

LOW DOSES OF RADIATION: ARE THEY DANGEROUS?

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REMOTE CONSEQUENCES OF THE CHERNOBYL DISASTER: ASSESSMENT AFTER 13 YEARS

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Assessment of the Chernobyl accident consequences reduced to the estimation of the effect of low chronic combined (external and internal) irradiation on human health and well-being of living organisms. The paper presents the analysis of literature and original findings of laboratory and epidemiological investigations accumulated for 13 years concerning the remote consequences of the Chernobyl catastrophe. The following parameters were considered: estimates of radiation doses taken by the population; biological effects of low levels of chronic irradiation; such remote stochastic effects of radiation as thyroid cancer, leukaemia and solid cancer; genetic effects in somatic and germ cells; increased sickness rate in inhabitants of radiocontaminated regions.

THE ANALYSIS OF THE AMASSED INFORMATION ALLOWS PREDICTION OF SERIOUS RADIATION RISK FOR THE POPULATION OF BELARUS

Assessment of the Chernobyl accident consequences reduces to the estimation of the effect of low dose chronic combined (external and internal) radiation on human health and well-being of living organisms.

According to the information of the Belarusian Committee for Hydrometeorology and Atlas of caesium contamination of Europe after the Chernobyl accident (Atlas..., 1996) practically the whole area of Belarus proved contaminated by ^{137}Cs above the level of global fall-out. Contamination density equal to 37 kBq/m^2 is accepted as a limited value for distinguishing the so-called clean regions from contaminated ones. The radiocontamination level in the so-called clean regions is below 37 kBq/m^2 (1 Ci/km^2) and that in radiocontaminated regions making up 23% of the country area is above this value.

Reconstruction of ^{131}I fall-out has shown that practically the whole country was contaminated by this isotope. So, the whole population of Belarus (above 10 million people) as well as flora and fauna have been exposed to radiation due to the Chernobyl catastrophe since 1986. Clear understanding of this fact is of great importance for interpreting the effects recorded.

The findings of epidemiological and laboratory investigations accumulated for years allow evaluation of remote consequences of the Chernobyl catastrophe.

ASSESSMENT OF RADIATION DOSES

Assessment of radiation doses due to the Chernobyl fall-out is a complicated and still unsettled problem.

The summarized data were given in the report of Cardis et al. and in some others in Vienna in 1996. According to this information liquidators who had worked in 1986–1987, took, on the average, a dose of about 100 mSv and some of them received 250–500 mSv. The calculated average effective dose over the period of 1986–1995 for the population from the regions of strict control with the radiocontamination level above 555 kBq/m² (15 Ci/km²) makes up 50–60 mSv and that for the population living in the less contaminated areas is 6–20 mSv.

The estimate of the collective equivalent dose for 7 million people living in Belarus, the Ukraine and Russia in the areas with the radiocontamination level above 37 kBq/m² adds to 35000–100000 man-Sv. At the same time according to M.V.Malko's calculations (Malko, 1998a) the total collective equivalent radiation dose with due account of all short-lived isotopes (including ^{131}I) and Cs isotopes for Belarusian inhabitants living in the areas with the contamination density above 37 kBq/m² will make up 11.85×10^4 human-Sv over 70 years, including 6.35×10^4 human-Sv from ^{131}I , 4.25×10^4 human-Sv from ^{137}Cs and 0.86×10^4 human-Sv from ^{134}Cs .

The data of Kenigsberg and Minenko (1995) on the estimation of the collective effective dose and average effective dose over the period of 1986–1995 for the whole population of Belarus are given in Table 1. The estimates of the average dose for country people in the most contaminated zones of Gomel and Mogilev Regions were 13,4 and 8,82 mSv respectively.

Table 1. Bulk and cumulative average group radiation dose of inhabitants in Belarus over the period 1986–1994

Region, town	Bulk radiation dose, Sum, Person/Sv	Cumulative doses of rural population, >18 years, mSv	Cumulative doses of urban population, >18 years, mSv
Brest Region	163 5	1.90	1.07
Vitebsk Region	213	0.24	0.20
Gomel Region	100 05	13.40	7.42
Grodno Region	614	0.74	0.80
Minsk Region	776	0.69	0.41
Mogilev Region	420 0	8.82	1.88
Brest	74		0.32
Vitebsk	59		0.19
Gomel	247 0		5.53
Grodno	99		0.41
Minsk	366		0.26
Mogilev	456		1.42

From: Ecological, medicobiological and socio-economic consequences of the Chernobyl NPP Disaster in Belarus. Ed., E.F. Konoplya, I.V. Rolevich, Minsk, 1996

For all the uncertainty of these estimates, the estimate of the individual radiation dose received by the people within 1986 and 1987 is a matter of the greatest difficulty. For a retrospective dosimetry estimate for the population living in radiocontaminated areas the method of ESR-dosimetry for enamel was developed at the Institute of Biophysics in Russia. This method was certified for metrology and makes it possible to determine accurately the individual dose of external irradiation from the background level up to some Gy (Keirim-Markus et al., 1995).

According to investigation of Keirim-Markus et al. (1995) the accurately measured dose of external γ -irradiation that was received by the population in 1986–1987 proved to be greater by several fold than the maximal calculated estimates. Thus, the median dose for the inhabitants of Novozybkov district of Brest Region made up 290 mGy, and the highest individual doses were 5–6 times as high.

It should be noted that Gomel and Mogilev Region in Belarus are much more contaminated than Bryansk Region. So, the research of Keirim-Markus et al. has shown the necessity for retrospective reestimation of accident doses since the calculated values turned out very reduced.

The research works (Krivoruchko, Naumov, 1997; Dubina, Kulich, 1997) convincingly corroborated this fact. According to their calculation the population of Khoiniki district took 2–25 cGy dose for the first 10 days.

BIOLOGICAL EFFECTS OF CHRONIC LOW-DOSE RADIATION

Reality of biological effects of low and extremely low doses of irradiation as well as their nature and shapes of the dose-response relationships remains unclear. But more and more information on significant effects of low doses is being collected in laboratory and epidemiological investigations as well as when studying chronically irradiated natural populations. Regarding risk assessment the various types of dose-effect curves might lead to different risk scenarios for the human population exposed to the Chernobyl fall-out.

