ECRR Conference in Molyvos, Lesvos, May 2009

How reliable are the dose estimates of UNSCEAR for populations contaminated by Chernobyl fallout? A comparison of results by physical reconstruction and biological dosimetry.

Inge Schmitz-Feuerhake

According to the United Nations Committee on the Scientific Effects of Atomic Radiation UNSCEAR which is adopted by the World Health Organisation WHO in evaluating the sequels of the Chernobyl accident the average dose of the population in the contaminated regions was very low – except for the thyroid in the nearby countries. The main contributions for the other tissues are thought to be generated – externally and internally – by the cesium isotopes 137 and 134. Relevant nuclides for the exposure as Sr-90 and Pu-239 are assumed to be negligible in distances greater than 100 km from the plant. Even for highly contaminated regions outside the evacuation zone where more than 37 kBq/m^{2}of Cs-237 surface activity were measured the mean effective dose was estimated to only about 10 mSv. For the neigbouring country of Turkey und the Central European countries in greater distances the estimated exposures remain below 1.2 mSv (effective dose).
These results are in contradiction to findings by biological dosimetry. Several research groups investigated radiation-specific cytogenetic alterations in the lymphocytes of persons in the contaminated regions directly after the accident or some years later. The majority of studies revealed that the rate of unstable and stable chromosome aberrations is much higher – by up to about 1 to 2 orders of magnitude – as would be expected if the physically derived exposures were correct. A further finding was the occurence of multiaberrant cells which indicate a relevant contribution of incorporated alpha activity. Emitted nuclear fuel and breeding products should therefore be considered in the physical dose calculations.

Introduction

Many observations about cancer and other radiation effects in the populations affected by Chernobyl fallout are denied by UNSCEAR and other international committees refering to the very low exposures which were derived by physical considerations. It is therefore important to realize that numerous reports in the literature show different results. The authors base their estimates either on own calculations or on EPR measurements in teeth or on cytogenetic studies which have been applied for the purpose of biological dosimetry.

We have compiled data about radiation-induced chromosome aberrations because they allow an assessment whether the physically derived value will grossly underestimate the true exposure. Some thousand persons have been investigated in the contaminated regions by cytogenetic methods who can be considered as random sample of the population living there. For such comparison, we prefer the results about dicentric chromosomes in the lymphocytes together with centric rings. These aberrations can be regarded as radiation-specific (Hoffmann and Schmitz-Feuerhake 1999).

Dicentric chromosomes are used as biological dosimeter since decades (Fig.1). They are instable, i.e., they leave the system with half-lives of about 1.5 years. The reason is that they fail to undergo a division in about 50 % of cases because of the two centromers. The advantage is, however, that the background rate remains low. Further, the background rate is almost constant over the world (only about 4 dicentric chromosomes in 10.000 metaphases of adults, 1 in 100.000 of children). Therefore, the method is very sensitive. The doubling dose is about 10 mSv for an acute and homogeneous whole body exposure. But even this method would show no significant elevation in a population if the average additional dose does not exceed a few mSv.

Centric rings (cr) are usually counted together with the dicentric chromosomes (dic). They are originated by the same primary mechanism. They undergo division without loss and thus they are stable, but they are generated less frequently (only 10% in comparison to dic). Sometimes, it is therefore possible to derive from the relation between cr and dic that the exposure occured far back in the past.

The application of dose-effect relationships for chromosome aberrations demands an homogeneous whole body exposure which is usually not fulfilled in the case of incorporated radioactivity. The element cesium is, however, considered to distribute homogeneously in the body. Therefore, if the exposure is mainly generated by Cs 134 and Cs 137 – externally and internally – as claimed by UNSCEAR, the method can be used to decide whether the calculated dose values are realistic.

Another important information is given by the distribution of the aberrations among the cells. For low doses, a low LET radiation (gamma, x-rays) leads to a Poissonian distribution of the dic, i.e., there is usually only one dic per cell. If an overdispersion appears, i.e., a clustering of dic and/or multiple aberrations in a cell, it is an indication for densely ionizing radiation.

Fig.1 Dicentric chromosomes (black arrows) in a human metaphase and associated acentric fragments after high dose exposure (from Fritz-Niggli 1997)

We refer also to results of the studies about reciprocal translocations in lymphocytes (visualized by FISH) which are used to estimate the accumulated dose because these aberrations are also stable. The background rate is, however, highly variable and accumulating with age, therefore the sensitivity is not always sufficient to evaluate exposures by environmental radioactivity.

