Chapter IV. Radiation Protection after the Chernobyl Catastrophe

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Key words: **Chernobyl; dose burden; radionuclide decorporation**

Since the Chernobyl catastrophe more than 5 million people in Belarus, Ukraine, and European Russia continue to live in the contaminated territories. Many thousands more live in other European countries contaminated with radiation, including Sweden, Finland, Norway, Scotland, Britain, and Wales (see Chapter I for details). Radiation protection is necessary for all of these people.

After the catastrophe there were enormous efforts to introduce countermeasures in Belarus, Ukraine, and Russia—to relocate hundreds of thousands of people and to try to lessen exposure to radioactive contamination. Steps that were taken included restricted food consumption and changes in food preparation, as well as changes in agricultural, fishery, and forestry practices under the guidance of qualified scientists (Bar'yachtar, 1995; Aleksakhin *et al.*, 2006).

The situation in regard to radiation protection in the contaminated territories places public health advocates in what is described in Russian as between an "upper and nether millstone," and in the West, as between a rock and a hard place. Authorities allocate as little as possible to provide financial resources for rehabilitation and disaster management and at the same time are reluctant to accept data about dangerous levels of contamination of populations, food, and the environment. These attitudes hold for officials practically everywhere.

The reluctance on the part of officialdom to acknowledge the truth about Chernobyl's consequences has led to concerned citizens organizing to find additional sources of information and devising ways to help those who are suffering. Hundreds of such public local, national, and international organizations have been created, such as "Children of Chernobyl," "Physicians of Chernobyl," "Widows of Chernobyl," and Liquidator's Unions in Belarus, Ukraine, Russia, and many other countries including Germany, Austria, France, Switzerland, Canada, the United States, and Israel.

In 1987, initiated by physicist and humanist Andrei Sakharov, famous Belarussian writer Ales' Adamovich, and world chess champion Anatoly Karpov, the Belarussian Institute of Radiation Safety–BELRAD was established as an independent public organization devoted to helping Belarussian children—those who suffered most after the catastrophic contamination from Chernobyl. For 21 years the BELRAD Institute has collected an extensive database in the field of radiation protection and has become unique as a nongovernmental Chernobyl center for both scientific and practical information.

Chapter IV is based primarily on the BELRAD materials. Chapter IV.12 presents data on the Chernobyl contamination of food and humans in many countries, Chapter IV.13 reports on the Belarussian experience with effective countermeasures to lower levels of incorporated radionuclides such as the use of

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Chernobyl: Ann. N.Y. Acad. Sci. 1181: 287–327 (2009).
doi: 10.1111/j.1749-6632.2009.04836.x

enterosorbents, and Chapter IV.14 outlines common countermeasures against radioactive contamination in agriculture and forestry.

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12. Chernobyl's Radioactive Contamination of Food and People

Alexey V. Nesterenko, Vassily B. Nesterenko, and Alexey V. Yablokov

In many European countries levels of I-131, Cs-134/137, Sr-90, and other radionuclides in milk, dairy products, vegetables, grains, meat, and fish increased drastically (sometimes as much as 1,000-fold) immediately after the catastrophe. Up until 1991 the United States imported food products with measurable amounts of Chernobyl radioactive contamination, mostly from Turkey, Italy, Austria, West Germany, Greece, Yugoslavia, Hungary, Sweden, and Denmark. These products included juices, cheeses, pasta, mushrooms, hazelnuts, sage, figs, tea, thyme, juniper, caraway seeds, and apricots. In Gomel, Mogilev, and Brest provinces in Belarus 7–8% of milk and 13–16% of other food products from small farms exceeded permissible levels of Cs-137, even as recently as 2005–2007. As of 2000, up to 90% of the wild berries and mushrooms exceeded permissible levels of Cs-137 in Rovno and Zhytomir provinces, Ukraine. Owing to weight and metabolic differences, a child's radiation exposure is 3–5 times higher than that of an adult on the same diet. From 1995 to 2007, up to 90% of the children from heavily contaminated territories of Belarus had levels of Cs-137 accumulation higher than 15–20 Bq/kg, with maximum levels of up to 7,300 Bq/kg in Narovlya District, Gomel Province. Average levels of incorporated Cs-137 and Sr-90 in the heavily contaminated territories of Belarus, Ukraine, and European Russia did not decline, but rather increased from 1991 to 2005. Given that more than 90% of the current radiation fallout is due to Cs-137, with a half-life of about 30 years, we know that the contaminated areas will be dangerously radioactive for roughly the next three centuries.

