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EU-CIS Joint Study Project 2

Radiological Conditions and Risk Quantifications in CIS

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Abstract The radiological conditions after the Chernobyl accident in the CIS republics Ukraine, Belarus and Russia have been evaluated for the period following 1991. Differential population distributions on dose rate or surface contamination density and differential mass distributions for milk on activity concentration of ^{137} s in milk have been used to calculate individual avertable and residual doses. The residual lifetime doses in the three republics with reference to the year 1991 have been calculated to be of the order of 30 mSv on average. The potential avertable individual lifetime doses are therefore less than the lifetime doses from the natural background radiation and less than 10% of the variation of the lifetime doses from natural background radiation in Europe. The corresponding residual individual lifetime risks have been calculated from the European ASQRAD model to be of the order of 0.06–0.14%, depending on age at start of exposure, and assuming an effective half-life of the annual exposure of 10 years and a dose and dose rate effectiveness factor (DDREF) of 2. A risk model is being developed in Russia for the assessment of risks to the exposed populations from atmospheric nuclear weapons tests in the Semipalatinsk region (Altai region) in the forties and fifties. Calculated age-dependent risks from an acute exposure of the Altai population have been compared with results from similar calculations with the ASQRAD model and reasonable agreement has been found between the two models.

This work has been performed as a part of the EU/CIS Joint Study Project 2, "Development and Application of Techniques to Assist in the Establishment of Intervention Levels for the Introduction of Countermeasures in the Event of an Accident".

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Foreword

The Chernobyl Centre for International Research (CHECIR) has been established by the former Soviet Union "for the purpose of conducting research programmes to be concluded on a bilateral or multilateral basis in the area of nuclear safety". The EU-CIS bilateral research projects within the CHECIR programme for 1994 cover several **Experimental Co-operative Projects** (ECPs) and **Joint Study Projects** (JSPs).

The Joint Study Project 2 (JSP 2) has been subdivided in 1994 into the following tasks:

- Psychological and social factors related to the implementation of countermeasures,
- Conceptual basis for developing criteria for setting intervention levels, and
- Dose distributions.

In the third project year the work on bases for criteria has concentrated on the following subjects:

- new concepts of setting intervention levels in CIS
- distributions of population on surface contamination density and external dose rate in CIS
- averted and avertable doses by taking long-term protective actions in CIS
- risk quantification of avertable and residual doses at given intervention levels in CIS

This report covers the work during the third year carried out by the CIS-partners from the Ukrainian Research Centre for Radiation Medicine in Kiev, the Chernobyl State Committee in Minsk, the Research Institute of Radiation Medicine in Gomel, the Institute of Radiation Hygiene in St. Petersburg, the Russian Research Centre "Kurchatov Institute" in Moscow and the EU-partner from Risø National Laboratory in Denmark.

1 Introduction

Averted radiation doses by taking long-term protective measures in the CIS Republics affected by the Chernobyl accident as well as doses that can be averted in the future can be determined from the huge amount of measurements and realistic dose projection models which have been developed in the CIS. Averted and avertable doses can be quantified by dose distribution parameters. Quantified relations between such distribution parameters and calculated doses would be useful to decision makers responsible for implementing and withdrawing protective measures. Risk distributions would be equally useful for providing realistic and comprehensive information to the public on the levels of either avertable risk by continuing countermeasures or residual risk by lifting existing countermeasures.

2 Radiological conditions in CIS

Almost ten years after the Chernobyl accident in 1986 the post-accident situation in the affected areas are in what can be characterised as a recovery phase. The radiation doses to the population in the areas affected by the accident are of the same order of magnitude or even lower than doses from the natural background radiation. The long-term countermeasures still being implemented include different agricultural countermeasures many of which are very cost-effective. Relocation is a very expensive and often unacceptable countermeasure and although existing regulations and laws would allow future relocations they would probably not be implemented.

2.1 Russia

In the Republic of Russia the total area having a surface contamination density of ^{137}Cs larger than 37 kBq·m^{-2} in 1991 is assessed to be 55,000 km^2 with a total population of 2.4 million. The decision-making process on countermeasures is based on the radiological consequences in the contaminated areas, and either surface contamination density or annual effective dose is used as an index.

2.1.1 Division of contamination areas

The Russian Federation Law "On social protection of the people affected by radiation caused by the catastrophe at the Chernobyl power plant" was adopted in May 1991 and confirmed with minor changes in June 1992. In accordance with this Law, protective and social measures should be implemented in territories with ^{137}Cs contamination (surface contamination density) larger than 37 kBq·m^{-2} (1 Ci·km^{-2}) or with an annual effective dose in 1991 larger than 1 mSv. The territories where the ^{137}Cs contamination is in the range of 185-555 kBq·m^{-2} (5-15 Ci·km^{-2}) is the zone where the population has the right to be relocated. The territory where the contamination level is larger than 555 kBq·m^{-2} is the zone for relocation, including compulsory relocation from settlements where the contamination level is larger than 1,480 kBq·m^{-2} (40 Ci·km^{-2}) or the annual effective dose is above 5 mSv. Criteria on surface contamination density of ^{90}Sr and ^{239,240}Pu are also included (Table 1), but the reference levels are not exceeded anywhere in Russia. The maximum measured values are 48 kBq·m^{-2} (1.3 Ci·km^{-2}) for ^{90}Sr and 0.3 kBq·m^{-2} (0.008 Ci·km^{-2}) for ^{239,240}Pu (Orlov et al. 1984).

Table 1. Criteria for contaminated zones in Russia adopted by the Federal Act in 1991.

Zone	Radiological criteria			
	Annual dose (mSv)	Surface contamination		
		^{137}Cs	^{90}Sr	^{239,240}Pu
Exclusion	evacuated or resettled in 1986 and later			
Obligatory relocation	5	1,480	-	-
Relocation	1	555	110	3.7
Right for relocation	-	185	-	-
Favourable social and economical status	-	37	-	-

The area in Russia with a surface contamination density of ^{137}Cs larger than 37 kBq·m^{-2} is distributed in 15 administrative regions ("Oblasts"). The zone for relocation is limited to only one region - the Bryansk Oblast.

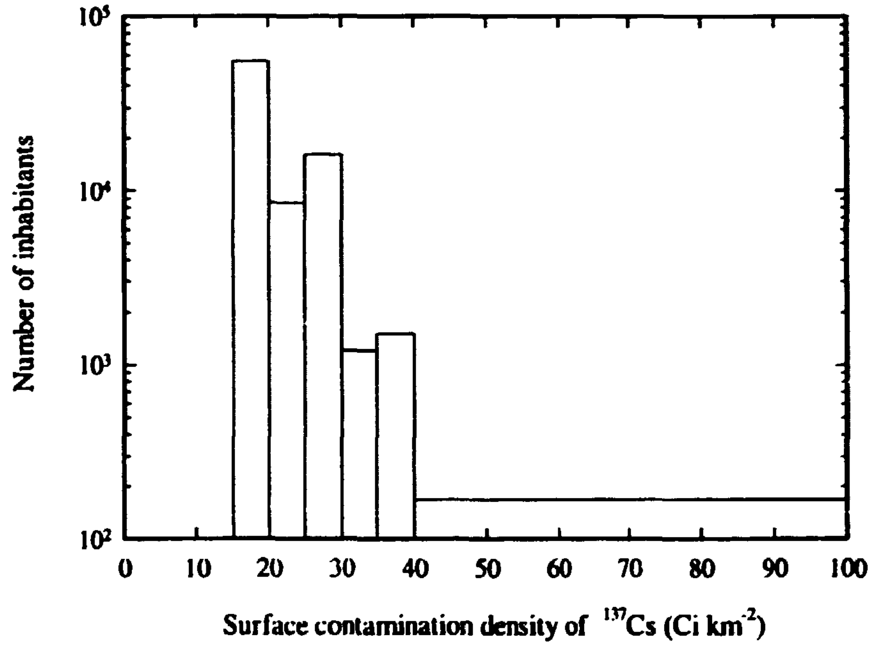

Figure 1. Population distribution in 1991 on surface contamination density of ^{137}Cs in the zone for reloaction with a surface contamination density larger than 555 kBq·km^{-2}.

Figure 1 presents the distribution of population in the zone for relocation, i.e. on the territories with ^{137}Cs contamination larger than 555 kBq·m^{-2}. The largest settlement is the city of Novozybkov with a population of 44,800. There are one small town and two so-called "settlements of urban type" (actually all three are semi-urban settlements) with a population of 1,900 to 6,000 each. Other populations live in rural settlements with a number of inhabitants ranging from 1,000 to 2,700 each.

2.1.2 Population distribution on individual doses

The dose assessment for the year 1991 was published in the "Reference Book on Radiation Situation and Radiation Doses in the Year 1991 for Population of the Districts of the Russian Federation Affected by Radioactive Contamination Caused by the Accident at the Chernobyl Nuclear Power Plant" (M.I. Balonov, Editor) prepared at the Institute of Radiation Hygiene, St.Petersburg, 1993. The assessment was based on data for ^{137}Cs and ^{90}Sr surface contamination density, specific activity of these radionuclides in cow's milk and potatoes of local production, and generalized regional transfer factors "soil-milk" and "soil-potatoes". Data on individual monitoring of local population on exposure to external gamma radiation with thermoluminescent dosimeters and on content of caesium radionuclides in the body with whole body counters were also used.

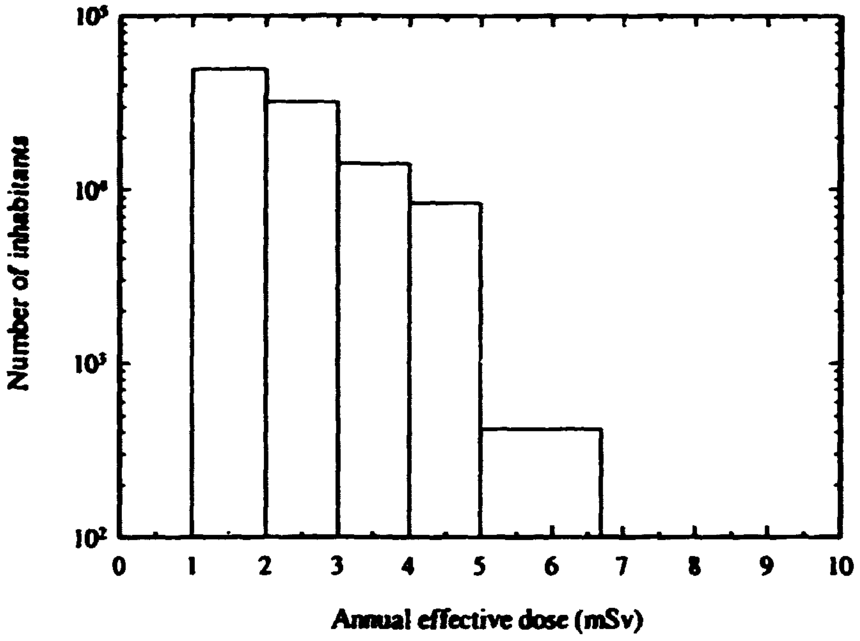

Figure 2. Population distribution on annual effective dose in 1991.

The distribution of individual doses to the population living in settlements with an annual effective dose in excess of 1 mSv is shown in Figure 2. Actually, this distribution is designed in such a manner that an average dose calculated for a settlement was ascribed to any inhabitant of this settlement. Individual dose distributions for inhabitants in single settlements are studied in another task of JSP 2 (Skryabin et al. 1995).

The excess of 1 mSv was found for all settlements in the zone of relocation, i.e. with a surface contamination density of ^{137}Cs in excess of 555 kBq·m^{-2}, excluding Novozybkov. For rural settlements the annual dose was a more restrictive criterion than the level of surface contamination density. The major part of the rural people living in zones "with the right to be relocated" in the Bryansk Region are inhabitants of settlements with annual effective doses assessed as exceeding 1 mSv for the year 1991. Moreover, 19,000 are inhabitants in settlements beyond this zone, i.e. in territories with a ^{137}Cs contamination less than 185 kBq·m^{-2} and an annual dose above 1 mSv. In these settlements and also in some areas with a surface contamination density larger than 185 Bq·m^{-2} and specifically high values of transfer factors in the food chain "soil-plant-cow-milk", a predominant mode of exposure is intake of radiocaesium via foods. This exposure pathway gives up to more than 90% of the dose, whereas an average ratio of external to internal dose is 48:52, averaged for the whole population with a total dose more than 1 mSv in 1991. This ratio varies widely, and a contribution of external radiation dose to total dose may reach up to more than 90%, especially in some settlements beyond the Bryansk Region where the above-mentioned transfer factor is low for chernozem soils (Tula Region).