Chromosome aberration studies in evacuees

One day after the accident 45.000 inhabitants were evacuated from Prypiat, further 90.000 persons from the 30 km zone 7-9 days later (Imanaka and Koide 2000). The evacuation was finished 18 days after the accident. The evacuees were therefore exposed to very different degree. Among them acute radiation effects were registered by official report which means that whole body doses above 1 Sv have been reached.

A mean effective dose estimate for this population of 14 mSv is reported by UNSCEAR and WHO (UN 2005). The external dose alone was derived by Imanaka and Koide (2000) to 20-320 mSv. An estimate of Pröhl et al. (HP 2002) including the internal exposure lead to values for adults between 6 and 330 mSv and for the 1 year old child between 13 and 880 mSv.

Results of chromosome aberration studies in random samples of the evacuees are shown in table 1. All investigations show significant elevations of the mean rate of dic+cr even when they were carried out several years after the main exposure. Elevation factors of 3 to 100 correspond to at least mean doses of 20 mSv to 1 Sv assuming homogeneous whole body exposure. Maznik and coworkers derive a mean dose of about 400 mSv for the evacuees from their chromosome studies which is higher by a factor 30 than the value given by UNSCEAR.

Chromosome studies in highly contaminated regions

Tables 2 and 3 show the results of chromosome studies in highly contaminated regions. They also exceed by far the physical dose estimates assumed by UNSCEAR. Remarkable is the appearance of overdispersion and multiaberrant cells which proves a significant contribution of incorporated alpha activity.

Table 1 Biological dosimetry in evacuees from the 30 km zone

Dic dicentric chromosomes, cr centric rings

Region	Sample	Date of investiga-tion	Method	Results Mean elevation & specialities	Authors	Remarks
Evacuees from Prypiat and nearby	43 adults	1986	Dic	18-fold No overdisper-sion	Maznik et al. 1997	Result of the cited authors 430 mSv
Evacuated zone	60 children	1986	Dic+cr	15-fold No overdisper-sion	Mikhalevich et al. 2000	Result of the cited authors 400 mSv
Evacuees from Prypiat and nearby	102 adults 10 children	1987-2001	Dic+cr	Maximum 18-fold in 1987, then decline but staying sign. elevated	Maznik 2004	Result of the cited author 360 mSv
Evacuated zone	244 children	1991	Dic+cr	circ 100-fold*)	Sevan´kaev et al. 1993	Dose calculation after IAEA (1991) 1-8 mSv
Evacuated from Pripyat	24 children	1991-1992	Dic	circ 3-fold*)	DeVita et al. 2000	
Evacuated zone	12 adults	1995	Dic+cr	7-10 fold *)	Pilinskaya et al. 1999	
Evacuation zone, residents	33 adults, not evacuat-ed	1998-1999	Dic+cr	5.5-fold	Bezdrobnaia et al. 2002	

*) estimation by the writers

Table 2 Biological dosimetry in inhabitants of Gomel and Gomel region

Dic dicentric chromosomes, cr centric rings Tralo translocations

Sample	Date of investiga-tion	Method	Results Mean elevation & specialities	Authors	Remarks
43 pregnant wom-en 18 infants	1986-1987	Dic+cr	5-fold 40-fold	Feshenko et al. 2002	
8 persons	1988-1990	Dic+cr	circ 40-fold*)	Serezhenkov et al. 1992	Comparison with ESR
330 healthy adults	1988-1990	Dic+cr Tralo, FISH	15-fold 6.5-fold	Domracheva et al. 2000	
46 patients with hematol. malignan-cies	1988-1990	Dic+cr Tralo, FISH	(6-18)-fold (6.5-16)-fold	Domracheva et al. 2000	
35 adults	1990	Dic	circ 30-fold*) overdispersion; 2 multiaberrant cells	Verschaeve et al. 1993	
36 children	1994	Dic	(3.2-8)-fold	Barale et al. 1998	
20 children	1996	Tralo, FISH	3-fold significant	Scarpato et al. 1997	Controls from Pisa
70 children	1996	Dic+cr	18-fold	Gemignani et al. 1999	10 years after the accident !!