However much money is allocated by any government for radiation protection (e.g., in Belarus in 2006 nearly $300 million was allocated to reduce radioactive contamination in agricultural production), no nation has the ability to provide total protection from radiation for populations living in contaminated areas and eating locally produced vegetables, forest products, and fish and game that are contaminated with radionuclides.

Thus it is of prime importance that radiation-monitoring capability be established on the local level so that citizens have access to the information and the ability to monitor their own locally produced food and to actively participate in organizing and carrying out radiation protection. Too often, central data monitoring repositories have little incentive to ensure that people around the country get the information that they should have.

12.1. Radiation Monitoring of Food

12.1.1. Belarus

At the end of 1993, in order to monitor food radiation, the BELRAD Institute with support from the State Belarus Committee of Chernobyl Affairs ("Comchernobyl") created 370 public local centers for radiation control (LCRC) to monitor foodstuffs in the contaminated areas. The general database

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on contaminated foodstuffs available from BELRAD today has more than 340,000 measurements, including some 111,000 tests of milk.

1. According to the BELRAD database up to 15% of milk from small farms and up to 80% of other food produce in three Belarus provinces was contaminated with Cs-137 above the permissible levels (Table 12.1).

2. The percentage of food products with radioactive contamination in excess of official permissible levels did not decrease for 14 years after the catastrophe; on the contrary, in 1997 in the Gomel and Brest areas this percentage began to increase (Table 12.2).

3. Up to 34.3% of all milk tested from Brest Province in 1996 had radiation levels higher than the permissible ones. The number of milk tests showing dangerous levels was significantly higher in Gomel and Brest than in Mogilev province. From 1993 to 2006, there was some reduction in the number of milk tests that exceeded the permissible level (Table 12.3).

4. The portion of dangerous milk tests noticeably increased year by year: for example, from 19.3% in 1994 to 32.7% in 1995 in Brest Province; from 9.9% in 2003 to 15.8% in 2004 in Gomel Province; and from 0.7% in 2004 to 7.2% in 2005 in Mogilev Province.

5. In some places the percent of milk tests that showed dangerous levels of Cs-137 was significantly above the average. For example, in 2006 in Luga Village, Luninetsk District, Gomel Province, results in 90.7% of the tests exceeded the permissible level and levels were more than 16-fold higher than the province average.

TABLE 12.1. Cs-137 Concentration in Some Foodstuffs in Brest, Gomel, and Mogilev Provinces, Belarus, 1993 (BELRAD data)

Foodstuff	Number of samples	Above official permissible level for 1992	Official permissible level (1992), Bq/kg
Mushrooms (starry agaric)	133	80.5	370
Cranberry	429	62.7	185
Blackberry	1,383	61.0	185
Meat (game)	125	58.4	600
Mushrooms (dried)	459	57.7	3,700
Rough boletus	160	57.5	370
Edible boletus	561	54.4	370
Mushrooms (boiled)	87	52.9	370
Chanterelle	125	52.8	370
Blackberry (preserves)	150	42.0	185
Kefir	71	25.4	111
Honey fungus	57	22.8	370
Milk	19,111	14.9	111
Lard	234	14.1	185
Sour cream	242	12.8	111
Raspberry	154	11.7	185
Pot cheese	344	11.6	111
Carp	152	11.2	370
Strawberry	73	9.6	185
Water	2,141	8.8	185
Beetroot	1,628	8.2	185
Cream	51	7.8	111
Garden strawberries	389	6.4	185
Carrots	1,439	5.8	185
Cabbage	590	4.4	185
Meat (beef)	297	3.7	600
Cucumber	433	3.2	185
Tomatoes	141	2.8	185
Pears	208	2.4	185
Apples	1,547	2.3	185
Onion	435	2.1	185
Cherry	196	2.0	185
Meat (pork)	969	2.0	600
Butter	51	2.0	185
Potatoes	4,996	1.6	370