The real ecological situation makes it involved to distinguish the role of a radiation factor in recordable epidemiological and other effects. That's why the study on the effects of chronic low dose radiation under strictly monitored conditions is very important

Thus, we have studied reproductive parameters of carp stripped fishes kept in the radiocontaminated pond since 1986 (γ -activity for ^{137}Cs in bottom deposits was 2812 Bq/kg) and defined morphological and cytogenetic characteristics of their offspring at early developmental stages (embryos, two-day larvae). It should be noted that neither surface-active substances, heavy metals, pesticides (aldrin, DDT, hexachlorine, cyclohexane, hexachlorane, keltan, heptachlorine) and herbicides (simazine), nor traces of fertilizers (salty and albuminoid ammonia, potassium), oil products and phenols were detected. Factory incubation was performed in Weiss' apparatus under strict control of all technological conditions of incubation by thermooximeter Horiba U-7.

A group of even-age females and males labelled by a special dye and with their numbers was selected from the run of stripped fishes for estimating reproductive properties. This made it possible to study reproductive properties of the same stripped fishes over a period of several years, as well as to evaluate offspring quality from each pair of parents.

A list of reproductive parameters of pond carp stripped fishes is given in Table 2. Figure 1 represents the coefficients of pair and multiple correlation of the studied parameters to the radionuclide content in female hard roe, male milt, as well as in reproductive products of each pair of parents.

We have shown that such reproductive parameters of carp stripped fishes as milt quality, fecundation percentage, the number of hatched prelarvae and larvae, larvae survival as well as frequencies of morphological anomalies and cytogenetic injuries in their offspring at early developmental stages (embryos, two-day larvae) depend on radionuclide concentration in reproductive products of stripped fishes (48–157 Bq/kg in hard roe, 133–281 Bq/kg in milt) and, consequently are induced by radiation effect. An absorbed dose due to internal and external irradiation of germ cells of stripped fishes made up 4,7–5,4 μGy per day (Goncharova et al., 1997).

Direct relationship between values of morphological and cytogenetic parameters of carp fry, being an offspring of chronically irradiated stripped fishes and reared in radiocontaminated ponds, and concentration of incorporated radionuclides (the calculated absorbed dose per day due to external and internal irradiation was 0,4–5,5 μGy) was proved. Genetic radiosensitivity of fish was revealed to be similar to that of mammals (Shima, Shimada, 1988).

Similar comparison between cytogenetic indices and radionuclide concentration in animals from natural populations were made by us (Goncharova et al., 1997; Goncharova et al., 1999).

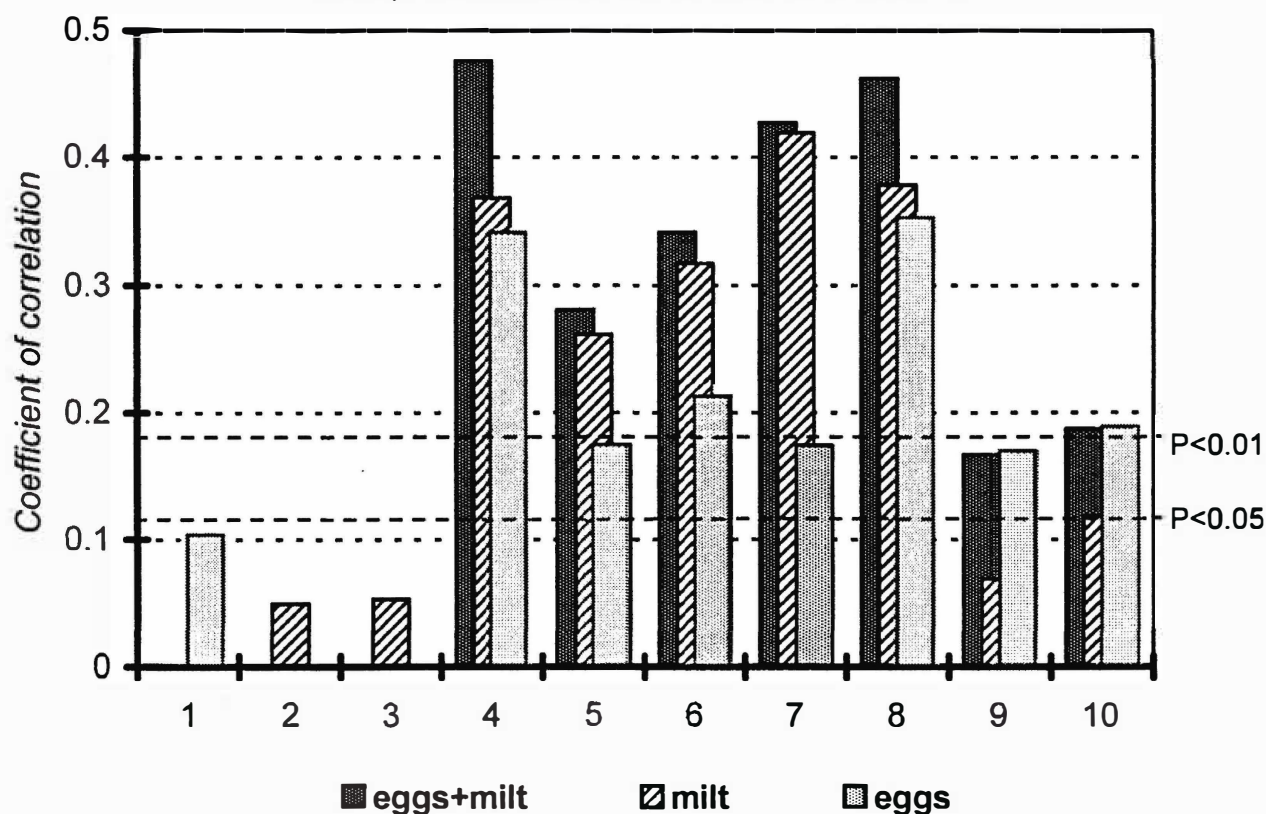
Increased mutability of somatic cells in bank vole, whose populations live for 10 years under artificially increased radiation background (5–1526 kBq/m^2 for ^{137}Cs) was revealed to depend on low concentrations of incorporated radionuclides and on absorbed dose rate (2 – 730 $\mu\text{Gy/day}$) (Goncharova et al., 1999). This fact points to genetic efficiency of very low doses of chronic irradiation for somatic cells of small mammals. The regression analysis has shown that the form of this relationship is nonlinear and is better described by the parabola equation of the second order (Goncharova, Smolich, 1998; Goncharova et al., 1999).