*) Estimation by the writers

Table 3 Biological dosimetry in highly contaminated regions > 37 kBq/m^2
Dic dicentric chromosomes, cr centric rings

Region	^{137}Cs kBq/m^2	Sample	Date of investiga-tion	Method	Results Mean elevation & specialities	Authors	Remarks
Ukraine/Lugyny district Malahovka		130 children	1988-1990	Dic+cr	Increase to 6.6-fold in 1990	Eliseeva et al. 1994	Effect not explainable by ^{137}Cs
Russia/Kaluga region Mladenik Ogor	 140 43	 17 adults 16 adults	 1989	 Dic+cr	 circ 5-fold*) circ 2-fold*)	 Bochkov et al. 1991	
Russia/Bryansk region Clynka Yordevka Klincy Russia/Kaluga region Uljanovo Chicdra	 633 444 230 140 100	 61 adults 432 adults 170 adults 666 adults 548 adults	 1989-1998	 Dic+cr	 7-fold 1.5-fold 2-fold 4-fold 2.5-fold	 Sevan´kaev 2000	 2 multiaberrant cells 27 multiaberrant cells
Kaluga-Bryansk region Uljanova district Chicdra district	 200 100	 333 children & juveniles 407 children & juveniles	 1989-1998 1990-2003	 Dic+cr	 3-fold 3.7-fold no decline	 Sevan´kaev et al. 2005	 Physical estimates (to 2001) 11.4 mSv and 6.7 mSv
Ukraine region	> 550	6 adults	1991	Dic	circ 5-fold*)	Ganina et al. 1994	
Bryansk and Bryansk region	> 550	1300	1992	unstable; stable	5 % > 400 mSv 1 % 1000 mSv	Vorob´ev et al. 1994	Physical estimate 17-35 mSv multiaberrant cells
Bryansk region Mirnye	> 1100	100 adults	1993	cr	4-fold 6 multiaberrant cells	Salomaa et al. 1997	Controls from Krasnye Rog < 37 kBq/m^2 (Dics 0,43%, multiaberrant cells 2)

*) Estimation by the writers

Biological dosimetry in western parts of Europe

In Austria and Germany, the Alps regions were predominantly affected by Chernobyl fallout which was washed out there by rain falls. Some chromosome studies were therefore also carried out in these regions. Pohl-Rüling et al. (1991) studied 16 adults of Salzburg city, Austria, in 1987 (June-August). The results for dic+cr are given in Table 4. The physical dose estimate was derived by the authors using UNSCEAR modeling. Two of the citizens had been studied already in 1984/1985, i.e., before the accident. They were followed up also in 1988 and 1990 (Fig. 2).

Stephan and Oestreicher (1993) studied 29 persons in Berchtesgaden, Germany, which is only 20 km away from Salzburg. Two areas with low contamination in southern Germany, Baden-Baden and Tirschenreuth (near to the Czech frontier), were selected for control (Table 4). The physical dose estimates were taken by the authors from German authorities. The elevation factors given for the dic+cr rate in table 4 were derived by us using the former published labor control of the authors 0.9 10^{-3} (Stephan and Oestreicher 1989).

Table 4 Biological dosimetry in persons living in West European regions contaminated by Chernobyl releases

Region	Sample	Date of study	Results		Physical excess dose estimate
			dic+cr	overdispersion	
Austria Salzburg	16 adults	1987	6-fold		0.1-0.5 mSv
Germany Berchtesgaden	27 adults and 2 children	1987-1991	3-2 fold	6 cells with 2 dic	≤1.6 mSv
Baden-Baden	20 adults	”	3-fold	In 1 person 3 cells with 2 dic	<0.14 mSv
Tirschenreuth	11 adults	”	2-fold	1 multiaberrant cell	<0.14 mSv
Berchtesgaden Subgroup	5	87/88	3-fold		
“	”	90/91	1.6-fold		
Norway, selected regions	44 reindeer sames and 12 sheep farmers	1991	10-fold		5.5 mSv

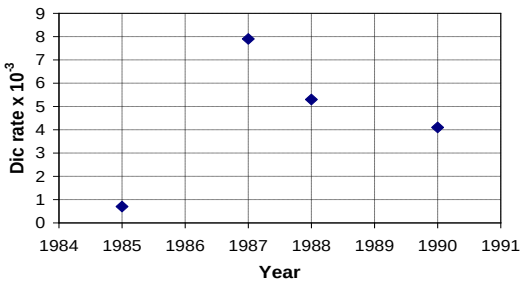

Fig.2 Mean rate of dic+cr in 2 citizens of Salzburg (Pohl-Rüling et al. 1991)

Both studies in the Alps region lead to elevations of dic+cr which are far above the equivalent calculated excess exposures. While the Salzburg investigators found a correlation between aberration rate and measured Chernobyl deposition, the German investigators doubted the causation by radiation because of the high aberration rates in their controls. In contrast to this they found a significant decrease with time in a subgroup of the Berchtesgaden sample (Table 4). Further there were several cells showing an overdispersion of aberrations and therefore an incorporation of alpha radioactivity.