12.1.2. Ukraine

1. Even up to the year 2000, Cs-137 levels remained in excess of admissible levels: 80% in berries and mushrooms in Rovno Province, 90% in Zhytomir Province, 24% in forest-steppe Vinnitsa and Cherkassk provinces, and 15% in the Volyn' Province (Orlov, 2002).

2. According to data from the Ukrainian Ministry of Health, in 2000, from 1.1 up to

TABLE 12.2. Percent of Food Products with Excess of Permissible Levels of Cs-137 in Gomel, Mogilev, and Brest Provinces, Belarus, 1993–2007 (BELRAD Database)

	Years							
Province	1993–1994	1995–1996	1997–1998	1999–2000	2001–2002	2003–2004	2005–2006	2007
Gomel	12.1	9.6	12.0*	12.7	14.8	19.9	14.8	16.3
Mogilev	9.2	4.0	4.2	5.3	4.8	5.4	15.2	n/a
Brest	15.5	16.6	14.2	17.8	18.0	19.2	13.0	12.5

*Data on the Gomel Province since 1995 may be underestimated (24 LCRC from the heavily contaminated Lel'chitsy District were withdrawn from BELRAD and transferred to the official Institute of Radiology—Comchernobyl).

70.8% of milk and meat in the private sector in Volyn', Zhytomir, Kiev, Rovno, and Chernygov provinces had levels of Cs-137 in excess of allowable limits (Omelyanets, 2001).

12.1.3. Other Countries and Areas

There are considerable data in other countries concerning the contamination of food as a result of Chernobyl.

1. FINLAND. The level of Cs-137 in milk, beef, and pork in Finland drastically increased immediately after the catastrophe (Figure 12.1). Beginning in 1995, some 7.7 tons of mushrooms (mostly *Lactarium* genus) that were collected annually contained 1,600 MBq of Cs-137, or about 300 Bq of Cs-137 per person (Rantavaara and Markkula, 1999).

2. BALTIC SEA AREA. A significantly increased Cs-137 contamination occurred in Baltic fish (Figure 12.2) and there was an even greater increase in freshwater fish (Table 12.4). All game species were heavily contaminated; for example, Cs-137 and Cs-134 levels reached about 6,700 Bq/kg in the golden-eye duck and about 10,500 Bq/kg in other waterfowl (Rantavaara *et al.*, 1987).

3. CROATIA. After the catastrophe the concentration of Cs-137 in wheat increased more than 100-fold (Figure 12.3).

4. FRANCE. In 1997 in Vosges Cs-137 contamination in wild hogs and mushrooms exceeded the norms by up to 40-fold (Chykin, 1997).

5. GREAT BRITAIN. The peak Chernobyl contamination of milk was reached in May 1986 and was up to 1,000-fold as compared with the mean values reported in 1985 for I-131 and Cs-137 and up to four times higher for Sr-90 (Jackson *et al.*, 1987). Twenty-three years after the catastrophe, according to Great Britain's Ministry of Health, 369 farms in Great Britain, accounting for more than 190,000 sheep, continued to be dangerously contaminated with Chernobyl's Cs-137 (Macalister and Carter, 2009).