2.1.3 Avertable doses by relocation

Avertable doses have been assessed using real data on the reduction of external radiation and radionuclide concentration in local foods in the period 1991-1994 and realistic assumptions for future time periods. A decrease of external radiation is easily forecasted from radioactive decay of the caesium radionuclides, but it is more complicated for other removal processes such as migration of radiocaesium in soil (further deepening into the ground). The latter effect was studied for the western districts of the Bryansk Region, where the ratio of the external dose accumulating over the following 25 years to the annual external dose in 1991 is assessed in the range of 6.8 to 14.9 depending on assumptions on the future migration rate. The most likely average ratio was suggested to be 9±1.4 (Lebedev et al. 1993). In the assessment of avertable doses these values were used with a corrected projection to the lifetime period of dose accumulation. In the long-term projection of internal doses both the general trends during the last four years (1991-1994) and local conditions for various settlements derived from doses assessed for 1991 were taken into consideration to calculate avertable (in case of relocation) or residual (without relocation) doses starting from 1992.

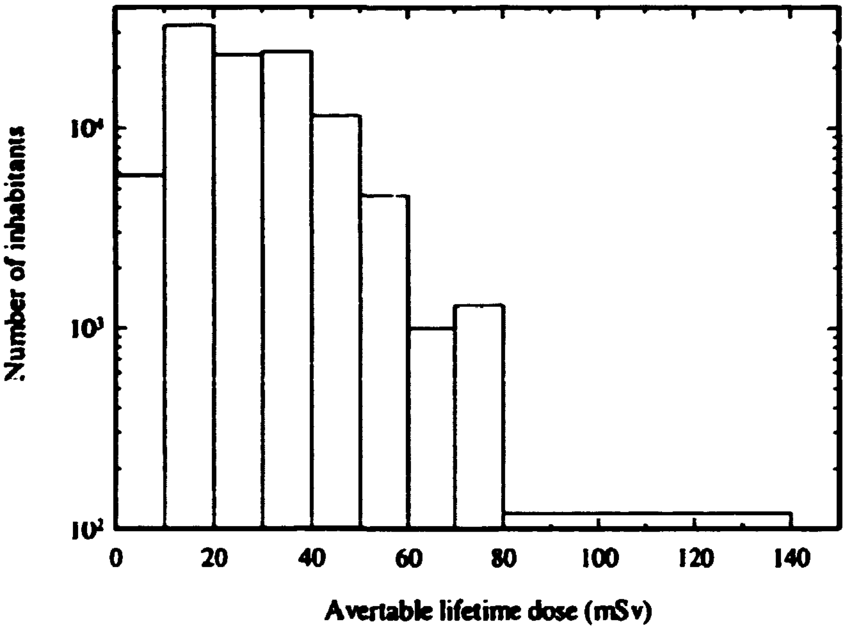

Figure 3. Distribution of avertable individual effective doses by relocation of settlements where the annual effective dose in 1991 exceeded 1 mSv.

The distribution of population on avertable effective individual lifetime doses by relocation in 1991 is shown in Figure 3 for inhabitants of those settlements where the calculated annual dose in 1991 exceeded 1 mSv. The reduction of population due to the normal mortality function has not been included in the calculation of avertable doses. Summary data for the two alternative criteria for relocation are given in Table 2. Data for the surface contamination criterion include Novozybkov, where individual doses in 1991 were less than 1 mSv. About 96% of the population assigned to relocation in accordance with the annual dose criterion lived in the Bryansk Region, the rest lived in the Kaluga and Tula Regions.

Table 2 Population data and doses for relocation in 1991.

Radiological criteria	Number of people	Collective dose in 1991 (man Sv)	Individual dose in 1991 (mSv)	Avertable collective lifetime dose (man Sv)	Avertable individual lifetime dose (mSv)
Surface contamination of ^{137}Cs > 15 Ci·km^{-2}	84,000	152	1.6	2,400	29
Annual effective dose > 1 mSv	105,000	251	2.4	2,960	28

Avertable doses are much less than the Intervention Levels (IL) recommended for relocation by ICRP (ICRP93) and IAEA (IAEA94). Only for two settlements would the avertable lifetime doses from 1991 exceed 10% of the lifetime dose level of 1 Sv recommended by ICRP as the almost always justified intervention level for relocation (ICRP93). The effective individual doses from Chernobyl fallouts may be compared with those from natural background radiation. The latter was assessed as 2.3 mSv·y^{-1} on average for the former USSR (Krisjuk et al. 1984). The lifetime dose from natural background radiation would thus be about 160 mSv in comparison with an average residual indivdual dose of 28 mSv from Chernobyl averaged to the population assigned to relocation according to the criterion of an effective annual dose of 1 mSv in 1991. The maximum residual lifetime dose from Chernobyl averaged for a single settlement starting from 1992 is also less than the lifetime dose from natural background radiation.

2.2 Belarus

In the Republic of Belarus the decision-making process on countermeasures is based on the radiological consequences in the contaminated areas, and the effective dose is used as a risk index. Areas with an initial surface contamination density of ^{137}Cs greater than 1,480 kBq·m^{-2} (40 Ci·km^{-2}) amounted to approximately 2,000 km^2 in the calendar year 1994 of which about 80% is in the Gomel region and about 20% in the Mogilev region.

2.2.1 Division of contaminated areas

After the Chernobyl accident, intervention criteria and subdivision of areas were based on the level of surface contamination with ^{137}Cs, ^{90}Sr and ^{239}Pu. The measured contamination levels were used to calculate the potential doses to the population from external radiation and from ingestion of contaminated foodstuffs. The contaminated areas were subdivided into five zones depending on the contamination density of cesium, strontium and plutonium as were approved by the Supreme Soviet of the Republic in the special laws "On Legal Treatment of the Territories Affected by Radioactive Contamination as a result of the Chernobyl Nuclear Power Plant Catastrophe and On Social Protection of Citizens Affected by the Chernobyl Nuclear Power Plant Catastrophe". The subdivision is shown in Table 3 (Rolevich 1994).

Table 3. Basic protective measures in the contaminated zones in the Republic of Belarus.

Zone	Dose ($mSv \cdot y^{-1}$)	^{137}Cs ($kBq \cdot m^{-2}$)	^{90}Sr ($kBq \cdot m^{-2}$)	^{239}Pu ($kBq \cdot m^{-2}$)	Basic measures
1	0.1	37 - 185	-	-	periodical control
2	0.1	185 - 555	18.5 - 74	0.37 - 1.85	right to be resettled
3	0.5	555 - 1,480	74 - 111	1.85 - 3.7	subsequent resettlement
4	-	1,480	111	3.7	immediate resettlement
5	-	-	111	3.7	zone of evacuation

Taking into consideration that the basic protective measure is the relocation of people from the most contaminated areas, the number of people in these areas is steadily decreasing. In 1986 more than 2.1 million people lived in contaminated areas. In 1991 this number was reduced to 1.853 million and in 1994 to 1.850 million. These changes are connected mainly with the relocation of people from the zones 3-4 in accordance with the criterion in the laws mentioned:

- surface contamination density larger than 555 $kBq \cdot m^{-2}$ of ^{137}Cs, 111 $kBq \cdot m^{-2}$ of ^{90}Sr and 3.7 $kBq \cdot m^{-2}$ of ^{239}Pu;
- individual effective doses due to the accident larger the 5 $mSv \cdot y^{-1}$.

The dynamics of the population during the period 1991-1994 is shown in Table 4 (Rolevich 1994).

Table 4. Population data in the contaminated zones of the Republic of Belarus.

Zone Year	Belarus	Brest region	Vitebsk region	Gomel region	Grodno region	Minsk region	Mogilev region
1991 Total	1852949	166172	99	1409963	44594	37401	194720
4	2944	–	–	1122	–	–	1822
3	79066	–	–	70080	–	–	8986
2	281309	17781	–	180703	1188	3894	77743
1	1589630	148391	99	1158058	43406	33507	106169
1992 Total	1840758	170472	116	1399673	43770	40055	186672
4	1132	–	–	422	–	–	710
3	57245	–	–	52232	–	–	5013
2	297671	19306	–	180852	1187	5836	90490
1	1484710	156166	116	1166167	42583	34219	90459
1993 Total	1854326	183941	102	1397489	45739	40241	186814
4	353	–	–	285	–	–	68
3	43198	–	–	40460	–	–	2378
2	322425	31456	–	193347	1164	5824	90634
1	1488350	152485	102	1163397	44575	34417	93374
1994 Total	1850025	183032	101	1396417	45683	40008	184784
4	251	–	–	226	–	–	25
3	41928	–	–	39589	–	–	2339
2	317301	28519	–	191701	1150	5794	90137
1	1490545	154513	101	1164901	44533	34214	92283

2.2.2 Population distribution on total individual doses

Substantial work was carried out to assess the exposure of the population in the Republic of Belarus. The assessment was based on the surface contamination density and the activity concentration in milk, meat and potatoes. The dose assessment for the year 1992 was published in the report "Catalogue of the Dose Irradiation of the Inhabitants of the Settlements of the Republic of Belarus". The data are summarised in Table 5 (Rolevich 1994).

It appears from the data in Table 5 that the major part of the population affected by the Chernobyl accident (84%) receives doses from activity in the environment less than 1 mSv per year. About 0.1% of the affected population receives doses in excess of 5 mSv per year.

Table 5. Distribution of total internal and external radiation doses to the population of Belarus in 1992.

Dose (mSv/y)	Belarus	Brest region	Vitebsk region	Gomel region	Grodno region	Minsk region	Mogilev region
Population							
< 1	1590105	181071	118	1197589	44408	37256	136395
1 - 2	192150	18845	–	128299	468	3239	41299
2 - 3	70595	2886	–	58616	–	39	9054
3 - 4	26497	1521	–	22853	–	10	2113
4 - 5	8435	692	–	5708	–	–	2035
> 5	1511	–	–	1289	–	–	222
Number of settlements							
< 1	2181	198	3	961	174	252	593
1 - 2	761	39	–	464	3	14	241
2 - 3	222	6	–	141	–	2	73
3 - 4	94	3	–	73	–	2	16
4 - 5	51	3	–	31	–	2	17
> 5	22	–	–	18	–	–	4

2.2.3 Differential distributions on ^{137}Cs-contamination

Differential population distributions on outdoor effective dose rate or surface contamination density represent the number of people exposed to these quantities in differential intervals. It can be used to calculate the number of people who - in the absence of relocation - would receive individual doses above a given intervention level. In addition, calculations can be made of the avertable collective dose in given individual dose intervals. The differential population distributions on surface contamination density of ^{137}Cs have been constructed (Skryabin 1994) and these distributions are shown in Figures 4 and 5 for the years 1986 and 1993.

Differential mass distributions for foodstuffs on activity concentrations of different radionuclides can be used to calculate the amount of foodstuffs with an activity concentration above a given intervention level and also the corresponding avertable collective ingestion dose. The avertable doses realized by restricting foodstuffs can be expressed as an avertable collective effective dose per unit mass of a specific category of foodstuff. The basic data needed for such calculations would be the differential foodstuff mass distribution on ^{137}Cs-concentration in those foodstuffs.

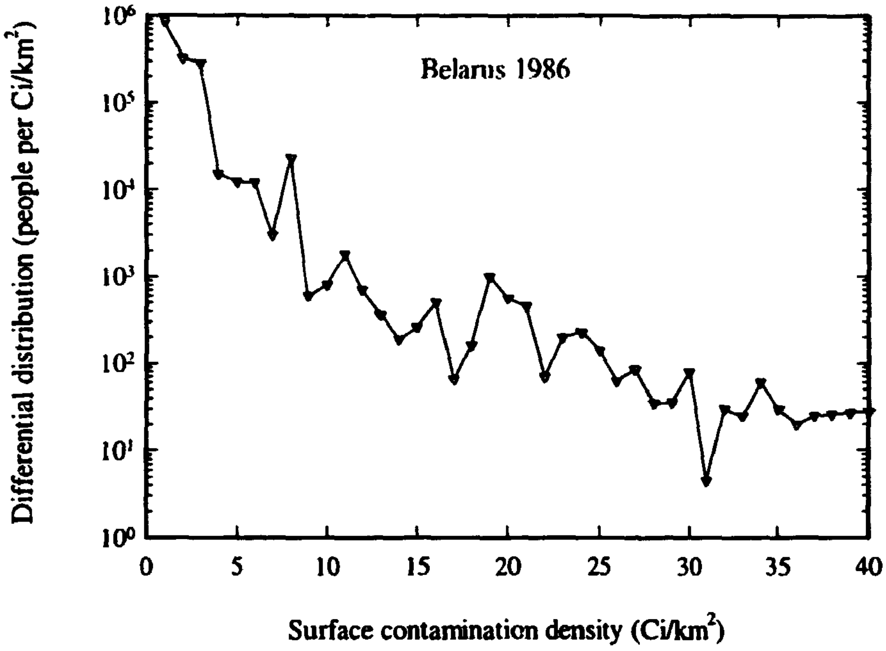

Figure 4. Differential population distributions on surface contamination density of ^{137}Cs for calendar year 1986.