Coefficients of determination calculated from the equations of multiple regression show that relationship between biological effects and the radionuclide content in pond carp and small mammals, as a rule, is poor or very poor. Thus, in the low dose region the share of the chronic radiation factor influence was minor in the recorded effects. Nevertheless, these relations are significant and indicate biological efficiency of extremely low doses in the range of μGy of chronic irradiation (Goncharova et al., 1997; Goncharova et al., 1999; Riabokon, 1999).

Table 2. Reproductive characteristics of carp parents

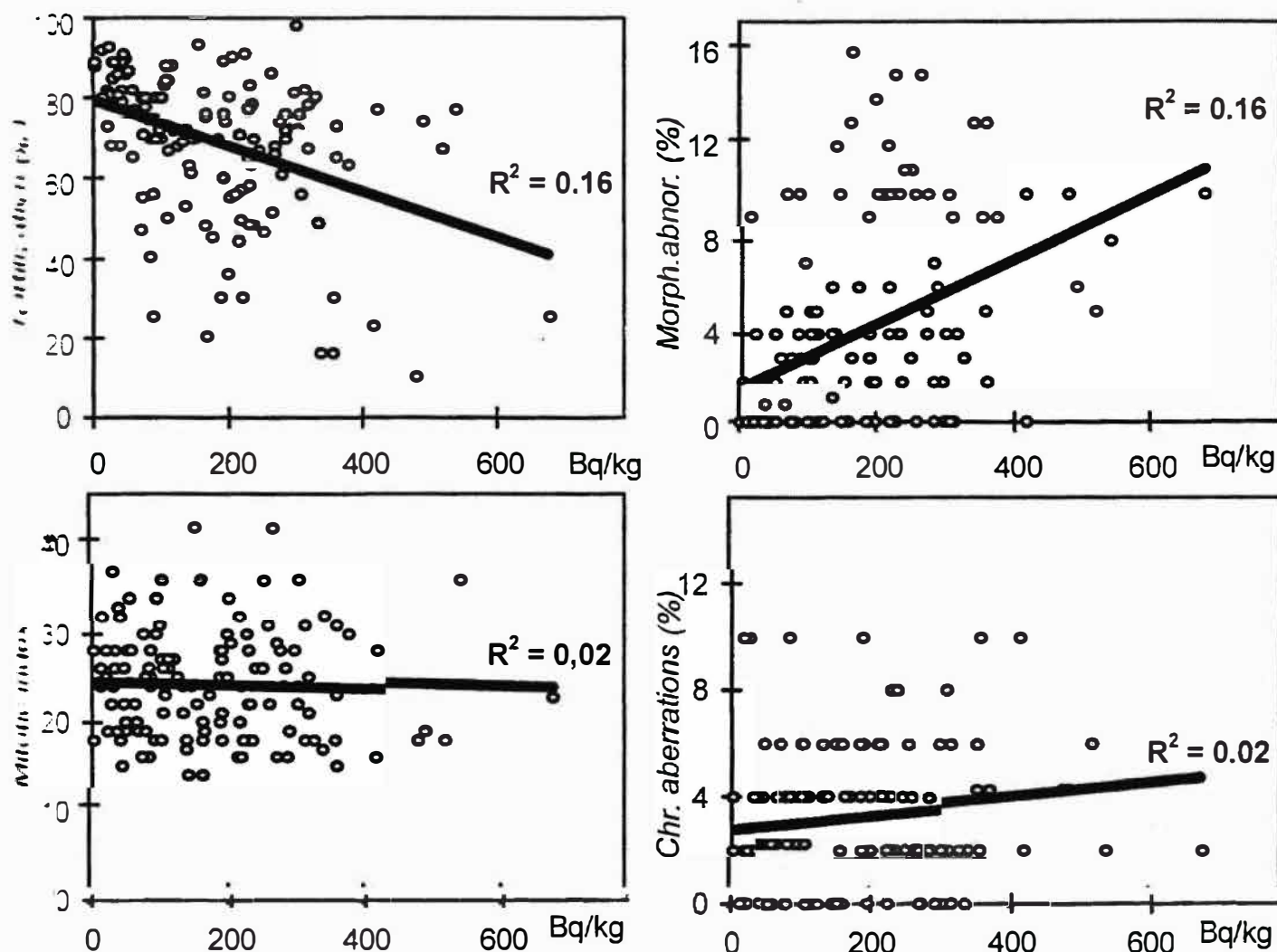
nn	Characteristic	Unit of measurement
1	Number of eggs	ths per female
2	Amount of milt	ml per male
3	Quality of milt	mark
4	Fertilization	%
5	Number of prelarvae	ths per female
6	Number of larvae	ths per female
7	Larva survival	%
8	Frequency of morphological abnormalities	%
9	Mitotic index	%
10	Frequency of chromosome aberrations at stage of late blastula	%

Figure 1. Coefficients of correlation between reproductive characteristics of carp parents and radionuclide concentration in their germ products (coefficients of correlation are given in absolute values). Characteristics are the same as in Table 2.



The form of dependence between such parameters as percent of fertility in carp stripped fishes as well as the number of morphological malformations, mitotic index and the frequency of aberrant cells in their progenies and the concentration of incorporated radionuclides can be judged by regression lines which are represented in Fig. 2.

Figure 2. Relationships between the studied characteristics of fishes and the radionuclide content in their parents.



It should be noted that the dependencies were quite well described by the equations of linear regression practically for all the recorded biological effects. This dependence was non-linear and well described by the equation of the 2nd order parabola for such a parameter as soft roe quality determined by spermatozoid mobility rate.

Thus, we have demonstrated unfavourable (negative) effects of very low doses of internal irradiation at early developmental stages of descendants whose parents live under regular chronic irradiation conditions.

Hence, our findings and the known facts on the existence of linear dependencies (Streffer, Tanooka, 1996) in the range of very low doses (2–45 mGy) give evidence for

the absence of threshold (Goncharova, 1998; Goncharova, 1999; Goncharova et al., 1999).

LONG-TERM HEALTH EFFECTS

According to the predictions of the Institute of Biophysics of the Academy of Sciences of the USSR (Iliin et al., 1989) and International Chernobyl Project (International Advisory Committee, 1991), carried out under the aegis of IAEA, minor increase in thyroid cancer that will hardly be distinguished from spontaneous disease could be the sole harmful effect of the Chernobyl fall-out.