TABLE 12.3. Percent of a Milk Tests Exceeding the Permissible Level of Cs-137 in Gomel, Mogilev, and Brest Provinces, Belarus, 1993–2007 (BELRAD Database)

	Years							
Province	1993–1994	1995–1996	1997–1998	1999–2000	2001–2002	2003–2004	2005–2006	2007
Gomel	16.6	8.6*	8.7	9.6	8.6	12.9	6.8	6.7
Mogilev	12.0	2.8	1.2	0.5	0.2	0.6	7.2	n/a
Brest	21.7	33.5	18.5	21.4	22.8	17.8	7.9	8.0

*See the footnote to Table 12.2.

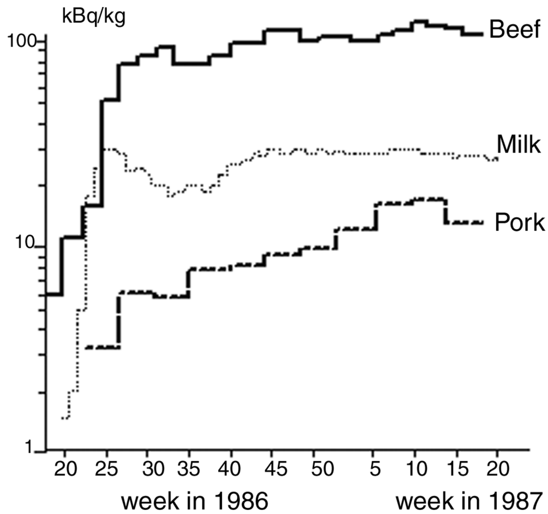

Figure 12.1. Countrywide mean concentration of Cs-137 in meat and milk in Finland (UNSCEAR, 1988).

6. ITALY. According to radiation measurements from the Directorate of Nuclear Safety Health Protection obtained in June 1988, meat, noodles, bread, milk, and cheese were still markedly contaminated by Chernobyl radionuclides (WISE, 1988a).

7. MEXICO. In 1988 Mexico returned 3,000 tons of milk powder to Northern Ireland because of radioactive contamination from Chernobyl (WISE, 1988b).

8. POLAND. In June 1987, a 1,600-ton shipment of powdered milk from Poland to Bangladesh showed unacceptably high levels of radioactivity (Mydans, 1987).

9. SWEDEN. Average Cs-137 concentration in moose (*Alces alces*) meat was 9–14 times higher after Chernobyl. Levels were 470 Bq/kg for calves and 300 Bq/kg for older animals, compared with the precatastrophe average level of 33 Bq/kg (Danell *et al.*, 1989).

10. TURKEY. Some 45,000 tons of tea was contaminated with Chernobyl radioactivity in 1986–1987, and more than a third of the 1986 harvest could not be used (WISE, 1988c).

11. UNITED STATES. Food contaminated in the United States as a result of Chernobyl is especially interesting because of the wide geographical scale of contamination and the broad range of contaminated foods. In spite of official secrecy (see Chapter II.3 for details) the full picture of Chernobyl food contamination