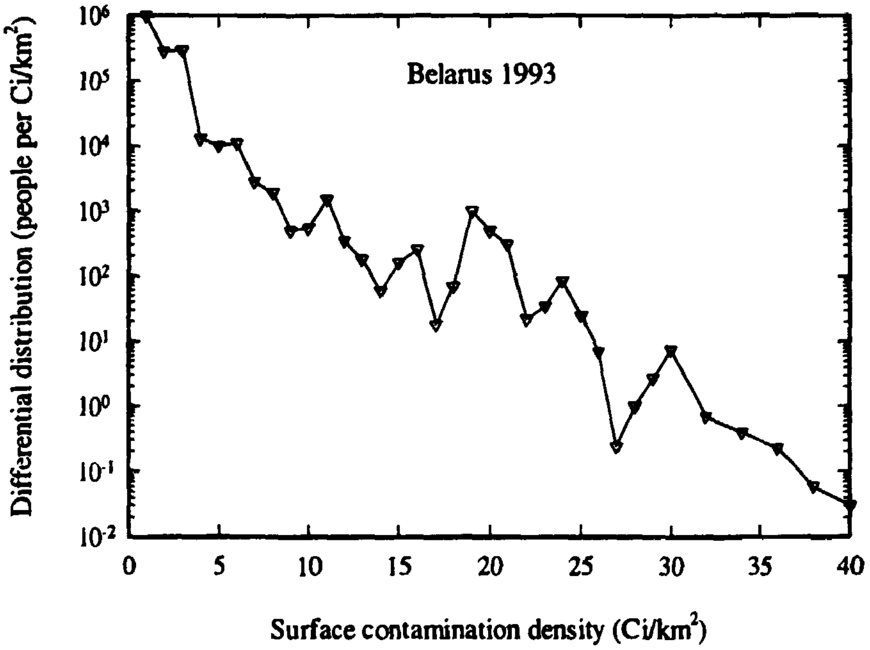

Figure 5. Differential population distributions on surface contamination density of ^{137}Cs for calendar year 1993.

From the distributions shown in Figures 4 and 5 the number of people living in areas with a surface contamination density above a given value can be calculated. In addition, the number of people receiving annual external individual doses above a given value can also be calculated. The results are given in Table 6.

Table 6. Number of people living in areas with a surface contamination density above a given value or receiving external annual doses above a given value. The numbers are calculated from the distributions in Figures 4 and 5.

Surface contamination ($Ci \cdot km^{-2}$)	Number of people		Individual effective dose ($mSv \cdot y^{-1}$)	Number of people	
	1986	1993		1986	1993
1	$9.4 \cdot 10^5$	$9.1 \cdot 10^5$	0.2	$4.2 \cdot 10^5$	$3.8 \cdot 10^5$
5	$3.8 \cdot 10^4$	$2.3 \cdot 10^4$	0.5	$5.5 \cdot 10^4$	$3.9 \cdot 10^4$
10	$7.4 \cdot 10^3$	$4.0 \cdot 10^3$	1.0	$1.6 \cdot 10^4$	$5.5 \cdot 10^3$
20	$2.4 \cdot 10^3$	$6.5 \cdot 10^2$	2.0	$4.2 \cdot 10^3$	$1.9 \cdot 10^3$
30	$1.0 \cdot 10^3$	$4.9 \cdot 10^1$	3.0	$1.8 \cdot 10^3$	$2.6 \cdot 10^2$
40	$6.1 \cdot 10^2$	$2.3 \cdot 10^1$	5.0	$7.1 \cdot 10^2$	$2.9 \cdot 10^1$

The annual external γ-doses in Table 6 have been calculated from a conversion factor from surface contamination density to an outdoor γ-dose rate of 1.24 $\mu Sv \cdot d^{-1} / Ci \cdot km^{-2}$ for ^{137}Cs. To account for shielding and indoor occupancy a time-averaged location factor of 0.3 has been used. Comparing the values in Tables 5 and 6 reveals an inconsistency between the two population distributions on individual dose. Although the individual doses in Table 6 are external doses calculated from Figure 4, the contribution from ingestion doses cannot fully explain this difference.

Differential distribution of milk production in Belarus on ^{137}Cs-concentration in milk for the year 1992 is shown in Figure 6 (Skryabin 1994).

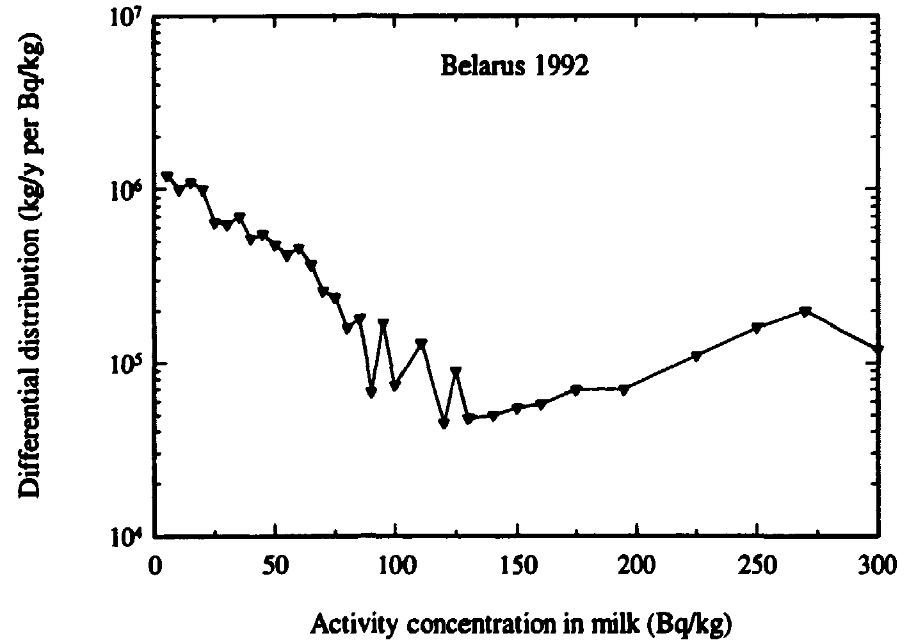

Figure 6. Differential distribution of annual milk production on ^{137}Cs-concentration in milk for the calendar year 1992.

The annual production of milk with a concentration above a given value as well as the annual collective ingestion dose from the consumption of all contaminated milk can be calculated from the distribution in Figure 6. The calculated production rates and resulting collective doses are shown in Table 7.

Table 7. Annual production rates of milk in 1992 with a concentration of ^{137}Cs above a given value and the corresponding annual collective doses from its consumption.

^{137}Cs-contamination in milk (Bq·kg^{-1})	Annual milk production (kg·y^{-1})	Annual collective dose (man·Sv·y^{-1})
0	$8.1 \cdot 10^7$	64
50	$3.2 \cdot 10^7$	55
100	$2.1 \cdot 10^7$	46
150	$1.7 \cdot 10^7$	42
200	$1.4 \cdot 10^7$	37
250	$9.5 \cdot 10^6$	26

An annual consumption of milk of 0.5 litre per day with a ^{137}Cs-concentration of 100 Bq·kg^{-1} would cause individual doses of about 0.2 mSv·y^{-1}, not very age-dependent.

2.2.4 Potential avertable doses

The annual collective dose from external and internal radiation to the population in Belarus living in contaminated areas where the individual doses in 1992 exceeded 1 mSv·y^{-1} is around 600 man·Sv according to the distribution shown in Table 5. The number of people receiving doses in excess of 1 mSv·y^{-1} is approximately 300,000 of which more than 70% lives in the Gomel region and around 20% in the Mogilev region.

The average annual individual doses that could be averted if the exposure to the sources were completely removed would thus be:

$$\overline{E}_{annual} = \frac{600 \text{ man·Sv}}{300,000 \text{ people}} \cong 2 \text{ mSv·y}^{-1}$$

A rough evaluation of typical resources allocated to avoiding radiation health detriment can be made using a simplified version of the human capital approach. On the basis of the risk factors given by the ICRP (ICRP90), the statistical loss of life expectancy (LLE) associated with 1 man·Sv can be found to be approximately 1 year. Because of the uncertainties associated with the risk coefficients for the effects of radiation, this value can be considered to be accurate only within a factor of about two. It can be shown that as a first approximation the level of health care in any country is proportional to the country's average annual GNP per head. On a purely economic basis, a minimum value to be associated with a statistical year of life lost is the annual GNP per head. Consequently, a first approximation would give a minimum value of the monetary cost per unit dose avoided, α, equal to $GNP \cdot LLE \approx GNP$.

The introduction of a countermeasure to avert individual doses can be evaluated in terms of its efficiency or cost-effectiveness. If the avertable individual doses are ΔE and the cost of the countermeasure per individual is ΔC, the introduction of the countermeasure would be justified if:

$$\frac{\Delta C}{\Delta E} < \alpha$$

There may be large differences in the absolute value of α between countries, but the use of a particular currency unit is relatively unimportant as the loss of life expectancy could be related to the country's GNP.

2.3 Ukraine

2.3.1 Surface and milk contamination

Among the most contaminated regions in Ukraine is the Rovno oblast. Surface contamination density of ^{137}Cs and ^{137}Cs-concentration in locally produced milk have been measured and data for 54 settlements are shown in Table 8.

Table 8. Data for the year 1991 for 54 settlements in the northern region of Rovno oblast, Dubrovichy region, listing the number of inhabitants, surface contamination density of ^{137}Cs and average concentration of ^{137}Cs in locally produced milk.

Settlements	Number of inhabitants (adults)	Surface contamination with ^{137}Cs (Ci·km^{-2})	Milk contamination with ^{137}Cs (nCi·l^{-1})
Beloe	261	5	10
Bereszki	1,287	3	11
Beresznitca	534	1	7
Berest'e	2,185	3	8
Borodetc	225	3	9
Budimlja	652	2	32
Velikie Osera	949	1	26
Velun'	594	6	10
Verbovka	450	3	10
Volnoe	64	1	9
Gorodische	557	1	14
Grani	88	1	5
Gritcki	215	2	6
Dubrovitca	8,769	3	10
Jaden	723	1	9
Zaleshan'	103	1	4
Zaluszie	1,351	3	6
Zalucha	694	3	7
Zelen'	502	1	8
Zolotoe	487	2	11
Kolki	1,516	2	11
Krivitca	211	1	5
Krupovo	578	1	7
Kurash	299	1	4
Lesovoe	363	2	10
Litvitca	311	2	5
Lugovoe	469	4	10
Ludin	602	4	12
Lutinsk	1,067	4	11
Miljachi	844	3	12
Mogulische	483	2	8
Nivetck	388	1	14

Table 8 continued.

Settlements	Number of inhabitants (adults)	Surface contamination with ^{137}Cs (Ci·km^{-2})	Milk contamination with ^{137}Cs (nCi·l^{-1})
Ozersk	490	1	7
Orvjanitca	1,570	2	5
Osovo	901	1	5
Partozanskoe	163	4	6
Perebrodi	1,115	1	13
Podlesnoe	414	2	9
Porubka	207	4	6
Pratcuki	19	2	15
Riski	122	3	53
Rudnja	468	5	10
Svaritcevichi	1,660	1	9
Seletc	1,758	3	8
Smorodsk	634	5	4
Solomievka	486	2	3
Tripunja	489	2	7
Tumen'	486	3	14
Udritck	751	4	5
Uzles'e	266	1	8
Hilin	30	2	9
Hochin	124	2	7
Chervonoe	215	2	7
Shabi	174	3	43

2.3.2 Averted doses by agricultural countermeasures

The doses which have been averted by agricultural countermeasures were estimated from the ^{137}Cs ingestion exposure model as the difference between doses from intakes (reference intake function) of ^{137}Cs in locally grown food and normal life style and doses from a reduced intake due to agricultural countermeasures, mainly replacement of locally produced food with food produced in relatively "clean" areas.

The data for the 54 settlements located in one of the northern regions of Rovno oblast were used to create two differential population distributions on ingestion doses - one for the situation without countermeasures (reference situation) and one for the real situation with countermeasures implemented. The two distributions are presented in Table 9. The collective ingestion dose without countermeasures, S_{ref}, has been calculated to be 2.35 man·Sv. With countermeasures implemented the collective ingestion dose, S_{real}, has been reduced to 0.21 man·Sv. The countermeasure efficiency for the year 1991 for this region of the Rovno oblast can thus be determined to be:

$$\varepsilon = \frac{S_{ref} - S_{real}}{S_{ref}} = \frac{\Delta S}{S_{ref}} \cong 91\%$$

for an averted dose, ΔS, of 2.1 man·Sv. The cost-effectiveness of the countermeasure can be calculated as $\Delta C/\Delta S$, where ΔC is the cost of the countermeasure.