In fact, a significant rise in thyroid cancer in children in Belarus began in 1990 and by 1998 above 900 children were diagnosed and operated. Similar increase in thyroid cancer occurrence, but to a lesser degree, was recorded in children in the Ukraine and Russia. Six years were necessary for the International Scientific Bodies to admit the reality of such an enormous increase in occurrence of this cancer and relationship between this rise and radiation due to the Chernobyl catastrophe.

This major discrepancy between the number of thyroid cancer appearing in those who were children at the time of the accident and the predicted number of such cancers and its latent time on the basis of standard thyroid dosimetry and current risk projection models has clearly revealed the deep crisis of the official radiobiology. The causes of such a failure were analysed in detail by M.V. Malko (Malko, 1998b).

Quite long ago were known the results of thorough examination of a large group of people (2634 persons) whose neck region was exposed to low-dose radiation at their young age. It should be noted that irradiation of neck and head was widely used in the USA and other countries before the sixties for curing such benign diseases as tonsillitis, adenoids and other similar benign diseases. Such a "treatment" has resulted in very serious consequences that had to be known to experts. Thyroid cancer was detected in 12 % of patients and different nodes were observed in 37 % of them, with 60 % of tumors being detected in people whose thyroid gland was exposed to 10–60 cGy radiation at their young age. A peak of relative risk of tumor emergence was revealed to be recorded in 25 years after irradiation but the effects of neck and head irradiation in children were monitoring up to 40 years (observation period) after impact.

The major conclusion drawn on the basis of these examinations is as follows: thyroid cancer is the most sensitive indicator of child irradiation even with such low doses as 10 cGy (Tsyb, Poverenyi, 1996).

Let's adduce in this context the known data of 250 thousand measurements of dose load rate on thyroid gland of Belarusian inhabitants made by research workers of the Institute of Biophysics of the USSR from May to August 1986. The average dose for adults was equal to 154 cGy and for children – 310 cGy, with more than 5 % of children having absorbed above 1000 cGy on thyroid gland and some of them – above 5000 cGy.

As a result of acute discussions during attending the Subcommittee for labour, health and education of the USA Senate, the director of the National Institute of Cancer Richard Kklausner had to admit that approximately 75 000 of additional incidences of thyroid

cancer can emerge due to nuclear tests carried out in Nevada in the fifties. This concerns primarily people who were children during these tests. The study on the consequences of nuclear explosions in Nevada is being carried out by this Institute on behalf of the USA Congress since 1982. The average irradiation dose for Americans, summing up 90 explosions made, was established in 1994 and made up 2 rad (Wadman, 1997).

As for the prediction of the Chernobyl consequences, it is as follows according to an independent M.V.Malko's analysis (Malko, 1998a). The occurrence frequency of thyroid cancers for inhabitants of Gomel, Mogilev and Brest Regions of Belarus (with the exception of liquidators) will be 10–20 thousand cases, including 1–2 thousand lethal ones. Hence, it is clear that a great value of “nonrealized” cancer will be expected in future. In my opinion the second peak of thyroid cancer diseases will be observed in 20–25 years following the Chernobyl accident.

Leukaemia is considered to be a good marker of radiation and in Japan a significant rise in leukoses was observed since 1950.

Till 1995 no excess number of haemoblastoses following the Chernobyl accident over the spontaneous level in 3 affected countries (Belarus, The Ukraine, and Russia), including leukaemia in children in Belarus (Ivanov et al., 1996, 1997), was revealed. On this basis it was stated at the International Conference “One decade after Chernobyl (Vienna, 1996) that “in summary, to date, no consistent attributable increase has been deluded either in the rate of leukaemia or in the incidence of any malignancies other than thyroid carcinomas”.

However, at that conference A.E. Okeanov has presented the data on a two-fold increase in the frequency of leukaemia and other cancers in liquidators in Belarus, the observed incidence of urinary bladder cancer, thyroid cancer and leukaemia being in excess of predictions (Okeanov, Polyakov, 1996). Besides, in Gomel Region, the most contaminated region of Belarus, an increase in morbidity and regression coefficient for malignant tumours of colon, rectum, lungs, mammary gland, urinary bladder, kidneys and thyroid was revealed (Okeanov, Yakimovich, 1996). The same authors (Okeanov, Yakimovich, 1999) have revealed statistically significant correlation between the additional number of cancerous diseases and radiocontamination density of regions. Such a relationship is shown for all cancer forms as well as for such localizations as carcinoma of the stomach, lungs and kidneys.

A significant rise in leukaemia caused by the Chernobyl radiation was recorded among liquidators in Russia (Tsyb, 1997). He notes that peak of radiogenic leukosis in liquidators, who worked in 1986–1987, was recorded in 4–5 years following the accident. At present every second incidence of leukosis revealed in liquidators is due to radiation. Greek and American researchers have reported that in Greek infants exposed in utero to ionising radiation due to the Chernobyl accident the incidence of leukaemia was 2.6 times as high as in unexposed children. Children born during the second half of 1986, the first half of 1987 and most of those born during the second half of 1987 were considered exposed to the Chernobyl radiation in utero whereas those born from 1980 to 1985 and those born from 1988 to 1990 were considered unexposed (Petridou et al., 1996). The author revealed that children born in regions with increased levels of radionuclide contamination had a higher incidence of leukaemia. Infant leukaemia is known to be a

distinct form associated with specific genetic abnormality in the 11 g 23 chromosome band. Caesium area contamination in Greece was $100\text{--}1000\text{ Bq/kg}^{-1}$ or $30\text{--}300\text{ kBq/m}^2$ an average exposure has been estimated at about 2 mSv. So, the authors think that infant leukaemia can be caused by very low doses of intrauterine radiation exposure.

Similarly to the results of Petridou et al., the analysis of the German Childhood Cancer Registry showed an increased incidence of infant leukaemia in a birth cohort of children born after Chernobyl accident in comparison to two cohort of children born before or at least 1.5 year after the accident (Steiner et al., 1998). However the author didn't show clear trend with regard to additional radiation exposure due to the Chernobyl accident.