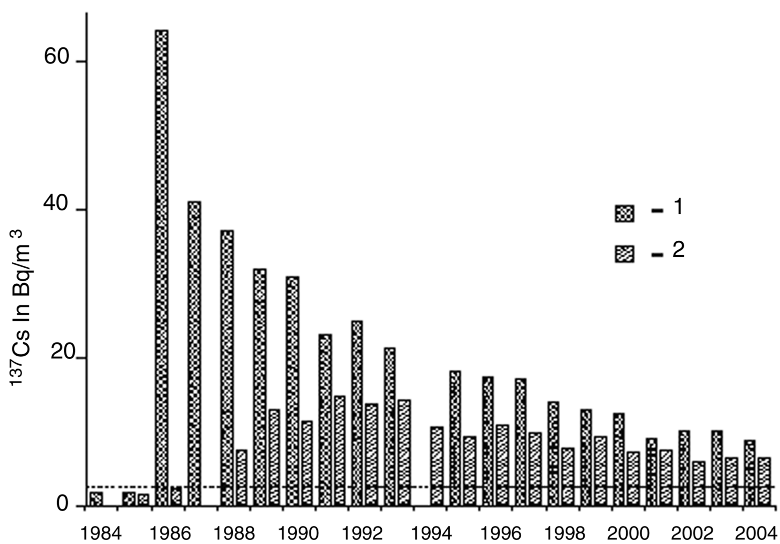

Figure 12.2. Cs-137 concentrations (Bq/kg) in: (1) plaice (*Platichthys flesus*) and (2) flounder (*Pleuronectes platessa*) from 1984 to 2004, as annual mean values in the Bornholm and southern Baltic seas. Pre-Chernobyl (1984–1985) concentrations were 2.9 for plaice and flounder (HELCOM Indicator Fact Sheets. 2006. Online 22.04.2008;//www.helcom.fi/environment2/ifs/en_GB/cover/).

TABLE 12.4. Fish Cs-137 Contamination in Finland, 1986 (Saxen and Rantavaara, 1987)

Species	Concentration, Bq/kg*
Perch	16,000
Pike	10,000
Whitefish	7,100
Bream	4,500
Vendace	2,000

*EU limit of Cs-137 for consumption of wild freshwater fish is 3,000 Bq/kg.

in the United States continues to become more visible. The peak of Chernobyl-derived I-131 in imported foods was observed in May–June 1986, and for Cs-134 and Cs-137, some 10 to 16 months after the catastrophe (RADNET, 2008, Section 9, Part 4).

Between May 5, 1986, and December 22, 1988, the FDA tested 1,749 samples of imported foods for I-131, Cs-134, and Cs-137 contamination. The survey had been classified and was only obtained after a recent freedom of information request (RADNET, 2008). The first food imported into the United States that was contaminated from Chernobyl radioactivity was fish from Norway with a detectable level of Cs-137. The contamination was revealed on May 5, 1986, that is, 11 days after the catastrophe. In May–June 1986, it was found that 15 samples of imported foods (mostly mushrooms and cheese from Italy, but also cheese from West Germany and Denmark) exceeded the I-131 level of 1,000 pCi/kg. Some 44% of such samples from February 1 to October 4, 1987, had Cs-137 levels higher than 100 pCi/kg, and 5% exceeded 5,000 pCi/kg. More than 50% of samples from February 5 to January 25, 1987, had Cs-137 levels higher than 1,000 pCi/kg, and about 7% of samples had more than 5,000 pCi/kg.

According to other data (Cunningham and Anderson, 1994), up to 24% of the imported food sampled in 1989 was noticeably contaminated. By 1990, 25% of samples were contaminated; in 1991, 8% of samples; and in 1992, 2%. "In spite of the general decline, contaminated foods were still occasionally found during FY91 and FY92; indeed, elk meat collected in FY91 contained the highest Cs-137 contamination found since the Chernobyl accident occurred": 81,000 pCi/kg (Cunningham and Anderson, 1994, p. 1426; cit. by RADNET, 2008). According to U.S. federal regulations, imported foods containing more than 10,000 pCi of Cs-134 + Cs-137 must be seized and destroyed (U.S. FDA guidelines on May 16, 1986, by RADNET, 2008). The official documents obtained through the RADNET request (Section 9) shows that between 1986 and 1988 there were 12 such occasions.