Table 9. Differential distribution of population on ingestion doses from contaminated milk without any countermeasures (reference situation) and for the situation with countermeasures implemented for the year 1991.

Individual doses (μSv)	Population distribution (without countermeasures)	Population distribution (with countermeasures)
< 20	2,539	40,911
20 - 40	6,928	122
40 - 60	22,216	173
60 - 80	7,389	0
80 - 120	1,450	0
120 - 160	949	0
160 - 200	652	0
200 - 260	173	0
260 - 320	122	0
Total	42,418	41,206

2.3.3 Avertable doses by relocation

The decision on relocation in Ukraine is based on a two-level concept of annual individual dose. If the annual individual doses are above 5 mSv the inhabitants should be relocated. The two most contaminated territories in Ukraine are the Rovno oblast (44 settlements) and the Jitomir oblast (37 settlements). The total individual doses, E_{total}, for the time period 1986-2056, and the avertable individual doses, $E_{avertable}$, for the time period 1991-2056 in settlements in these oblasts are shown in Table 10. In the calculation of the avertable doses the so-called reduction population factor reflecting the reduction of the exposed population by the normalized mortality function for each cohort has been included. The total individual doses include both the external γ-dose from deposited ^{137}Cs and doses from ingestion of food contaminated with ^{137}Cs and ^{90}Sr. The distribution of population on avertable doses is shown in Figure 7.

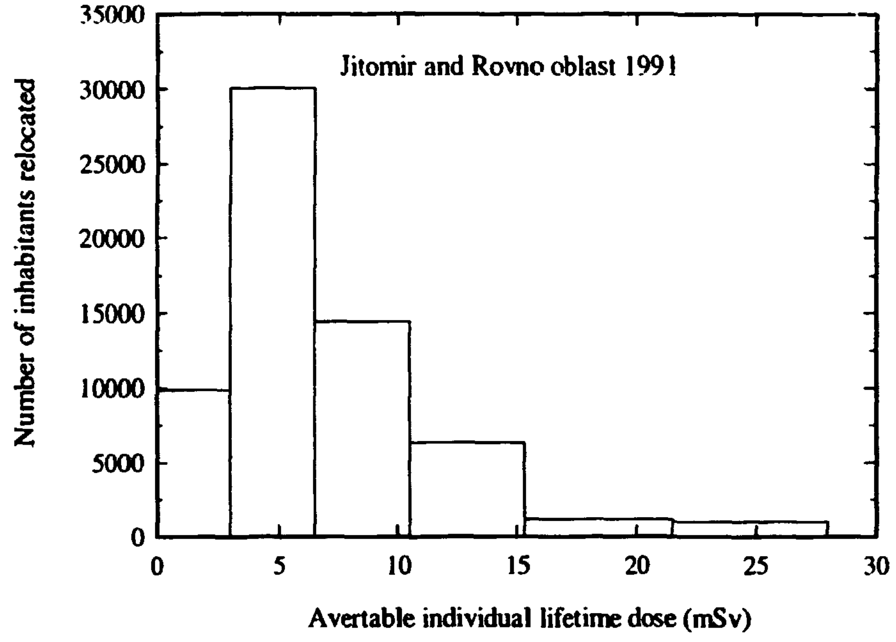

Figure 7. Distribution of avertable individual doses by relocation of settlements in the Jitomir and Rovno oblasts.

The avertable collective dose (1991–2056) from relocation, ΔS, has been calculated to be about 600 man·Sv with the distribution shown in Figure 7. The distribution of people living in ^{137}Cs-contaminated areas in the Jitomir and Rovno oblasts as well as the number of people that would have been relocated in 1991 are shown in Figures 8 and 9.

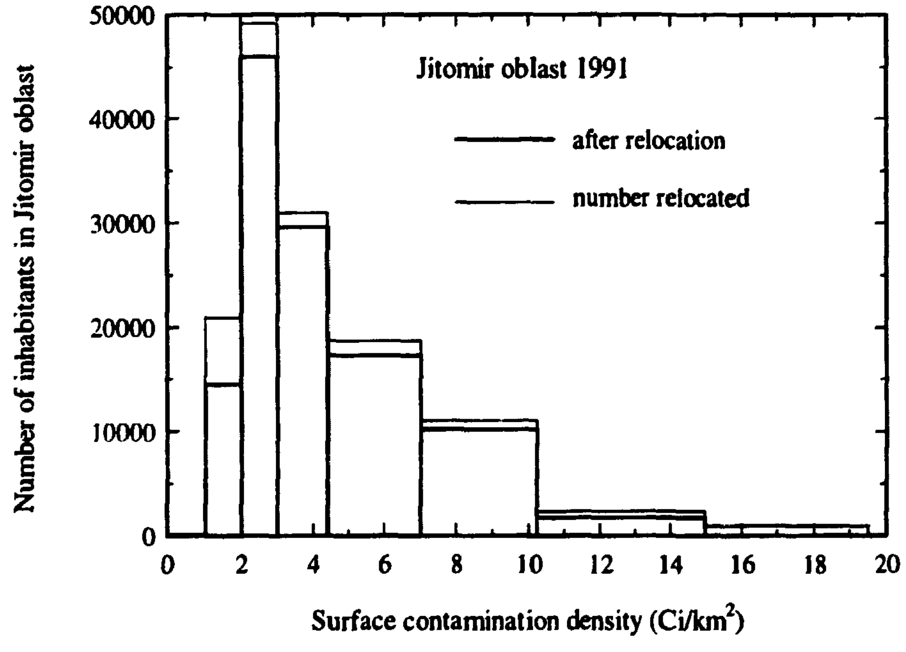

Figure 8. Distribution of people on surface contamination density of ^{137}Cs in contaminated territories of the Jitomir oblast without relocation and the corresponding distribution of people to be relocated in 1991.

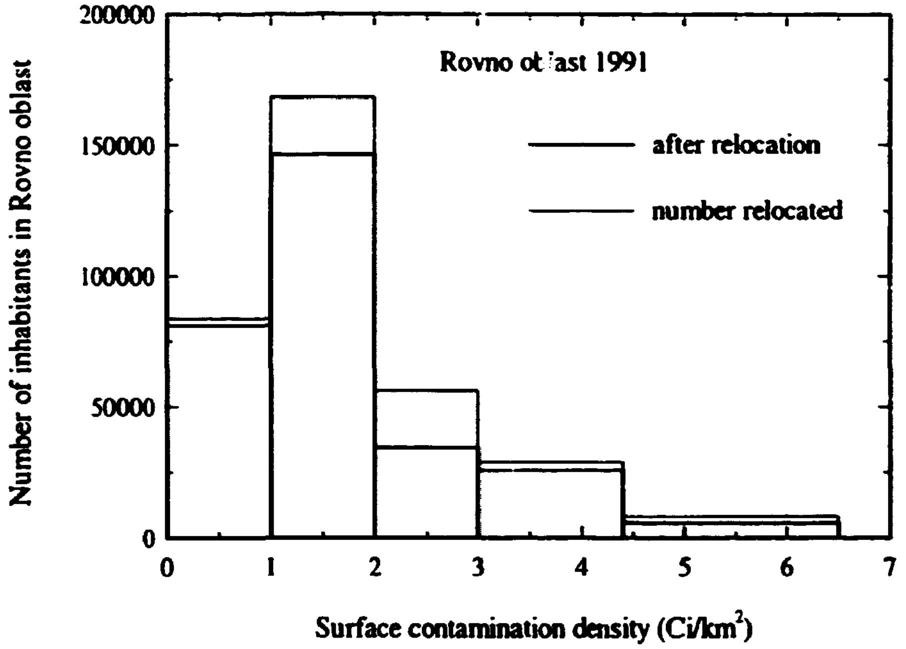

Figure 9. Distribution of people on surface contamination density of ^{137}Cs in contaminated territories of the Rovno oblast without relocation and the corresponding distribution of people to be relocated in 1991.

The number of people that would have been relocated in 1991 in accordance with the two-level concept is around 63,000. The average avertable lifetime dose is thus:

$$\overline{E}_{avertable} \cong \frac{600 \text{ man·Sv}}{63,000 \text{ people}} \cong 10 \text{ mSv}$$

The total collective dose for the period 1986-2056 for the settlements in the Rovno and Jitomir oblasts shown in Table 10 has been estimated to be 2,600 man·Sv of which approximately 2,000 man·Sv has been accumulated in the period 1986–1991.

Table 10. Committed effective individual doses (average values) from external and internal exposure for the adult population after the Chernobyl accident (1986–2056) and the individual avertable doses for the settlements of Jitomir and Rovno oblasts that would have occurred had those settlements been relocated in 1991. In the calculation of the avertable average doses the so-called reduction population factor reflecting the reduction of the exposed population by the normalized mortality function for each cohort has been included.

Areas and settlements	Population	E_{total} (mSv)	$E_{avertable}$ (mSv)
Luginskij region			
Bovsuny	1,148	14.3	2.8
Dubrova	110	18.6	3.7
Moschanica	110	93.8	18.6
Rudnja Jerevetckaj	293	64.5	13.4
Rudnja Povchanskaja	485	82.0	17.0
Narodichskij region			
Annovka	108	51.1	10.6
Velikie Miniki	93	61.6	12.7
Losnica	330	116.7	22.9
Rossokovckoe	214	94.9	18.7
Rudnja Basarskaja	220	47.9	9.9
Ovruchskij region			
Bengunj	1,946	11.3	2.3
Bondari	564	23.7	4.7
Belikaja Hajcha	1,308	20.3	4.0
Velijakovo	87	39.9	8.3
Vistupovichi	697	101.3	20.9
Gorodetc	909	7.5	1.6
Deleta	220	31.7	6.6
Duminskoe	237	31.1	6.4
Sadorojok	114	17.5	3.6
Ignatopol	1,840	12.9	2.7
Kovanka	226	16.1	3.4
Kosuli	51	6.6	1.4
Ludvinovka	77	48.4	10.1
Mlini	135	32.5	6.8
Pavlukovka	281	10.7	2.2
Pehotskoe	79	47.1	9.8
Pobichi	128	12.2	2.6
Priluki	420	12.9	2.7
Rudnja-Ignatopolskaja	182	13.5	2.8
Selesovka	282	16.1	3.4
Semeni	109	13.7	2.8
Slovechno	424	9.5	2.0
Ludin	762	52.0	8.4
Riski	154	59.7	12.6
Shahi	220	63.4	13.2

Table 10 continued.

Areas and settlements	Population	E_{total} (mSv)	$E_{avertable}$ (mSv)
Zarechnenskij region			
Aleksandrovo	496	21.6	4.0
Borovoe	131	19.5	2.6
Borodnitca	782	17.3	3.6
Volchitci	693	41.5	5.4
Golubnoe	157	39.7	8.3
Dubrovck	1,496	33.4	6.3
Jdan	146	35.4	4.6
Zarechnoe	6,600	29.9	4.8
Zelenaja Dubrava	10	29.9	3.9
Lisichin	237	36.0	4.7
Ostrovsk	512	42.7	5.6
Rechitca	123	33.6	7.0
Serniki	2,756	36.0	6.7
Tihovij	346	36.0	4.7
Rokitnovskij			
Borovoe	1,789	85.7	11.1
Budki Kamenskie	212	69.3	14.4
Vjajitsa	873	71.7	9.3
Grabun	347	44.9	9.3
Drosdin	1,432	40.4	5.3
Elnoe	773	71.8	9.3
Zalavie	704	38.0	7.9
Mushni	310	12.1	2.0
Perehodichi	492	102.0	13.0
Rokitno	7,339	28.8	4.6
St. Selo	2,558	37.4	4.9
Stariki	72	62.5	13.5
Hmel	851	22.9	3.0
Sarnenskij region			
Karpilovka	2,964	46.2	9.6
Klesov	5,311	46.7	9.7
Odrinki	570	11.8	1.9
Pugach	688	44.4	9.2
Rudnja-Karpilovckaja	617	57.0	11.8

3 Risk quantifications

Avertable doses from from protective measures can be expressed in terms of avertable individual risks or avertable expected consequences, e.g. avertable collective years of life lost, for the affected population. When countermeasures are not implemented because the projected doses will be less than the intervention level of avertable individual dose or when countermeasures are lifted, the residual doses can similarly be expressed as lifetime risks from the residual lifetime exposure of the different age groups in the population. The risks from acute and chronic exposures at different ages can be assessed from the risk modules developed for investigations of the health consequences of the nuclear weapons tests in the Semipalatinsk region (Belyaev et al. 1994) and from the risk projection models developed by UNSCEAR (UNSCEAR88) and BEIR V (NAS90).