Thus, already now we have the data contradicting the prediction stated in Vienna. In my opinion, the present situation with the occurrence of leukaemia and solid carcinomas in radiocontaminated areas is similar to the situation in 1990 when for the first time an increase in thyroid cancer in children in Belarus was recorded contrary to the prediction of the International Chernobyl Project. And actually, recently emerged an information about an increase in the occurrence frequency of pre-leukosis states in adult inhabitants of Mogilev, Gomel and Brest Region beginning from 1996 and about their quick transformation into different forms of acute leukosis in some patients (Ivanov et al., 1998). It is known that in Japan radiation-induced acute leukoses emerged at first in the form of pre-leukosis states (myelodysplastic syndromes).

Explanation of a sharp difference in realization of such stochastic radiation effects as leukaemia and thyroid cancer among the affected inhabitants of Belarus, Russia and Ukraine, and those of Hiroshima and Nagasaki was proposed by M.V. Malko (Malko, 1998a). The Japanese people, who survived after nuclear bombardments, had absorbed practically the same radiation doses on bone marrow and thyroid gland. As is known, a peak of leukaemia occurrence in Japan was observed in 6–7 years and a significant rise in thyroid cancer – in 10 years. It follows from this that at such radiation dose distribution the latent period of leukaemia is much shorter than that of thyroid cancer. According to M.V. Malko's calculations for the Chernobyl situation thyroid radiation doses are much more higher than radiation doses on bone marrow. Just therefore a sharp rise in the incidence of thyroid cancer in Belarus and other affected countries was the first manifestation of Chernobyl remote consequences.

Taking into consideration these data and the fact that an accurately measured dose of external γ -irradiation proved to be greater by several fold than the maximal calculated estimates (Keirim-Markus et al., 1995), one must admit the existence of a serious radiation risk for the population living in contaminated areas (Goncharova, 1998, 1999).

Nevertheless, it must be admitted that predictions of the major radiological impact of the Chernobyl radiation (cases of cancer), made on the basis of studies for high doses, are vague.

Up to now there are discussed questions on threshold dose existence and whether the dose-effect curve is linear in the range of low doses.

According to the latest information on cancer mortality among survivors of the atomic bombardments in Japan dose-effect relationship for solid cancer appears quite

linear up to about 3 Sv while for leukaemia apparent nonlinearity results in the fact that the risk of irradiation at 0.1 Sv makes up 1/20 of that due to 1 Sv irradiation dose (Pierce et al., 1996).

Epidemiological investigations have shown a significant increase in carcinogenesis after radiation exposures in the dose range equal or higher than 100 mSv (Streffer, Tanooka, 1996). It should also be noted that Hatch et al. (1990) and Wing et al. (1997) who had re-evaluated cancer incidence near the Three Mile Island Nuclear Plant, drew the same conclusion: a positive association between an accident dose (1 mSv) and all cancers as well as lung cancer and adult leukaemia was revealed.

Wing et al. (1997) consider that their results verify the hypothesis about the relation between an increased cancer incidence around the nuclear plant and radiation accident doses. However estimates of an "accidental dose" value differ greatly. The frequencies of unstable and stable (translocations, FISH-method) chromosome aberrations were analysed in a group of affected people in 1994–1995. A retrospective estimate of the mean value of radiation dose for this examined group was no less than 0.3 ± 0.1 Gy (Shevchenko, Snigireva, 1996).

Pobel and Viel (1997) obtained conclusive evidence for causality of the occurrence frequency of leukaemia in young people (under 25 years), who live in the vicinity of French nuclear processing plant in Normandy, with additional radiation effect. Exceptional elevation of children's leukaemia was observed in the proximity of the German Krümmel nuclear power plant (Schmitz-Feuerhake et al., 1997).

There is a heated debate about clusters of childhood leukaemia, especially about leukaemia clusters around nuclear installations in Great Britain and later in Germany and France (Burkart, 1998; Alexander, 1998).

The studies performed within the framework of IPHECA program have detected arrested mental development and deviations in behavioural and emotional responses in children exposed in utero (Kreisel et al., 1996). However, the importance of this real post-Chernobyl effect was not properly realized due to lack of individual dosimetry findings.

The direct consequence of radiation exposure is known to be eye cataract. The rise in this disease was revealed in persons who survived the atomic bombardment in Japan.

It should be noted that the high primary incidence of cataract was found in 1993 and 1994 in the population of Belarus living in contaminated areas. As seen from Table 3 the evacuated people and liquidators have the highest values, followed by the people living in contaminated regions (Ecological, medicobiological and socio-economic consequences of the Chernobyl NPP Disaster in Belarus, 1996). At present more information is collected that radiation cataract is of stochastic origin rather than deterministic (Worgul et al., 1996). Cataract-inducing dose is considered to be equal to 2 Gy under single acute irradiation. However, examination of people exposed to computer tomography has shown that X-irradiation in the range of 0.10–0.30 Gy can be cataract-genic (Worgul et al., 1996).

Table 3. Initial cataract (falling ill) in affected inhabitants of Belarus (per 100000)

Years	Belarus (adults and teenagers)	Liquidators	Evacuees	People living in contaminated areas	
				>15 Ci/km ²	1–15 Ci/km ²
1993	136.2	281.4*	354.9*	225.8*	189.6*
1994	146.1	420.0*	425.0*	365.9*	196.0*

* Difference from the mean republican value is significant

From: Ecological, medicobiological and socio-economic consequences of the Chernobyl NPP Disaster in Belarus. Eds. E.F. Konoplya, I.V. Rolevich, Minsk, 1996

In this connection it should be noted that linear dependence of lenticular opacity frequency in mice was detected in a very low dose range, namely 2–45 mGy of X-irradiation (Streffler, Tanooka, 1996). Practically, the whole population of Belarus took the same or higher doses of additional irradiation over the past period.

Taking into account the uncertainty in dose-effect relationship in the range of low doses of chronic irradiation (Ofstedal, 1991; Burlakova et al., 1996) and the fact that the whole population of Belarus is being exposed to additional radiation since 1986, long-term monitoring practically of the whole population of Belarus with the reconstruction of individual radiation doses accumulated for a long time should be carried out for correct estimation of the Chernobyl fall-out effect on the frequency of cancer and other diseases.