The food products contaminated by Chernobyl radioactivity imported into the United States from 1986 to 1988 originated from (in order of the number of cases): Turkey, Italy,

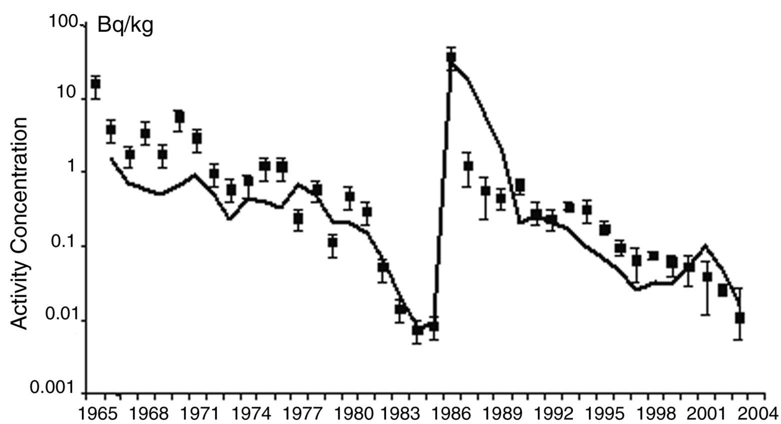

Figure 12.3. Cs-137 concentration in wheat in Croatia from 1965 to 2004 (Franic *et al.*, 2006).

TABLE 12.5. Concentration (pCi/l) of Chernobyl Radionuclides in Milk in the United States, 1986 (Various Authors from RADNET, 2008)

Radionuclide	Concentration	Location	Date
I-131	560	Redland	May 5
	167	Willamette Valley	May 12
	88	Vermont	May
	82	New York area	May 28
	52.5	Maine	May 16
	40	New York area	May 12
Cs-137	20.3	Maine	June
	39.7	Chester, New Jersey	May 17
	40.5	New York City	May
	66	Seattle	June 4
	80	New York area	May 12
	97	Willamette Valley	May 19
Cs-134	9.7	Maine	June
Cs-134 + Cs-137	1,250*	East Washington	May 5

*Food, pCi/kg.

Austria, West Germany, Greece, Yugoslavia, Hungary, Sweden, Denmark, Egypt, France, The Netherlands, Spain, and Switzerland. The contaminated foodstuffs, in order of prevalence, were: apple juice, cheese, pasta, oregano, berry juices, mushrooms, hazelnuts, filberts (*Corylus* sp.), sage (*Salvia* sp.), figs, laurel leaves, tea, thyme, red lentils (*Lens* sp.), juniper, caraway seeds (*Carum* sp.), endive (*Cychorium* sp.), apricots, and even Swiss chocolate.

Table 12.5 shows the level of radioactive contamination in local milk after the catastrophe all over of the United States. In spite of all the measurements, according to the official derived intervention level (DIL), it is a fact that Chernobyl fallout has deposited harmful radioisotopes across the entire extent of North America.

Concentration of Chernobyl Cs-134 + Cs-137 in elk meat was up to 3,000 Bq/kg (RADNET, 2008); the concentration of Ru-106 and Cs-137 in fiddleheads was 261 and 328 pCi/kg, respectively; in mushrooms the C-137 concentration was 3,750 pCi/kg (RADNET, 2008).

12. Some examples of radioactive contamination of food products in other countries are listed in Table 12.6. Although Cs-137, Sr-90, Pu, and Am concentrate in the root zone of plants, they will be mobilized for decades to hundreds of years into the future, and agricultural products will continue to contain radioactivity in all of the Northern Hemisphere countries contaminated by Chernobyl.

12.2. Monitoring of Incorporated Radionuclides

For effective radiation protection, especially for children, it is necessary to monitor not only food, but also to directly monitor radionuclides incorporated into the body. Such monitoring can determine the level of contamination for each particular location in a contaminated territory and for every group of people with high levels of incorporated radionuclides in order to adequately implement radiation protection.

12.2.1. Belarus

To determine the correlation between radioactive contamination of food and incorporated radionuclides in children (as children are the most subject to radiation risk) the BELRAD Institute chose the most intensely contaminated territories from the point of view of size of the mid-annual effective radiation dose and the level of local food contamination.