3.1 Risk assessments

For decision-making on radiation and social protection countermeasures it is necessary to assess avertable and residual risks on individual and population levels. This is impossible without developing and applying modern risk analysis methodology. Since 1994 in the framework of the Russian federal research programme (Chernobyl and Altai studies) and partly within the EU/CIS-project JSP 2, the research project "developing the methodology (MAR) and data bank (BARD) on risk analysis" has been carried out (Belyaev et al. 1994).

The BARD-project includes:

- service and calculation codes realizing the methodology mentioned;
- health-demographic data which are necessary for radiation and non-radiation risks assessment.

The main functions of BARD are:

- assessment of the radiological and non-radiological consequences of nuclear tests and accidents,
- assessment of the health of a population in terms of risk indices.

Besides these, BARD can also be used for other tasks related to risk analysis.

To the end of September 1994 within the framework of the research project (developing MAR and BARD) mentioned above the following have been achieved:

- the report "risk analysis methodology (the first version)" has been prepared,
- the first version of BARD (BARD-1) has been developed and is being made ready for its main application,
- radiation risks to populations living in radioactive contaminated territories from the Chernobyl accident and from other events (Altai, Ural, etc.) have been preliminary quantified.

A number of models for the quantification of radiation risk were developed on the basis of the epidemiological investigations by international and some national organisations (UNSCEAR, ICRP, UK NRPB, US BEIR etc.). These models are constantly being updated because of the appearance of new data and the high complexity of the modeling problem.

The latest version of the BEIR model (BEIR V) is used for the calculations in the BARD-project. The BEIR V model makes most complete allowance for the data obtained by the late eighties and, in particular, for the dependence of the model parameters on age at the moment of radiation exposure and also at the moment of observation.

3.2 Risks around the Semipalatinsk nuclear weapons test site

Assessments of the radiological consequences of the first nuclear weapons test (August 1949) at the Semipalatinsk test site for the most affected part of the population in the Altai region (the average exposure dose was estimated to be equal to 0.8 Sv) have been made by using up-to-date scientific knowledge on somatic and hereditary effects of ionizing radiation (Belyaev et al. 1994). Studies of the impact of the weapons tests on the Altai region population began in 1990 (since 1992 in the frame of the federal research program "Semipalatinsk test site/Altai").

The goal of the research is to obtain data on consequences of the tests for planning social protective measures as well as for future research. The research was carried out in the frame of the project "Developing methodology and data bank (BARD) for risk analysis" (federal research programme "Semipalatinsk test site/Altai") (Belyaev et al. 1994).

During the period 1949–1962 tens of atmospheric nuclear weapons tests were conducted at the Semipalatinsk test site. Some of them caused a considerable radiation exposure of the population in the adjoining territories. It follows from the data presently available that a part of the population in the Altai region was seriously affected by these tests.

In using the primary models of radiation risk, it is important also to take into consideration the dependence of risk on dose and dose rate. To do this a correction factor F_c is used. In accordance with the relatively "acute" character of the exposure as a result of nuclear weapon tests, a value of $F_c = 1.5$ has been used (that is, the risk of such irradiation is higher than that of chronic exposure with a low dose rate by a factor of 1.5). This correction factor is used in calculating the risk for malignant tumors of every kind except leukemia. The allowance for the above dependence in the case of leukemia is made by the quadratic term in the dose function.

The results of the calculations of the consequences of the nuclear weapons tests in 1949 for the most affected part of the population of the Altai region were made in terms of risk indices using the methodology, BARD-1. The calculations were made separately for the male and the female populations.

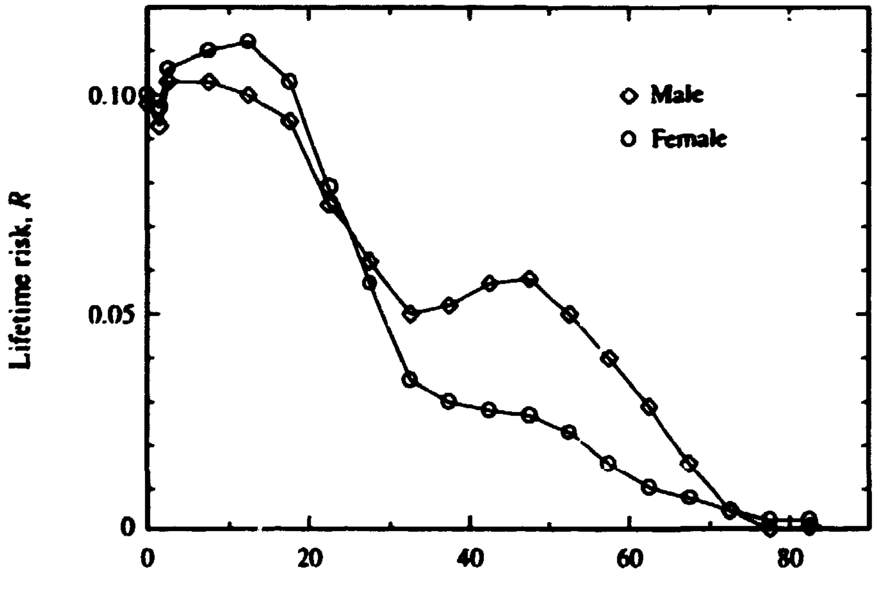

Figure 10. Lifetime risk, R, from lethal radiogenic cancers in its dependence on age at time of exposure.

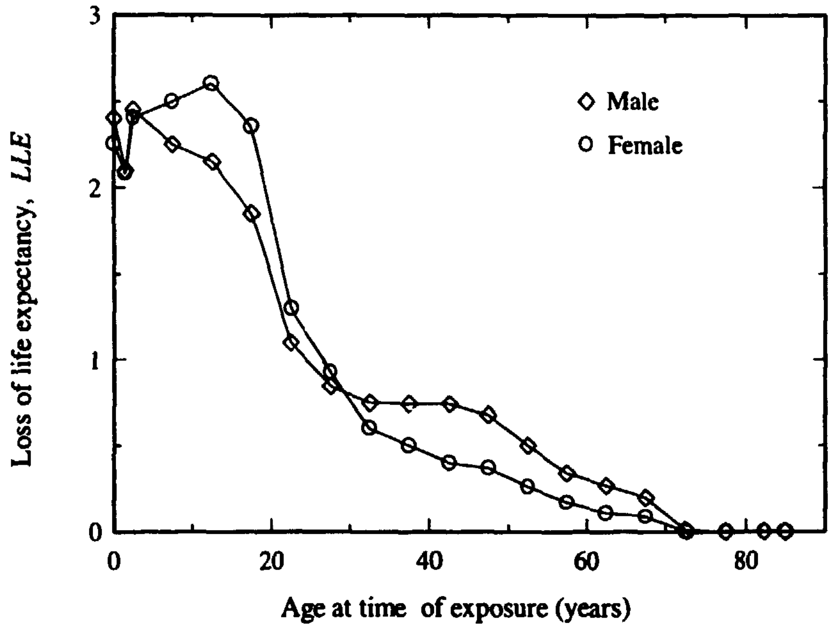

Figure 11. Loss of life expectancy, LLE in years in its dependence of age at time of exposure.

Figures 10 and 11 show the individual risk, R, and loss of life expectancy, LLE, as a function of age at exposure. A strong dependence of the individual risk indices on age at exposure is observed: the indices are relatively large for children and juveniles and decrease sharply toward older ages. This dependence is well known from the literature and can be found, for example, in the ICRP Publication 60 (ICRP90).

BARD-1 allows assessments to be made of the impact of nuclear weapon tests on public health depending on age, time after the test, type or localization of malignant tumors, local conditions, etc. at the cohort or population level. It is impossible to obtain such results in the framework of the traditional approach based on the effective dose concept.

3.3 Risks in the Briansk region from the Chernobyl accident

Some preliminary estimates have been made of the consequences of the Chernobyl accident for the population living in the Briansk region with a surface contamination density of ^{137}Cs in the range of 30–45 Ci·km^{-2}. These estimates were made with BARD for areas without any countermeasures and compared with the spontaneous cancer rate for both females and males.

The results are shown in Figures 12 and 13 for males and females in the age group 0–18 years. Figures 14 and 15 show the corresponding distribution on different cancers for females. Slightly different distributions are found for males. Figures 16–19 show the same picture for the age group above 18 years.

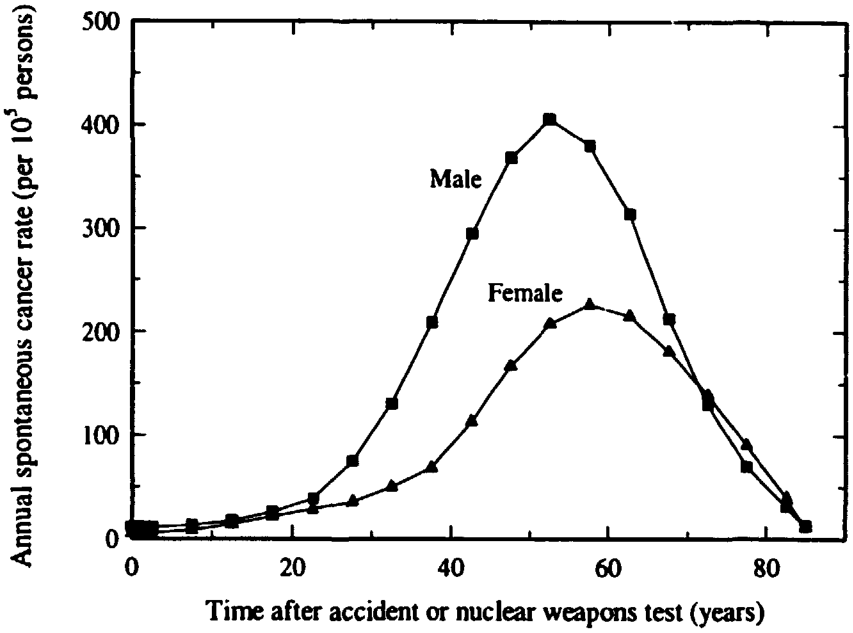

Figure 12. Annual mortality rate from all spontaneous cancers for the age group 0–18 years in 1989 as a function of time in rural areas in the Briansk region.

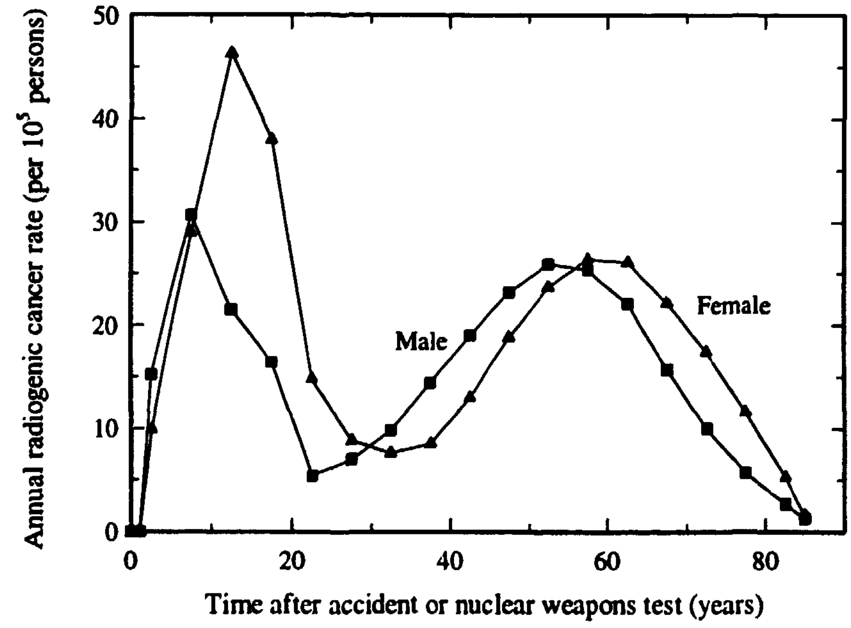

Figure 13. Annual mortality rate from all radiogenic cancers for the age group 0–18 years as a function of time after the Chernobyl accident in rural areas in the Briansk region with a surface contamination density of ^{137}Cs of 30–45 Ci·km^{-2}.

It appears from a comparison of the spontaneous annual cancer incidence rate shown in Figure 12 with the calculated annual radiogenic cancer incidence rate shown in Figure 13 that within the first 20 years after the Chernobyl accident the radiogenically induced cancers would be significantly increased above the spontaneous cancer rate.