GENETIC EFFECTS IN GERM CELLS

National genetic monitoring in Belarus was developed by Prof. Lazjuk G. and is functioning since 1979. The Belarusian monitoring can be compared with the monitoring of Eurocat and International Clearinghouse registers by the list of congenital developmental malformations of strict control (anencephalia, meningoceles, cleft lip and/or cleft palate, polydactylia, reduction defect of limbs, atresias of esophagus and anus, Down's syndrome and, separately, the group of multiple malformations) and by the method of their record-keeping. Research by G. Lazjuk (1996) according to the programme of Belarusian national genetic monitoring has revealed that "The frequency of Mandatory Registered Congenital Malformations has increased significantly since 1986 in all the regions of Belarus, being most pronounced in embryos, foetuses, and neonates from the areas with ¹³⁷Cs contamination of 15 Ci/Km² (555 kBq/m²). The observed increase in the congenital malformation frequency in neonates considerably exceeds the predictions made by the International Commission on Radiological Protection" (Lazjuk, 1996).

As seen from Table 4 an increase in the number of children with congenital and hereditary malformations in the so-called clean regions made up 24%, in the regions with

¹³⁷Cs contamination density from 1 to 5 Ci/km² did 30% and in the areas with contamination density of 15 Ci/km² and above made up 83%. Annual rise in all malformations observed was also revealed.

Table 4. Frequencies (per 1000 births) of congenital developmental malformations (CDM) of strict control in 3 zones of Belarus (1982–1992)

Year of observation	Contamination zones		Control group
	1–5 Ci/km ²	>15 Ci/km ²	
1982	5.74	3.06	5.62
1983	3.96	3.58	4.52
1984	4.32	3.94	4.17
1985	4.46	4.76	4.58
1982–1985	4.61	3.87	4.72
1987	5.54	8.14	5.94
1988	4.62	8.61	5.25
1989	6.32	6.50	5.80
1990	7.98	6.00	6.76
1991	5.65	4.88	5.52
1992	6.22	7.77	5.89
1987–1992	6.01*	7.09*	5.85*
Coefficient of increase	1.3	1.8	1.2

* $P < 0.05$

(From: Lazjuk et al., 1996)

The data of official statistics (Table 5) on recording infants with congenital malformations (CM) in obstetric institutions of the whole Republic of Belarus show a great increase in CM frequency (from 12.5 per 1000 infants in 1985 to 17.7 per 1000 infants in 1994 (Lazjuk et al., 1996; Lazjuk et al., 1998). However, if one takes into consideration the number of pregnancies that were aborted due to genetic indications (above 1500 pregnancies over the period of 1991–1994), the frequency of embryonal developmental disturbances doesn't prove to be stabilised. It proceeds to increase (from 18.2 in 1992 to 22.4 in 1994).

Lazjuk G. has compared mean doses, i.e. the sum of the effective equivalent doses of external and internal irradiation for the settlements where the parents lived with the frequency of CDMs in their children (Table 6) (Lazjuk, 1996). No direct relationship between the frequency of CDMs and the dose taken by one or both parents before fetus conception was observed. It should be noted, however, that the study on the function of individual dose distribution for the population in radiocontaminated areas showed that individual doses can be 5–6 times as high as the mean dose values (Keirim-Markus et al., 1995).

Taking into consideration the absence of significant correlation between the frequency of congenital developmental malformations and the Chernobyl dose, as well as rise in developmental malformations in “clean” regions Lazjuk G. supposes “The given data, in particular a great increase in malformations of multifactorial origin, indicate that the increase in embryonal development disturbances in the population of Belarus is caused not only and, possibly, not so much by ionizing radiation, as by additional factors”. Such additional factors can be the following: inferior diet, chemical environmental pollutants, alcoholization of reproductive age population and many others.

Table 5. Absolute numbers and congenital developmental malformation (CDM) frequency in children in Belarus (The data of official statistics)

Year	Absolute number of CDM	Frequency per 1000 births
1985	2101	12.5
1986	2273	13.2
1987	2262	13.8
1988	2276	13.9
1989	2273	14.8
1990	2395	16.8
1991	2146 (261)*	16.2 (18.2)**
1992	2180 (367)*	17.0 (19.9)**
1993	2009 (400)*	17.0 (20.4)**
1994	1968 (523)*	17.7 (22.4)**

* is the number of abortions due to genetic indications;

** is the total CDM frequency (the data of the Research Institute for Congenital and Hereditary Diseases at the Ministry of Public Health of the Republic of Belarus).

Table 6. Frequency of congenital developmental malformations (CDM) in ^{137}Cs contamination zone

Dose taken by puerperas (1986–1988)	CDM frequency per 1000 births (1987–1989)
0.8–1.4	7.02
1.4–2.3	8.67
2.4–8.14	8.14

(From: Lazjuk et al., 1996)

However interpretation of sharp increase in developmental malformations of strict control after 1986 and annual rise in all recorded developmental malformations should be quite different, in my opinion. My opinion is based on the following aspects:

The so-called “clean” regions in Belarus are also radiocontaminated. The myth on clean region greatly affects the researchers.

The forms of dose-effect relationships in the range of low doses of prolonged chronic irradiation remain uncertain. There is evidence for the existence of plateau phenomenon on dose curves. Therefore in the range of low doses a monotonous rise in the frequency of congenital developmental malformations with the dose increase might not be.

The type of nourishment for the whole population in Belarus is practically similar though in 1986–1989 the attempts were made to improve nourishment of people in the most contaminated regions.

The amount of chemical pollutants was considerably reduced due to crisis in economy and annual rise in embryonal developmental malformations is still observed. The above-stated, with good reason, makes it possible to regard an unquestionable fact of a dramatic increase in congenital developmental malformations as obvious consequence of the Chernobyl irradiation (Goncharova, 1998, 1999).

The results of comparing CDM frequencies over the period of 1982–1995 in country people of Gomel and Mogilev Regions (as the most radiocontaminated due to the CNPP accident) with cumulative average group and collective doses absorbed by the people of these Regions are given in Table 7 (Lazjuk et al., 1998, 1999). As the control were examined similar parameters in countryside of Vitebsk Region which was considered by authors as noncontaminated due to the Chernobyl accident.

Table 7. Comparison of CDM frequencies with additional radiation doses obtained by rural population of Belarus at the age of 18 years and older

Region under observation	Frequency of CDM per 1000 births		Average cumulative dose by Chernobyl (mSv)	Cumulative dose per % increase of CDM (mSv / %)
	1982–1985	1987–1995	1986–1994	
Gomel Region	4.06±0.39 Increase: 87 %	7.45±0.24	13.4	0.31
Mogilev Region	3.50±0.53 Increase: 83 %	6.41±0.30	8.82	0.20
Vitebsk Region	3.60±0.63 Increase: 47 %	4.75±0.27	0.24	—

(From: Lazjuk et al., 1998, 1999)

As seen from Table 7, SDM gain for inhabitants of Vitebsk Region made up 47 % and, in the authors' opinion, was not related to the impact of ionizing radiation. Therefore they assume that "only CDM increase in Gomel and Mogilev provinces by 40 % and 36 %, respectively (87–40 % and 83–47 %) can be considered in some way an additional irradiation consequence" (Lazjuk et al., 1999).