Norway was contaminated in spots up to 600 kBq/m^2 of Cs 137. Brogger et al. (1996) carried out chromosome studies in three such regions and found a 10-fold elevation of dic+cr still 5 years after the accident. The doses were calculated based on whole body counter measurement of Cs 134 and Cs 137 using dose conversion factors of the ICRP. The authors interprete the enormous discrepancy to the aberration findings as due to a biphasic dose-response. Salbu et al. (2004) reported that radioactive particles from Chernobyl were released predominantly by the fire after the explosion which contributed significantly to the population exposure even in Norway. They contained fission products but also heavy fuel and breeding products as U and Pu.

Discussion

Some of the cited authors used control cohorts from so-called uncontaminated regions, e.g. from Kyiv or Minsk. Persons living there show, however, significant elevations compared to background rates in really non-exposed individuals even after several years. This can be explained by the consumption of contaminated food.

To evaluate the real mean exposure of the population such investigations in the regions of low surface contamination by Cs-137 would be most informative. They are also to find in the literature. It must be mentioned that this present compilation of data is preliminary and incomplete.

Conclusions

Cytogenetic studies which are suitable to evaluate the dose estimates in regions contaminated by Chernobyl fallout were done in some thousand persons. The following conclusions can be drawn:

1. Assuming predominant exposure by external and internal Cs-137 the rate of dic+cr allows to estimate a minimum accumulated dose and using FISH to estimate the accumulated dose in the highly contaminated regions. Physically estimated dose values can therefore be falsified if being much lower.
2. Clustering of the aberrations in the cells and/or multiaberrant cells are a reliable indicator of incorporated alpha activity. This was observed in several studies outside the distance of 100 km from the source and means that the assumption of UNSCEAR that fuel and breeding products are abroad negligible is wrong.
3. If the rate of the instable dic does not or not adequately decline over years, which is shown in some of the studies, the exposure can also not be generated by predominant Cs-137 contribution because of the short biological half-life of Cs (circ 100 days), otherwise one had to assume a still increasing Cs-contamination in the food.
4. The dose assumptions of UNSCEAR have to be revised. The physical estimates of other authors and the numerous EPR-measurements should be also taken into account.
5. Statements that an observed effect can not be radiation-induced because there is no dose-effect relationship should be checked regarding the assumptions for dose calculation. A lacking correlation with the ground contamination by Cs-137 dose not justify such a conclusion.

Barale, R., Gemignami, F., Morizzo, C., Lori, A., Rossi, A., Antonelli, A., Di Pretoro, G., Panasuik, G., Ballardin, M.: Cytogenetic damage in lymphocytes of healthy andd thyroid tumor-affected children from the Gomel region (Belarus). Mutat. Res. 405 (1998) 89-95

Barcinsky, M.A., Abreu, M.C.A., de Almeida, J.C.C., Naya, J.M., Fonseca, L.G., Castro, L.E.: Cytogenetic investigation in a Brazilian population living in an area of high natural radioactivity. Am. J. Hum. Genet. 27 (1975) 802-806

Bezdrobnaia, L.K., Tsyganok, T.V., Romanova, E.P., Tarasenko, L.V., Fedorchenko, V.I.: Dynamic study of the cytogenetic effects in blood lymphocytes from humans living in the Chernobyl Atomic Energy Station exclusion zone without permission. Radiats. Biol. Radioecol. 42 (2002) 727-30 (in Russian)

Bochkov, N.P., Katosova, L.D., Sapacheva, V.A., Platonova, V.I., Smirnova, T.D., Pitkevich, V.A.: Cytogenetic analysis of the peripheral blood lymphocytes in people residing in regions of the Kaluga Oblast polluted with radionuclides. Med. Radiol. (Mosk.) 36 (1991) 50-52 (in Russian)

Bochkov, N.P., Katosova, L.D.: Analysis of multiaberrant cells in lymphocytes of persons living in different ecological regions. Mutat. Res. 323 (1994) 7-10

Brogger, A., Reitan, J.B., Strand, P., Amundsen, I.: Chromosome analysis of peripheral lymphocytes from persons exposed to radioactive fallout in Norway from the Chernobyl accident. Mutat. Res. 361 (1996) 73-79