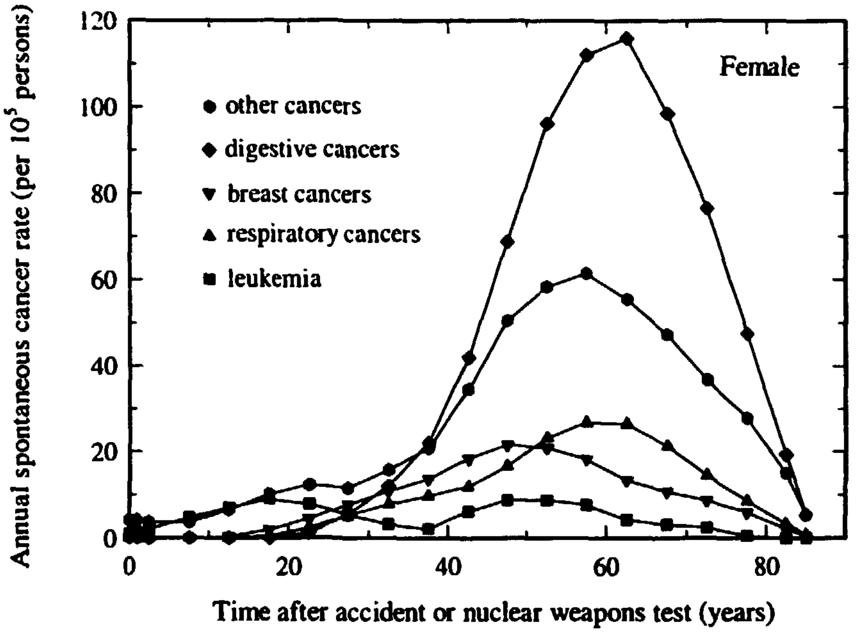

Figure 14. Annual mortality rate for females from different spontaneous cancer types for the age group 0-18 years in 1989 as a function of time in rural areas in the Briansk region.

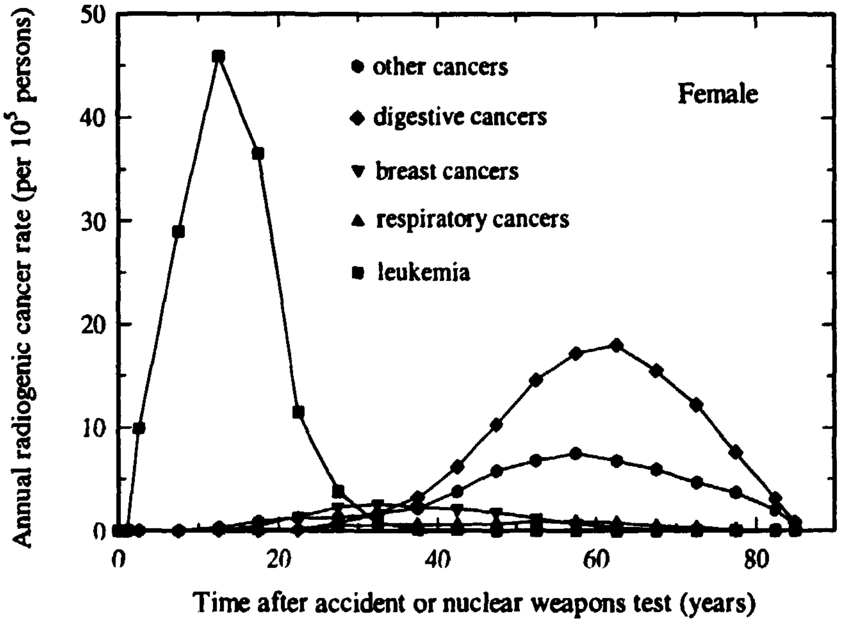

Figure 15. Annual mortality rate for females from different radiogenic cancer types for the age group 0-18 years as a function of time after the Chernobyl accident in rural areas in the Briansk region with a surface contamination density of ^{137}Cs of 30-45 Ci·km^{-2}.

Figures 14 and 15 show the mortality rates for females, both the spontaneous and the radiogenic distributed on different cancer types. The increase in the rates is due mainly to radiogenic leukemia.

Figures 16–19 show the annual spontaneous and radiogenic cancer rates for the age group above 18 years.

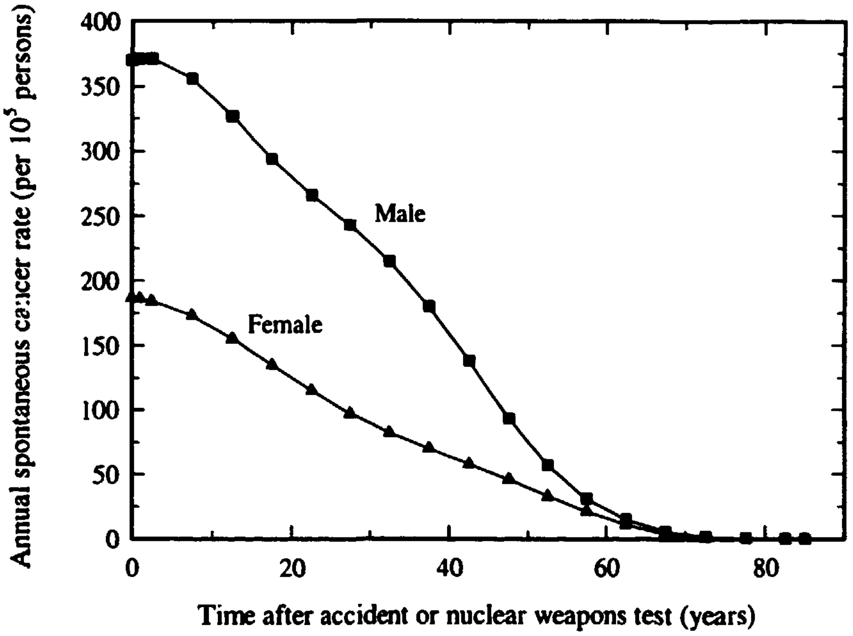

Figure 16. Annual mortality rate from all spontaneous cancers for the age group above 18 years in 1989 as a function of time in rural areas in the Briansk region.

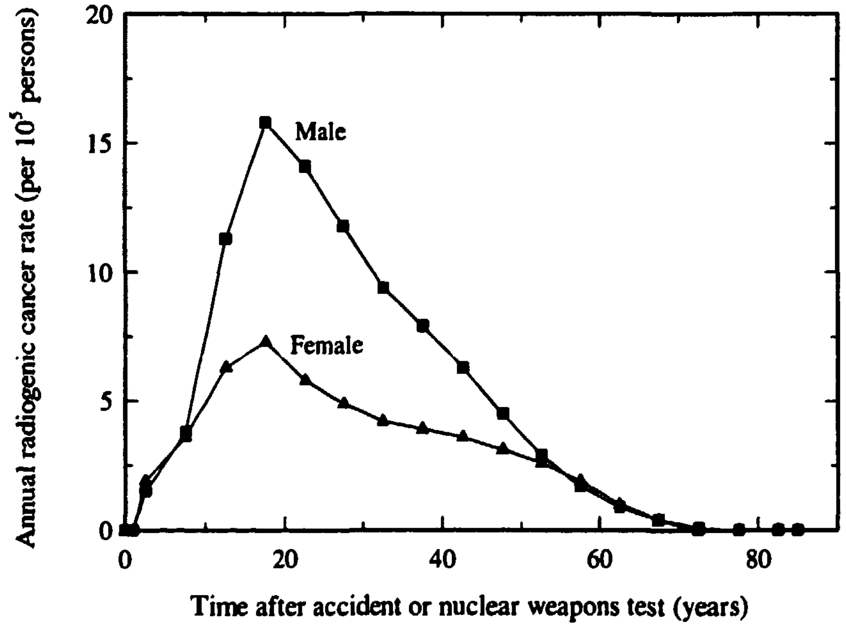

Figure 17. Annual mortality rate from all radiogenic cancers for the age group above 18 years as a function of time after the Chernobyl accident in rural areas in the Briansk region with a surface contamination density of ^{137}Cs of 30–45 Ci·km^{-2}.

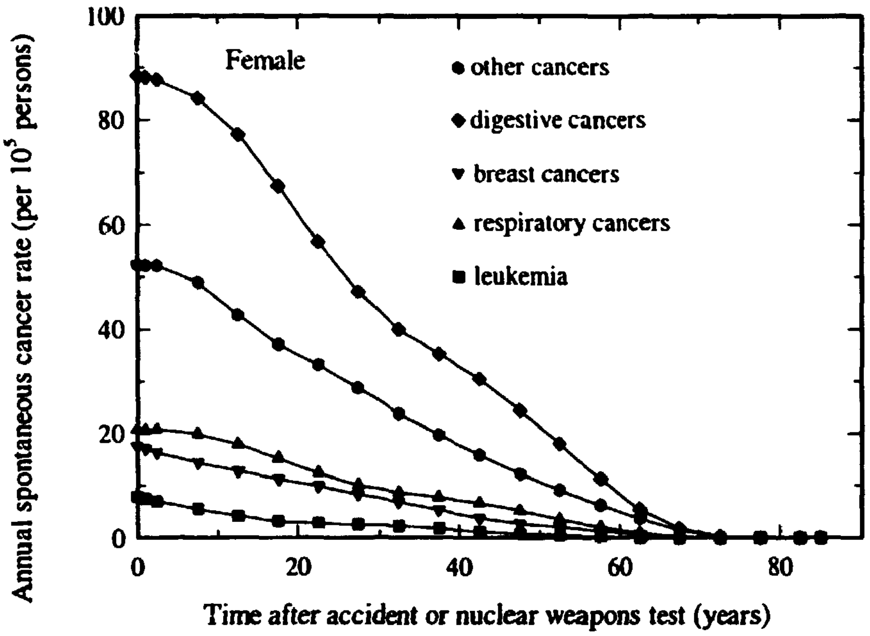

Figure 18. Annual mortality rate for females from different spontaneous cancer types for the age group above 18 years in 1989 as a function of time in rural areas in the Briansk region.

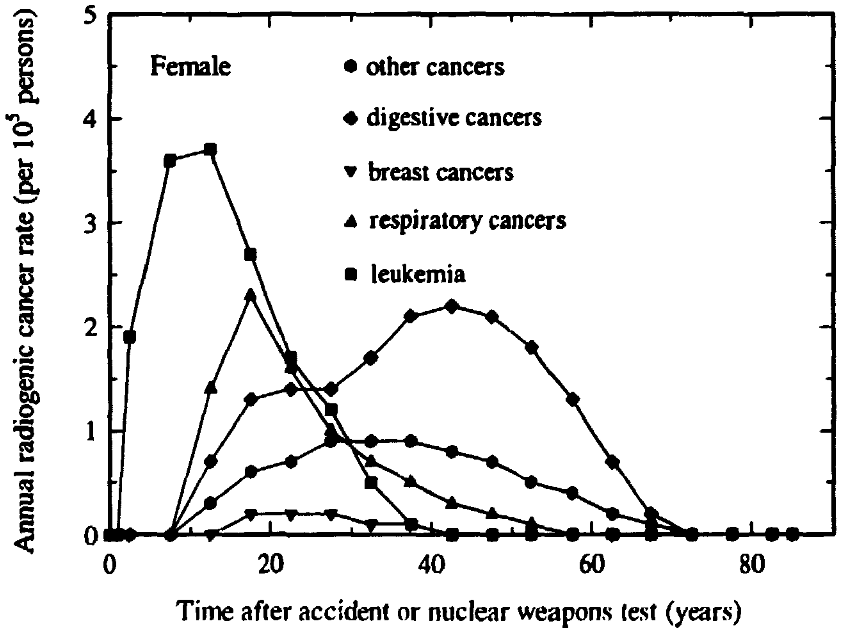

Figure 19. Annual mortality rate for females from different radiogenic cancer types for the age group above 18 years as a function of time after the Chernobyl accident in rural areas in the Briansk region with a surface contamination density of ^{137}Cs of 30-45 Ci·km^{-2}.

Whether it would be possible to detect this increase or not will depend on the size of the population and the individual doses within that group.

In general, the detection of an increase of the spontaneous cancer rate in a given population due to a radiation exposure would be possible only if the excess cancer rate would be larger than two standard deviations of the spontaneous cancer rate. It can be shown that the number of person years to be monitored in an epidemiological study would be proportional to the spontaneous cancer rate under observation (e.g. leukemia) and inversely proportional to the *square* of *both* the annual dose and the attributable risk factor.

As an example, if a group of children and juveniles (age 0–18 years) were exposed to an annual bone marrow dose of 0.002 Sv and the risk factor for leukemia were assumed to be 0.02 Sv^{-1} for that age group, the necessary number of person years for an epidemiological study would be of the order of 10^5. For an exposure period of 20 years, the exposed group of juveniles should be larger than 5,000 were the spontaneous leukemia rate of the order of $5 \cdot 10^{-5}$ y^{-1}.