The authors note the existence of a positive correlation between the CDM frequency and collective and average group radiation doses and the absence of linear dose-effect relationship. They believe that a radiation factor play a certain role in the CDM dynamics. However, as mentioned above, the whole Republic of Belarus, including Vitebsk Region is radiocontaminated (Atlas, ... 1998). The ^{137}Cs value, due to the Chernobyl fallout, for environmental objects, mammals and for inhabitants of Vitebsk Region corroborate well this fact (Harlenok et al., 1999; Goncharova, Riabokon, 1998). Thus, I think the presence of the positive correlation shown in the works of Lazjuk et al. (1998, 1999) confirms that increased CDM frequencies in Belarus after 1986 were caused by low-dose radiation impact due to the Chernobyl accident. As to the form of dose dependence for genetic effects in human germ cells in the range of low doses, this is another problem that requires additional study.

Discrepancy between the data of Lazjuk et al. (1996) and those for children whose parents had suffered from atomic bombardments in Japan seemed to be caused by different conditions of radiation as a result of the Chernobyl disaster and atomic explosions.

The joint research work of English, Russian and Belarusian investigators (Dubrova et al., 1996) on the frequency of mutations in children whose both parents constantly lived in the radiocontaminated Mogilev Region of Belarus since the instant of the catastrophe is of great interest. The range of area contamination was from 1 to 15 Ci/km². An

accurate dose taken by the parents was unknown. The ^{137}Cs contamination level of the area, however, was a satisfactory indicator for moderate collective radiation dose. The children born in February – September 1994 in 79 families formed the group under examination. Since the whole Belarus is radiocontaminated, the children from 105 families of the Great Britain formed the control group. The frequency of mutations in minisatellite loci of the children from Mogilev Region turned out to be increased twice, the total mutation number in the more contaminated regions was 1.5 time as much as in the less contaminated ones. So, the mutation frequency was shown to be correlated with the caesium contamination level of the area.

What is the dose absorbed by the people in Mogilev Region over the years 1986–1994? Its accurate value is unknown. However, according to the assessment made in Belarus (Kenigsberg, Minenko, 1996) an individual equivalent dose due to external and internal irradiation is no less than 5 mSv per year (0.5 rem). An accumulated dose for 9 years achieves about 45 mSv or 4.5 rem. Reconstruction of cumulative doses of each family pair allowed Dubrova et al. (Dubrova et al., 1999) to prove statistically significant relationship between the observed mutation frequencies in minisatellite loci of children and the value of the family absorbed dose of chronic irradiation from ^{137}Cs from the time of the accident up to the conception of the child. The family dose value was determined as respective paternal and maternal dose average value. The main dose for all the studied families constituted 27.6 ± 3.3 mSv.

This research work presented statistically significant data of two-fold increase in the mutation frequency in germ cells of irradiated parents. The frequency of molecular changes in minisatellite loci was increased to a greater extent in liquidators' children (Weinberg et al., 1997). It should be noted that it is an unexpectedly high frequency of mutability for mutations under the influence of radiation. The value of a double dose for mutations in human germ cells resulting in serious consequences for progeny health makes up 1 Gy (United Nations. Sources, Effects and Risk of Ionizing Radiation, 1988). The origin of molecular changes in minisatellite loci was established incompletely, in particular their recombination origin is discussed (Buard, Vergnaud, 1994; Jeffreys et al., 1998). Mutations in tandem repetitive sequences of minisatellites are assumed to occur as a result of DNA double-strand breaks (Buard, Vergnaud, 1994).

This is a very small dose in comparison with the value of the double dose for human germ cells equal to 1 Gy.

Dubrova et al. admit that either the estimates of the dose taken are rather reduced or low doses of chronic irradiation are much more effective inductors of mutations than high doses of acute irradiation. However reduced the estimates of the taken doses were, they, nevertheless, will be much lower than the accepted value of the double dose (Health effects ..., 1990).

For a long time I am developing an idea of far higher efficiency of chronic combined external and internal irradiation induced by the radionuclide compared to acute or prolonged irradiation (Goncharova, Riabakon, 1995; Goncharova, 1996; Goncharova et al., 1999).

A significant gain in the frequency of congenital and hereditary pathology in children of the first irradiated generation as well as an increased minisatellite mutation frequency

in germ cells (Dubrova et al., 1996) at low effective equivalent doses received by their parents indicates a mutagenic effect of low doses of Chernobyl radiation.

There are forcible grounds for supposition that the value of a double dose calculated on the basis of the data obtained for high radiation doses is much higher than a double dose calculated by genetic effects of low doses. Thus, when estimating a genetic risk of the Chernobyl disaster, one should not base oneself completely upon the data obtained for Japan. Now, when confidential information on morbidity of people exposed to long-term chronic irradiation in the Urals, Kazakhstan, the Altai and many other places of the former USSR became available, were initiated investigations on determining risk values for carcinogenic effects of chronic irradiation (Gusev et al., 1998; Kossenko et al., 1999). Just determination of risk coefficients for chronically irradiated populations of the former USSR and people exposed to radiation due to the Chernobyl accident (Jacob et al., 1996) will give a reply to the question whether risk coefficients differ for acute irradiation and long-term chronic irradiation in the range of low and medium doses.

Long-term investigations by T. Nomura (1982, 1984, 1988) in mice have shown that:

- a) mutations resulting in phenotypic anomalies (transplacental heritable anomalies) emerge in germ cells under the influence of radiation
- b) occurrence frequency of such mutations is 4–40 times as high as that of other types of mutations;
- c) sensitivity patterns of germ cells of mice and man to emergence of heritable phenotypic anomalies according to Nomura's data are similar.

Taking into account the above-stated points, increased radiosensitivity of subsequent mammal generations to radionuclide mutagenic effect illustrated by us (Goncharova, Ryabokon, 1995; Goncharova et al., 1996) and some other aspects, I think that for Chernobyl conditions (constant irradiation of a number of generations) an increased frequency of hereditary defects in children will remain in the present irradiated generation and after 1996, but it will increase in subsequent generations till it reaches an equilibrium state (Goncharova, 1996, 1998, 1999).