Domracheva, E.V., Aseeva, E.A., Obukhova, T.N., Kobzev, Y.N., Olshanskaya, Y.V., D`achenko, L.V., Udovichenko, A.I., Zakharova, A.V., Milyutina, G.I., Nechai, V.V., Vorobiov, A.I.: Cytogenetic features of leukaemias diagnosed in residents of areas contaminated after the Chernobyl nuclear accident. Appl. Radiat. Is. 53 (2000) 1171-1177

Eliseeva, E., Iofa, E.L., Stoian, E.F., Shevchenko, V.A.: An analysis of chromosome aberrations and SCE in children from radiaiton-contaminated regions of Ukraine. Radiats. Biol. Radioecol. 34 (1994) 163-171 (in Russian)

Feshchenko, S.P., Schröder, H.C., Müller, W.E.G., Lazjuk, G.I.: Congenital malformations among newborns and developmental abnormalities among human embryos in Belarus after Chernobyl accident. Cell. Mol. Biol. 48 (2002) 423-426

Fritz-Niggli, H. (1997) Strahlengefährdung/Strahlenschutz, 4th ed., Hans Huber, Bern, Switzerland

Ganina, K.P., Polischuk, L.Z., Buchinskaya, L.G., Nesina, I.P., Kindzel`skii, Demina, E.A., Usatenko, V.D., Chebotareva, E.D., Yakimova, T.P., Maznik, N.A., Nikiforova, N.A.: Cytogenetic investigation in individuals exposed to radiation in some regions of Ukraine. Tsitologiya i Genetika 28 (3) (1994) 32-37

Gemignani, F., Ballardin, M., Maggiani, F., Rossi, A.M., Antonelli, A., Barale, R.: Chromosome aberrations in lymphocytes and clastogenic factors in plasma detected in Belarus children 10 years after Chernobyl accident. Mutat. Res. 446 (1999) 245-253

Hoffmann, W., Schmitz-Feuerhake, I.: How radiation-specific is the dicentric assay? J. Exp. Analysis Environ.Epidemiol.2(1999)113-33

Jiang, T., Hayata, I., Wang, C., Nakai, S., Yao, S., Yuan, Y., Dai, L., Liu, Q., Chen, D., Wei, L., Sugahara, T.: Dose-effect relationship of dicentric and ring chromosomes in lymphocytes of individuals living in the high background radiation areas in China. J. Radiat. Res. 41, Suppl. (2000) 63-68

Imanaka, T., Koide, H.: Assessment of external dose to inhabitants evacuated from the 30-km zone soon after the Chernobyl accident. Radiats. Biol. Radioecol. 40 (2000) 583-589

Maznik, N.A., Vinnikov, V.A., Lloyd, D.C., Edwards, A.A.: Chromosomal dosimetry for some groups of evacuees from Prypiat and Ukraine liquidators at Chernobyl. Radiat. Prot. Dos. 74, Nos. 1/2 (1997) 5-11

Maznik, N.A.: Long-term follow-up cytogenetic survey and biological dosimetry in persons evacuated from 30-km Chernobyl zone. Radiats. Biol. Radioecol. 44(5) (2004) 566-573 (in Russian)

Mikhalevich, I.S., Lloyd, D.C., Edwards, A.A., Perepetskaya, G.A., Kartel, N.A.: Dose estimates made by dicentric analysis for some Belarussian children irradiated by the Chernobyl accident. Radiat. Prot. Dos. 87, No.2 (2000) 109-114

Padovani, L., Caporossi, D., Tedeschi, B., Vernole, P., Nicoletti, B., Mauro, F.: Cytogenetic study in lymphocytes from children exposed to ionizing radiation after the Chernobyl accident. Mutat. Res. 319 (1993) 55-60

Pilinskaia, M.A., Dybskii, S.S., Red`ko, D.V.: The cytogenetic effect in a group of settlers from a 30-kilomter area of right of way. Tsitol. Genet. 33(6) (1999) 39-44 (in Russian)

Pohl-Rüling, J., Haas, O., Brogger, A., Obe, G., Lettner, H., Daschil, F., Atzmüller, C., Lloyd, D., Kubiak, R., Natarajan, A.T.: The effect on lymphocyte chromosomes of additional burden due to fallout in Salzburg (Austria) from the Chernobyl accident. Mutat. Res. 262 (1991) 209-217