From 1995 to 2007 BELRAD conducted measurements of absorbed radionuclides in about 300,000 Belarussian children. Measurement of the Cs-137 contamination is carried out by automated complex spectrometry of internal radiation, utilizing an individual radiation counter (IRC) "SCANNER-3." The Institute of Ecological and Medical Systems, Kiev, Ukraine, makes the equipment. The BELRAD Institute has eight such IRC SCANNER-3M instruments, which measure the activity of incorporated gamma-radionuclides (Cs-137, Cs-134, Ca-40, Ra-226,

TABLE 12.6. Chernobyl Radioactive Contamination of Food in Several Countries, 1986–1987

Radionuclide	Food	Maximum concentration	Country	Reference
Cs-137*	Reindeer meat	44,800 Bq/kg	Sweden	Ahman and Ahman, 1994
	Mushrooms	> 20,000 Bq/kg	Germany	UNSCEAR, 1988
	Sheep's milk	18,000 Bq/liter	Greece	Assikmakopoulos *et al.*, 1987
	Mushrooms	16,300 Bq/kg**	Japan	Yoshida *et al.*, 1994
	Reindeer	>10,000 Bq/kg	Sweden	UNSCEAR, 1988
	Potatoes	1.100 ± 0.650 Bq/kg	Croatia	Franic *et al.*, 2006
	Lamb	1,087 Bq/kg	Sweden	Rosen *et al.*, 1995
	Milk	500 Bq/liter	United Kingdom	Clark, 1986
	Meat	395 Bq/kg	Italy	Capra *et al.*, 1989
	Milk	254 Bq/dm^3	Italy	Capra *et al.*, 1989
	Perch	6,042 (mean) Bq/kg	Sweden	Hakanson *et al.*, 1989
	Perch	3,585 (mean) Bq/kg	Sweden	Hakanson *et al.*, 1989
	Farm milk	2,900 Bq/liter	Sweden	Reizenstein, 1987
	Milk	400 Bq/liter	Bulgaria	Energy, 2008
I-131	Milk	135,000	Italy	Orlando *et al.*, 1986
	Yogurt	6,000 Bq/kg	Greece	Assikmakopoulos *et al.*, 1987
	Edible seaweed	1,300 Bq/kg	Japan	Hisamatsu *et al.*, 1987
	Milk	500 Bq/liter	United Kingdom	Clark, 1986
	Breast milk	110 Bq/liter (mean)	Czechoslovakia	Kliment and Bucina, 1990
	Breast milk	55 Bq/l (mean	Czechoslovakia	Kliment and Bucina, 1990
	Pork	45 Bq/kg (mean)	Czechoslovakia	Kliment and Bucina, 1990
	Milk	21.8 Bq/liter	Japan	Nishizawa *et al.*, 1986
	Milk	20.7 Bq/liter	United States	RADNET, 2008
Total	Reindeer meat	15,000 Bq/kg	Sweden	Fox, 1988
	Mutton	10,000 Bq/kg	Yugoslavia	Energy, 2008
	Milk	3,000 Bq/liter	Yugoslavia	Energy, 2008
	Fruits	>1,000 Bq/kg	Italy	Energy, 2008

*Limits of Cs-137 for consumption in EU: 600 Bq/kg for food items; 370 Bq/kg for milk and baby food; 3,000 Bq/kg for game and reindeer meat.

**Year 1990.

Th-232, Mn-54, Co-60, I-131, etc.) in an individual's body as well as the specific dose. It is certified by the Belarus State Committee on Standardization and also registered by the State Registry of Belarus. Each IRC scanner undergoes an annual official inspection. All measurements are done according to protocols approved by that committee. For additional accuracy, the BELRAD IRC SCANNER-3M system was calibrated with the "Julich" Nuclear Center in Germany (see Table 12.7).