3.4 Comparison of BARD and ASQRAD risk calculations

The risk calculation program ASQRAD (Assessment System for the Quantification of Radiation Detriment) has recently been developed by the NRPB (National Radiological Protection Board) and the CEPN (Centre d'etude sur l'evaluation de la protection dans le domaine nucleaire) with support from the European Commission (ASQRAD94).

The aim of ASQRAD is to provide a common framework for applying measures of radiation detriment. The code has been designed to be a flexible, easy-to-use tool with the facility to quantify somatic and hereditary effects, based on a wide selection of health effect models for both individuals and populations. It also allows alternative data and model parameters to be used as input, e.g. demographic data.

A range of models for somatic effects are available within the program. These include the multiplicative and additive models proposed by UNSCEAR (UNSCEAR88) and the Radiation Effects Research Foundation (RERF) as well as the models proposed by the BEIR V Committee (NAS90). Also included in the program is a model to quantify the hereditary effects from a radiation exposure. The parameter values of all these models can be changed by the user.

Calculations have been made with ASQRAD for an acute exposure of 0.8 Sv which was used in the similar calculations of risks from the nuclear weapons tests in the Semipalatinsk region. The risk projection model from BEIR V (NAS90) has been used together with demographic data for the 1988 UK-population. A dose and dose rate effectiveness factor (DDREF) of 1.5 has been used as in the BARD calculations. The results are shown in Figures 20 and 21.

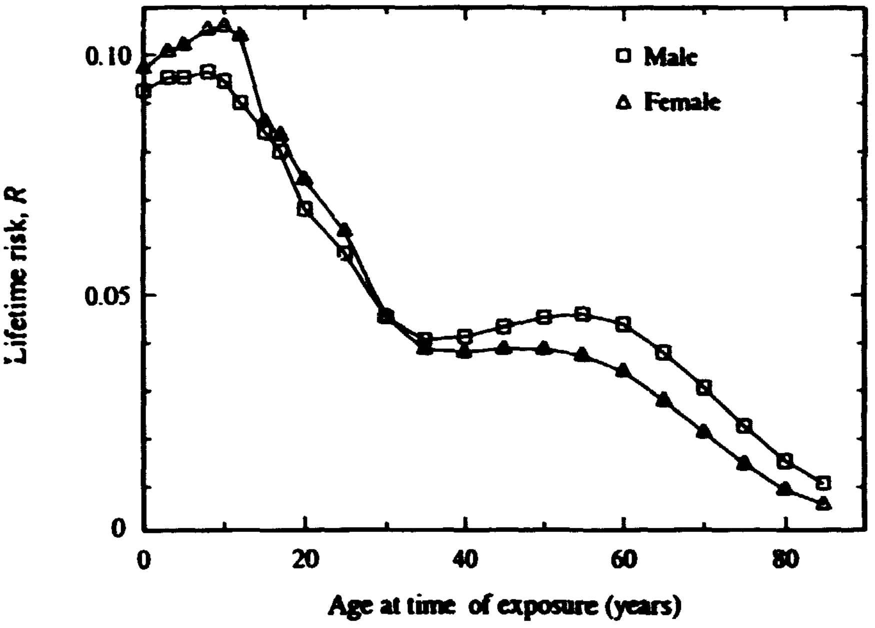

Figure 20. Lifetime risk, R, from lethal radiogenic cancers in its dependence on age at time of exposure.

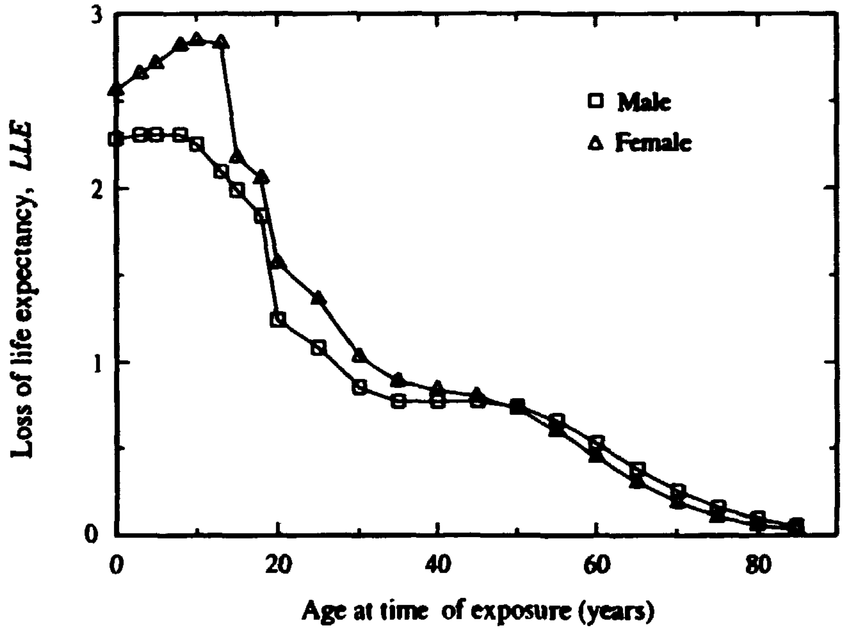

Figure 21. Loss of life expectancy, LLE, from lethal radiogenic cancers in its dependence on age at time of exposure.

The ASQRAD and the BARD risk calculations gave comparable results. By comparing Figures 10 and 20 it appears that the lifetime risk, *R*, from an acute exposure of 0.8 Sv for different ages at time of exposure calculated with the BARD methodology and demographic data is somewhat higher for males up to the age of 55 compared to the ASQRAD calculations for a UK-population. Above the age of about 55 for males the calculated lifetime risk with the ASQRAD program exceeds the BARD risk figures. For females, the same picture appears but the dividing age is here about 30.

The calculated loss of life expectancy, *LLE*, from an acute exposure of 0.8 Sv for different ages at the time of exposure with the two methods seems to be in very good agreement for males. For females the BARD values are somewhat higher than the ASQRAD values for ages above 30.

The differences would most probably be due to the different demographic data used in the two models. In fact, the population in the Semipalatinsk region in the fourties and fifties had a significantly higher fraction of young people than the national average.

3.5 Attributable risks from prolonged radiation exposures

The attributable lifetime probability of death from radiation exposure will depend on the age at the time of exposure. A defined exposure scenario will add a conditional increment of probability rate to the background rate. The rate is conditional, because it will be expressed only if the individual is alive at the ages for which it is defined. The attributable lifetime probability of death due to an extended exposure can be calculated from the dose rate as a function of time, the probability rate of death per unit dose and the survival probability function.

The exposure of a population after a nuclear accident would always be decreasing in time due to radioactive decay and other removal processes. After the Chernobyl accident the effective half-life of the deposited ^{137}Cs in the environment has been measured to be in the range of 5–15 years.

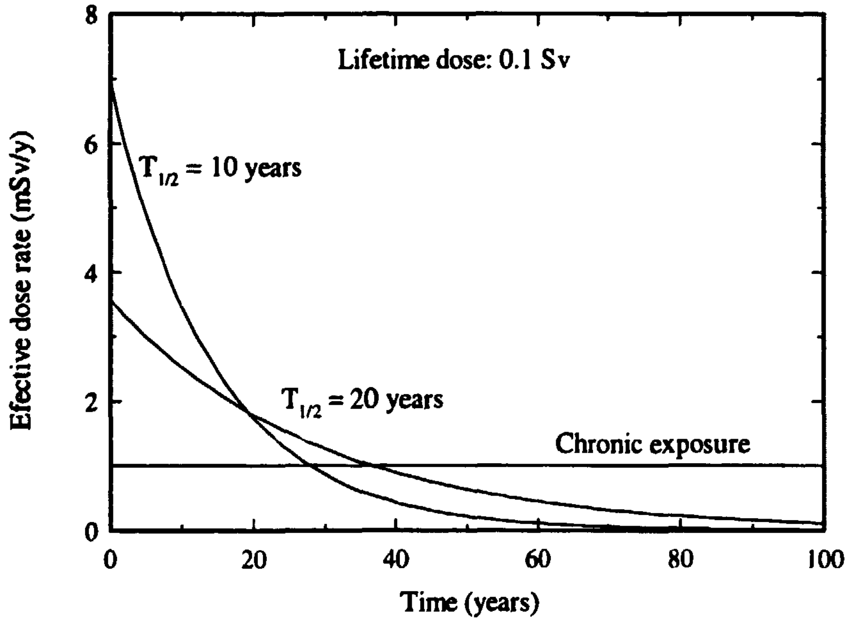

Figure 22. Prolonged exposure situations of individuals. The lifetime dose from age 0 to 100 years is 100 mSv for each of the three exposure situations. The lifetime dose for individuals of older ages at start of exposure would be less than 100 mSv.

Three different extended exposure situations have been used in the present risk calculations, one with a constant (chronic) exposure in time and two decreasing exposures in time as shown in Figure 22.

In all three exposure situations the lifetime doses for newborns have been normalised to 0.1 Sv (in 100 years). For older ages the lifetime doses would consequently be lower than 0.1 Sv as the expected remaining lifespan will be less than that for newborns.

For each of the three exposure situations the lifetime probabilities of radiation induced fatal cancer have been calculated for both males and females based on the ASQRAD-system. The risk projection model from BEIR V (NAS90) has been used together with demographic data for the 1988 UK-population. A dose and dose rate effectiveness factor (DDREF) of 2 has been used in the risk calculations. The results are shown in Table 11.

Table 11. Lifetime probabilities of fatal cancer for males and females at various ages at start of different prolonged exposures. The lifetime dose from age 0 to 100 years is 0.1 Sv for each of the three exposure categories.

Age at start of exposure (years)	Chronic exposure		Decreasing exposure $T_{1/2} = 10$ years		Decreasing exposure $T_{1/2} = 20$ years	
	Male	Female	Male	Female	Male	Female
0	$3.7 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$5.2 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$	$4.1 \cdot 10^{-3}$
10	$3.2 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$	$5.4 \cdot 10^{-3}$	$4.4 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$
20	$2.7 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$	$5.4 \cdot 10^{-3}$	$4.4 \cdot 10^{-3}$	$4.7 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$
30	$2.2 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	$5.4 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$
40	$1.6 \cdot 10^{-3}$	$1.3 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	$3.9 \cdot 10^{-3}$	$3.7 \cdot 10^{-3}$	$2.9 \cdot 10^{-3}$
50	$1.1 \cdot 10^{-3}$	$8.4 \cdot 10^{-4}$	$3.8 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$2.6 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$
60	$5.6 \cdot 10^{-4}$	$4.5 \cdot 10^{-4}$	$2.4 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
70	$2.4 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$	$1.2 \cdot 10^{-3}$	$8.8 \cdot 10^{-4}$	$7.1 \cdot 10^{-4}$	$5.4 \cdot 10^{-4}$
80	$7.6 \cdot 10^{-5}$	$5.1 \cdot 10^{-5}$	$4.2 \cdot 10^{-4}$	$2.8 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	$1.6 \cdot 10^{-4}$
90	$2.2 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$	$1.3 \cdot 10^{-4}$	$7.4 \cdot 10^{-5}$	$7.2 \cdot 10^{-5}$	$4.1 \cdot 10^{-5}$

In Belarus the average annual individual dose in 1992 from external and internal doses from ^{137}Cs has been estimated to be 2 $\mathrm{mSv \cdot y^{-1}}$ for individuals receiving annual doses above 1 $\mathrm{mSv \cdot y^{-1}}$. If it is assumed that the effective removal half-life is 10 years, the average lifetime dose for a newborn in 1992 would be approximately 30 mSv.

Relocation of the population in the Rovno and Jitomir oblasts in 1991 would have averted an average lifetime dose of 10 mSv. In this dose calculation a reduction population factor has been included (see Table 10). The average maximum lifetime dose in Ukraine that would have been averted would be about 3 times higher, i.e. 30 mSv, which is the same order of magnitude as the individual lifetime doses in Belarus.

In Russia, avertable individual doses were assessed to be 2.3 $\mathrm{mSv \cdot y^{-1}}$ on average. The average individual lifetime dose was assessed to be of the order of 28 mSv from Chernobyl averaged to the population assigned to relocation according to the criterion of an effective annual dose of 1 mSv in 1991. The maximum residual dose from Chernobyl averaged for a single settlement starting from 1992 is less than the lifetime dose from natural background radiation.

The attributable lifetime probability of death averaged over both sexes due to an extended exposure of 30 mSv and an effective half-life of 10 years can be calculated from the values in Table 11 to be:

Age	*Lifetime probability*
newborn	$1.4 \cdot 10^{-3}$
20 year	$1.4 \cdot 10^{-3}$
40 year	$1.3 \cdot 10^{-3}$
60 year	$6.4 \cdot 10^{-4}$

The natural background of ionising radiation received by humans comprises cosmic rays and radiation from naturally occurring radionuclides that are present in the environment and are incorporated in the body from the intake of radionuclides in foods. The average lifetime doses from the background radiation in European countries varies between 100 mSv and 500 mSv as shown in Figure 23 (IAEA94).