Pröhl, G., Mück, K., Likhtarev, Kovgan, L., Golikov, V.: Reconstruction of the ingestion dose received by the population evacuated from the settlements in the 30-km zone around the Chernobyl reactor. Health Physics 82 (2002) 173-181

Salbu, B., Lind, O.C., Skipperud, L.: Radionuclide speciation and its relevance in environmental impact assessments- J. Environ. Radioactivity 74 (2004) 233-242

Salomaa, S., Sevan`kaev, A.V., Zhloba, A.A., Kumpusalo, E., Mäkinen, S., Lindholm, C., Kumpusalo, L., Kolmakow, S., Nissinen, N.: Unstable and stable chromosomal aberrations in lymphocytes of people exposed to Chernobyl fallout in Bryansk, Russia. Int. J. Radiat. Biol. 71 (1997) 51-59

Scarpato, R., Lori, A., Panasiuk, G., Barale, R.: FISH analysis of translocations in lymphocytes of children exposed to the Chernobyl fallout: preferential involvement of chromosome 10. Cytogenet. Cell Genet. 79 (1997) 153-156

Scheid, W., Weber, J., Petrenko, S., Traut, H.: Chromosome aberrations in human lymphocytes apparently induced by Chernobyl fallout. Health Phys. 64 (1993) 531-534

Serezchenko, V.A., Domracheva, E.V., Klezeval, G.A., Kulikov, S.A., Kuznetzov, S.A., Mordvintcev, P.I., Sukhovskaya, L.I., Schlokovsky-Kordi, N.E., Vanin, A.F., Voevodskaya, N.V., Vorobiev, A.I.: Radiation dosimetry for residents of the Chernobyl region: a comparison of cytogenetic and electron spin resonance methods. Radiat. Prot. Dosi. 42, No.1 (1992) 33-36

Sevan´kaev, A.V., Tsyb, A.F., Lloyd, D.C., Zhloba, A.A., Moiseenko, V.V., Skrjabin, A.M., Climov, V.M.: ´Rogue`cells observed in children exposed to radiation from the Chernobyl accident. Int. J. Radiat. Biol. 63 (1993) 361-367

Sevan´kaev, A.V.: Results of cytogenetic studies of the consequences of the Chernobyl accident. Radiats. Biol. Radioecol. 40(5) (2000) 589-595 (in Russian)

Sevan´kaev, A.V., Mikhailova, G.F., Potetnia, O.I., Tsepenko, V.V., Khvostunov, I.K., Golub, E.V., Piatenkko V.S., Pozdyshkina, O.V., Shepel`, N.N., Matveenko, E.G.: Results of dynamic cytogenetic study of children and teenagers living in areas radioactive by contamination after the Chernobyl accident. Radiats. Biol. Radioecol. 45(1) (2005): 5-15 (in Russian)

Stephan, G., Oestreicher, U.: An increased frequency of structural chromosome aberrations in persons present in the vicinity of Chernobyl during and after the reactor accident. Is this effect caused by radiation exposure? Mutat. Res. 223 (1989) 7-12

Stephan, G., Oestreicher, U.: Chromosome investigation of individuals living in areas of southern Germany contaminated by fallout from the Chernobyl reactor accident. Mutat. Res. 319 (1993) 189-196

UN Chernobyl Forum Expert Group "Health" (EGH). Health Effects of the Chernobyl Accident and Special Health Care Programmes. Geneva: World Health Organisation 2005

Verschaeve, L., Domracheva, E.V., Kuznetsov, S.A., Nechai, V.V.: Chromosome aberrations in inhabitants of Byelorussia: consequence of the Chernobyl accident. Mutat. Res. 287 (1993) 253-259

DeVita, R., Olivieri, A., Spinelli, A., Grollino, M.G., Padovani, L., Tarroni, G., Cozza, R., Sorcini, M., Pennelli, P., Casparrini, G., Crescenzi, G.S., Mauro, F., Carta, S.: Health status and internal radiocontamination assessment in children exposed to the fallout of the Chernobyl accident. Arch. Environ. Health 55 (2000) 181-186

Vorob`ev, A.I., Domracheva, E.V., Klevezal`, G.A., Meshcheriakov, L.M., Moiseeva, T.N., Osechinskii, I.V., Serezhenkov, V.A., Shklovskii-Kordi, N.E.: Cumulative radiation dosage and epidemiological research in the Chernobyl region. Ter Arkh. 66(7) (1994) 3-7