assessments evaluated by using of ERR estimations and data from [17] one might expect that the contribution of the Chernobyl accident to annual excess of cancer morbidity would be about 10%. It should be stressed that the latent period for solid cancers is about 10 years and the annual excess of cancer morbidity increases with age. On this reason the mentioned value of the Chernobyl contribution to cancer morbidity for the period 1991–2000 would be considered as overestimated assessment.

It is necessary to note that the quantity ERR in question is general index including all types of solid cancer. An excess of some types of cancer, which are characterized by the small weight coefficient, may be considerably larger than the above-mentioned assessments. For example, in the period 1991–2000 the thyroid cancer morbidity of the population of the easten contaminated region increased about 7 times (see [17]). For this reason it is of great interest to perform long–term epidemiological investigations in Belarus to deduce dose-risk relationship for some types of cancer.

Conclusion

Accumulated doses for adult residents of contaminated regions of Belarus were calculated for different periods after the Chernobyl accident. The results show that about 80% of dose accumulated for the 15-years period were taken during the first five years after the accident. Distributions of accumulated doses were deduced for adult population of the southern and the eastern contaminated regions. Average values of the accumulated dose for residents of the southern region are about 30% higher than those for the eastern region.

Modern data of epidemiological observations of Japanese survivors cohort and radiobiological researches of low dose damages in cells of different biological objects were analysed in terms of Two Defence Reactions (TDR) model. The results show that this model satisfactorily describes non-linear dose-effect relationships for considered biological objects. The TDR model parameters obtained by treating of data on mortality of adult survivors of Hiroshima and Nagasaki were used for calculation of the excess of the relative risk for adult residents of contaminated regions of Belarus on the basis of the accumulated dose distributions. The results show that the excess of the relative risk of cancer mortality as a result of Chernobyl accident is about 5–6% during the whole life. ERR values obtained in terms of TDR model is about six times larger than values calculated on the basis of ICRP recommendations.

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