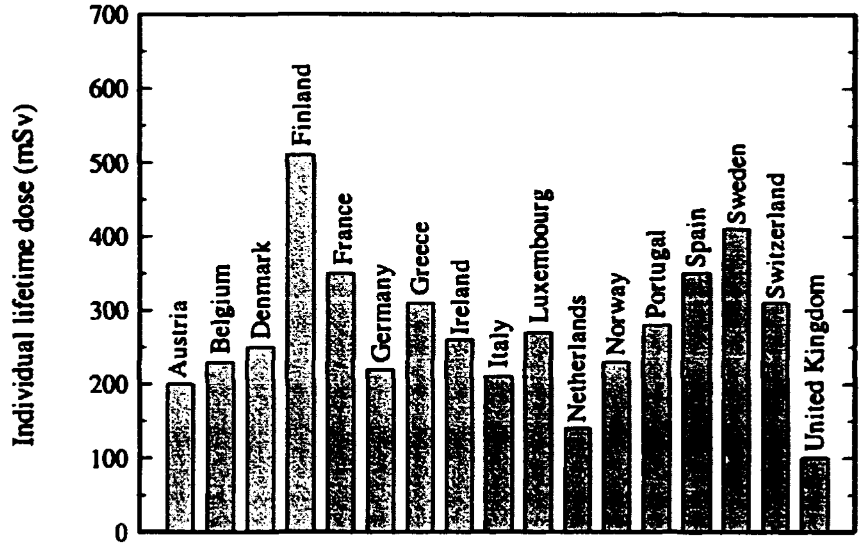

Figure 23. Average lifetime doses in 70 years from the natural background radiation in Western European countries.

The potential avertable lifetime dose in Belarus, Ukraine and Russia is about 30 mSv on average if the effective environmental half-life is of the order of 10 years. This dose is of the order of 7% of the variation in average lifetime doses in the countries in Western Europe. The avertable individual risk from removing this exposure of 30 mSv from countermeasures or the residual individual risk if no countermeasures are introduced is equivalent to an individual average loss of life expectancy of 100–200 hours.

4 New regulations in Russia

The situation with developing regulations in FUSSR and Russia in 1986–1993 has been described in earlier JSP 2/Task 3 documents (Hedemann et al. 1993, 1994). This development has continued in Russia during 1994–1995. It was caused by the necessity and possibility to take into consideration:

- more deeply the lessons learned from the experience of intervention practice and the development of national regulation and international recommendations on intervention levels (ICRP90, ICRP93, IAEA94),

- ideas from risk analysis applied to the assessment of the consequences of nuclear weapon tests and nuclear accidents.

The former of the above items was considered in the JSP 2/Task 3 report for 1994 (Hedemann et al. 1994).

4.1 New basic recommendations

The following three documents (first versions) were elaborated in the frame of the Russian federal research programme (the Chernobyl case study):

- Recommendations on intervention levels and strategy of remedial actions after a nuclear accident (working group headed by A. Tsyb);
- Recommendations on optimisation of intervention and remediation actions after a nuclear accident (working group headed by V. Demin);
- Recommendations on risk analysis in application to protection and remediation actions after a nuclear test or accident (working group headed by V. Demin).

These documents are being coordinated with each other. The first versions (drafts) were adopted by the Russian NCRP (RNCRP) in December 1994. The aim of that activity of RNCRP is adoption of national experience on liquidation of the consequences of large nuclear accidents and nuclear weapons tests to become national practice for remedial actions and national radiation safety standards.

The main features of the new regulation documents are to:

- combine considerations of all phases of post-accident activity,
- consider not only pure radiation protection but include both radiation as well as non-radiation risks,
- establish three sets of decision-making dose levels,
- develop definitions of critical groups, for which not only the highest individual doses but also the highest risks are taken into account.

4.2 System of intervention levels

The system of intervention levels includes *three* sets:

- General Intervention Levels (in terms of projected doses), which establish the strategy of intervention;
- Specified Intervention Levels (in terms of avertable doses) for radiation protection purposes;
- Specified Intervention Levels (in terms of residual doses) for social protection purposes.

The last set of levels was primary introduced for social protection of the population in the Altai region affected by the nuclear weapons tests at the Semipalatinsk test site (Hedemann et al 1994). Obviously, this set of levels should have a wider application and should be improved taking into account new data and new experience.

The General Intervention Levels include two principal levels:

- *an upper dose level* (the dose constraint) above which the introduction of any countermeasures is compulsary in preventing people from receiving doses above this level;
- *a lower dose level* having the role of a non-action level.

The development of these regulatory documents will continue in 1995 and will be reported in detail in the JSP2 report of 1995–1996.

5 Discussion and conclusions

This study has elaborated on some of the radiation protection factors that are useful for an overview of an accidental situation where radioactive materials have been dispersed in the environment. These factors include avertable doses and avertable individual lifetime risks by long-term countermeasures as relocation, foodstuff restrictions and specific agricultural countermeasures.

Avertable doses in the republics of Ukraine, Belarus and Russia have been related to distributions of population on annual doses and surface contamination density and foodstuff production on activity concentration in foodstuffs. Such quantified relations between calculated doses and distribution parameters can be useful to decision makers responsible for implementing and withdrawing protective measures. The avertable and residual lifetime doses have been compared to the variation in lifetime doses in Europe. The lifetime doses have also been expressed as (avertable or residual) individual lifetime risks.

For decision-making on radiation and social protection countermeasures it is necessary to assess avertable and residual risks on both individual and population levels. Within the framework of the Russian federal research programme (Chernobyl and Altai studies) and partly within the EU/CIS-project JSP 2, the research project "developing the methodology (MAR) and data bank (BARD) on risk analysis" has been carried out to obtain data on consequences of the atmospheric nuclear weapons tests conducted at the Semipalatinsk test site during the period 1949–1962. The methodology for assessing the risks to the affected population groups from the combined acute and prolonged radiation exposure from these tests would form a useful basis for the planning of both protective measures and risk communications to populations affected by nuclear or radiological accidents as well as for future research.

Calculations have also been made with the ASQRAD risk model of the exposures from the nuclear weapons tests in the Semipalatinsk region and the results were compared to the BARD calculations. The calculated values from the ASQRAD model were somewhat lower for the younger age groups. These differences are probably due to the different demographic data used in the two models. In fact, the exposed population in the Semipalatinsk region had a higher fraction of younger people than the population used in the ASQRAD calculations.

The residual average annual doses from the Chernobyl accident in the affected CIS republics Ukraine, Belarus and Russia from 1991 and onwards are of the same order of magnitude or even lower than doses from the natural background radiation. This does not call for major protective measures to be introduced for reducing the residual doses to the affected population on radiation protection grounds. The residual individual risk of stochastic effects after protective measures have been taken is often a significant concern to national authorities. Indeed, in allocating resources for health protection, more are normally devoted to preventing effects to people at high risk than to those at low risk. In addition, sociopolitical and psychological factors may well contribute to, or even dominate, some decisions.

However, there will always be other competing health demands in a society, and the allocation of resources to protecting health after a large radiation accident ought not be significantly different from that to protecting against other hazards. Otherwise, a significant fraction of a country's economy could be diverted into preventing relatively few radiation induced health effects, out of all proportion to how the money could have been better spent on general health care.

References

ASQRAD94. *Assessment System for Quantification of Radiological Detriment.* NRPB and CEPN, September 1994.

Belyaev, S.T.; Demin, V.F.; Shoikhet, Ja.N.; Kiselev, V.I.; Algazin, A.I.; Zaitzev, E.V.; Kolyado, V.B., *Estimation of radiation health risk of nuclear tests at the Semipalatinsk test site for Altai region population.* Bulletin of the Research Programme "Semipalatinsk Test Site/Altai", No. 4, pp. 12-21, 1994.

Demin, V.F.; *Methodological recommendations on risk assessment in application to situations after nuclear weapons tests or accidents.* Bulletin of the State Research Programme "Semipalatinsk Test Site/Altai Case Study", No. 1, p. 5, 1995.

IAEA94, International Atomic Energy Agency, *Intervention Criteria in a Nuclear or Radiation Emergency,* Safety Series No. 109, IAEA, Vienna, 1994.

Hedemann Jensen, P.; Konstantinov, Y.O.; Demin, V.F., *CEC-CIS Joint Study Project 2 - Conceptual Framework of Intervention Level Setting.* Task 3 Report for 1992, February 1993.

Hedemann Jensen, P.; Demin, V.F.; Konstantinov, Y.O.; Yatsalo, B.I., *EU-CIS Joint Study Project 2 - Conceptual Framework of Intervention Level Setting.* Task 3 Report for 1993, Risø-R-716(EN), January 1994.

ICRP90, International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiation Protection,* Publication 60, Pergamon Press, Oxford, New York, Frankfurt, Seoul, Sydney, Tokyo, 1990.

ICRP93, International Commission on Radiological Protection, *Principles for Intervention for Protection of the Public in a Radiological Emergency,* Publication 63, Pergamon Press, Oxford, New York, Seoul, Tokyo (1993).

Krisjuk, E.M.; Konstantinov. Y.O.; Nikitin, V.V.; Ponikarova, T.M.; Prokofiev, O.N., *Radiation Doses to population.* Gigiena i Sanitarija 5, p.63 (in Russian) 1984.

Lebedev, O.V.; Erkin, V.G., *Forecast of External Radiation Dose to Population in Territories Contaminated by Caesium.* Atomnaya Energiya 74, p. 421 (in Russian), 1993.

Likhtariov, I.A., *Assessements of averted doses and effectiveness of different countermeasures.* Internal material. Ukrainian Scientific Centre for Radiation Medicine. Kiev. Ukraine, November 1994.

NAS90, U.S. National Academy of Sciences. *Health Effects of Exposure to Low Levels of Ionizing Radiation.* Report by the Committee of the Biological Effects of Ionizing Radiation (BEIR V). National Academy of Sciences/National Research Council, Washington D.C. (1990).

Rolevich, I.V., *Joint Study Project 2. Risk Analysis. Summary Information Report on the Work Done in 1994.* Chernobyl State Committee. Minsk, Belarus, December 1994.

Skryabin, A.M., *Graphical presentations of population distributions on surface contamination density of* ^{137}*Cs and external* γ*-dose rate.* Internal material. Research Institute of Radiation Medicine, Gomel, Belarus, October 1994.

Skryabin, A.M.; Savkin, M.N.; Konstantinov, Y.O.; Robinson, C.A. *The Distribution of Doses Received in Rural Areas Affected by the Chernobyl Accident.* JSP 2, Task 5, Final Report (To be published in 1995).

Orlov, M.Y.; Snykov, V.P.; Bochkov, L.P., *Soil Contamination in Settlements in*

Russia with Radionuclides Caused by the Accident at the Chernobyl Nuclear Power Plant. Atomnaya Energiya 76, p. 209, 1994.

UNSCEAR88, United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources, Effects and Risks of Ionising Radiation.* UNSCEAR 1988 Report to the UN General Assembly, with Annexes. United Nations, New York (1988).

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Abstract (Max. 2000 char.)

The radiological conditions after the Chernobyl accident in the CIS republics Ukraine, Belarus and Russia have been evaluated for the period following 1991. Differential population distributions on dose rate or surface contamination density and differential mass distributions for milk on activity concentration of ^{137}Cs in milk have been used to calculate individual avertable and residual doses. The residual lifetime doses in the three republics with reference to the year 1991 have been calculated to be of the order of 30 mSv on average. The potential avertable individual lifetime doses are therefore less than the lifetime doses from the natural background radiation and less than 10% of the variation of the lifetime doses from natural background radiation in Europe. The corresponding residual individual lifetime risks have been calculated from the European ASQRAD model to be of the order of 0.06–0.14%, depending on age at start of exposure, and assuming an effective half-life of the annual exposure of 10 years and a dose and dose rate effectiveness factor (DDREF) of 2. A risk model is being developed in Russia for the assessment of risks to the exposed populations from atmospheric nuclear weapons tests in the Semipalatinsk region (Altai region) in the forties and fifties. Calculated age-dependent risks from an acute exposure of the Altai population have been compared with results from similar calculations with the ASQRAD model and reasonable agreement has been found between the two models.

Descriptors INIS/EDB

A CODES; BELARUS; CESIUM 137; CHERNOBYLSK-4 REACTOR; FOOD; MATHEMATICAL MODELS; MILK; POPULATION RELOCATION; RADIATION DOSE DISTRIBUTIONS; RADIATION DOSES; RADIATION HAZARDS; RADIATION PROTECTION; REMEDIAL ACTION; RISK ASSESSMENT; RUSSIAN FEDERATION; SURFACE CONTAMINATION; UKRAINE

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