GENETIC EFFECTS IN SOMATIC CELLS

The study on dynamics of the mutation process in bank vole populations inhabiting radiocontaminated regions of Belarus has shown that over the period of 1986–1996, i.e. within many generations (1–22) increased levels (in comparison with pre-accident levels) of chromosome aberrations and genome mutations (polyploidy) which occur in every generation *de novo* were observed in bone marrow cells of animals (Goncharova et al., 1996). The frequencies of genome mutations gradually and considerably increased up to 1991 in the populations at all stations studied reaching 14–15% in heavily radiocontaminated regions (Goncharova, Ryabokon, 1995; Goncharova, Ryabokon, 1998). We have revealed an increased radiosensitivity of hereditary structures of bank vole somatic cells of subsequent generations (animals of 1989–1991) in comparison with

the previous generations (animals of 1986–1988) to the mutagenic influence of Chernobyl fall-out (Goncharova, Ryabokon, 1995; Goncharova et al., 1999). Our and other research works show that chronic irradiation of various animal species inhabiting radiocontaminated areas gives measurable cytogenetic effects in somatic cells at very low levels of absorbed doses (according to Cristaldi et al., 1991 for bank vole in Sweden – $4\text{--}40 \times 10^{-6}$ Gy/day, and according to our data (Goncharova, Smolich, 1998) for the same animal species from Belarus it is $(2.4\text{--}41.2) \times 10^{-6}$ Gy per day or per cell cycle).

Numerous data have shown that increased frequencies of cytogenetic damages are characteristic, during some years, of blood cells of people living in the radiocontaminated territories.

Rather demonstrative are the results of examination of 80 persons who lived in towns Mozyr, Gomel (contamination density $37\text{--}185$ kBq/m²), Bobruisk and Kiev (contamination density below 37 kBq/m²) in 1986 and then in 1989–1991 they emigrated to the USA. Shortly after arrival in the USA these people were thoroughly examined: for the purpose of determining concentration of incorporated caesium isotopes in the whole body, analysing micronuclei in lymphocytes and gene mutations in glycophorine locus in erythrocytes in heterozygous M/N individuals (Livingston et al., 1997).

Having used the multiple regression analysis of the data obtained for all the examined 80 persons, the authors established that the frequency of micronuclear lymphocytes depended on the radiocaesium concentration ($0\text{--}56.8$ Bq/kg) and the internal absorbed dose ($0.6\text{--}9.2$ mGy). The frequency of gene mutations in blood erythrocytes also depended significantly on the concentrations of incorporated caesium. Thus, Livingston et al. (Livingston et al., 1997) have demonstrated increased frequencies of chromosome and gene mutations in somatic cells of people who lived for 3–5 years in low-contaminated areas and proved their radiation causality. Hence, it should be noted that the experts of the International Chernobyl Project (International Advisory Committee..., 1991) did not reveal increased frequencies of chromosome aberrations and gene mutations in glycophorine locus of inhabitants living in much more contaminated regions. So, for a long time increased mutability in somatic cells was revealed to be peculiar to mammals and people exposed to chronic radionuclide effect and absorbing low dose loads. Extrapolation does not predict such results.

Genetic radiosensitivity of mammals and man is known to be quite close. Taking into account the above-stated and considering increased radiosensitivity of animals of subsequent generations, one can assume that an increased frequency of different type cytogenetic damages in somatic cells of people living in radiocontaminated regions will remain for quite a long time after 1996. Since chromosome aberrations are a prognostic test, the presence of increased frequencies and other types of mutations (gene, viability mutations etc.) should be expected (Goncharova, 1996).

Consequences of such a permanently increased level of somatic cell mutability for viability of living objects are considered below.

HEALTH STATE OF THE PRESENT IRRADIATED GENERATION

Epidemiological investigations have shown that in post-accident period a steady increase in overall morbidity of children, pregnant women and women of reproductive age as well as of the whole population is characteristic of Belarus population living in radiocontaminated regions. According to the data of Belarusian National Register on the contaminated regions overall morbidity indices are higher than the average republican data. A gain in diseases of thyroid gland, circulatory system, cardiovascular system (including especially cardiac ischemia), liver and pancreas is particularly pronounced. There is emerged the tendency towards a rise in infant death rate. An increase in the incidence of diabetes in liquidators was observed, the maximal rise being recorded in the age group of 30–39 years. (Ecological, medicobiological and socio-economic consequences of the Chernobyl NPP Disaster in Belarus, 1996)

There are different points of view on reasons of increased morbidity of people exposed to additional chronic radiation.

An increased level of cytogenetic damages in somatic cells was observed in people living in radiocontaminated areas. The influence of an increased frequency of different type mutation in somatic cells on people's health is not found out for the present. However now more information on the contribution of somatic cell mutations to occurrence of diseases such as atherosclerosis, heart diseases, diabetes, emphysema etc. is accumulated.

It allows us to propose an idea on the relation of increased morbidity and reduced steadiness of people to the influence of any stress factors with increased mutability of their somatic cells. In such sense additional irradiation of people in radiocontaminated areas is a factor promoting their increased sensitivity to any unfavourable effects.

So, I think that an increased sickness rate of the population living in radiocontaminated areas is a consequence of chronic low-dose radiation (Goncharova, 1996, 1998).

And actually, the investigations pursued under the leadership of Yu.I. Bandazhevsky at Gomel Medical Institute have shown the relationship between morphofunctional changes in kidneys and myocardium resulting in serious lesions of these vital organs, and the concentration of incorporated radiocaesium in people (Bandazhevsky et al., 1999). The relationship between morphofunctional changes in reproductive system, disturbance in hormonal homeostasis and the content of caesium isotopes in organism of young women, who didn't give birth, was also revealed (Yagodvik I.N., 1998). Pathology of lipoperoxide cascade and irreplaceable bioantioxidants in children from the radiocontaminated regions due to the Chernobyl accident was proved to be of radiogenic aetiology (Neifakh et al., 1998).

A statistically significant association between non-cancer mortality and radiation doses among atomic bomb survivors in Japan has also been evident for some time. So, Mabuchi K. (Mabuchi, 1998) reported a significant dose response to mortality from stroke and diseases of a heart, respiratory system and digestive system.

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