1. Measurements were taken in Valavsk Village, in the El'sk District, Gomel Province, where there were 800 inhabitants, including 159 children. The village is located in an area with Cs-137 contamination of 8.3 Ci/km^2 (307 kBq/m^2). According to the 2004 data, the total annual effective dose was 2.39 mSv/year, and an internal irradiation dose was 1.3 mSv/year.

2. There was a correlation between the levels of local food contamination (Figure 12.4) and the level of incorporated radionuclides in the children's bodies (Figure 12.5).

The pattern of curves in Figures 12.4 and 12.5 reflects the seasonal (within the year) variation of contaminated food consumption and thus the accumulation of Cs-137 in a child's body. As a rule, the level of contamination

TABLE 12.7. Cs-137 Body Burden in Children of Narovlya, Bragin, and Chechersk Districts as Measured by Individual Radiation Counters, 1999–2003 (BELRAD Data)

Date	Location	Measured by IRC children, n (% of total inhabitants)	% Children with exposure dose ≥ 1 mSv/year
June 1999	Grushevka	35 (18.6)	26
November 2001		44 (23.4)	11
April 2002		64 (34)	11
November 2001	Verbovichi	60 (20)	33
January 2002		65 (21.5)	9
April 2002		64 (21)	5
November 2002		41 (13.5)	20
December 2002		35 (11.6)	13
November 2003		51 (16.8)	20
November 2001	Golovchitsy	139 (33)	8
January 2002		56 (13.3)	4
November 2002		103 (24.5)	2
October 2003		130 (30.9)	2
January 1999	Demidov	109 (38.5)	10
November 2001		110 (38.8)	12
December 2001		91 (32.3)	9
April 2002		94 (33.2)	9
November 2002		75 (26.5)	12
January 2003		65 (23)	5
January 2000	Zavoit	51 (12.8)	4
November 2001		52 (13)	19
January 2002		49 (12.3)	2
October 2003		50 (12.5)	6
January 1999	Kyrov	94 (22.2)	16
March 1999		98 (23.1)	21
November 2001		92 (21.7)	22
January 2002		84 (19.8)	13
March 2002		91 (21.5)	22
April 2002		75 (17.7)	12
May 2002		90 (21.2)	12
June 2003		43 (10.1)	7
June 1999	Krasnovka	21 (11)	14
November 2001	Narovlya	34	5
January 2002		221	14
February 2002		170	8
November 2002		56	7
November 2003		140	6
December 2003		35	6
February 1999	Dublin	98 (28.3)	4
February 1999	Belyaevka	98 (23.8)	11
March 1999		96 (23.3)	
October 2001		81 (19.7)	
January 1999	Poles'e	132 (25.3)	14
October 1999		185 (35.4)	3
October 2001		95 (18.2)	25
November 2001		95 (18.2)	25
January 2002		148 (28.4)	11
April 2002		144 (27.6)	3

(Continued)

TABLE 12.7. *Continued*

Date	Location	Measured by IRC children, *n* (% of total inhabitants)	% Children with exposure dose ≥ 1 mSv/year
January 2003		148 (28.4)	5
September 2003		141 (27)	9
November 2003		140 (26.8)	10
December 2001	Sydorovychi	84 (30.3)	
January 2002		105 (37.9)	

increased in the autumn and winter (third and fourth quarters) because of increased consumption of especially heavily contaminated foods (mushrooms, berries, wild animal meat). Milk contamination reflects forage with high levels of Cs-137 prepared for the winter.

3. Of about 300,000 children from heavily contaminated territories of Belarus who were tested by BELRAD from 1995 to 2007, some 70–90% had levels of Cs-137 accumulation higher than 15–20 Bq/kg (leading to 0.1 mSv/year internal irradiation). In many villages levels of Cs-137 accumulation reached 200–400 Bq/kg, and some children in Gomel and Brest provinces had levels up to 2,000 Bq/kg (up to 100 mSv/year) (Table 12.7).

4. Belarus and Ukraine, with levels of incorporation of 50 Bq/kg, which is common for territories with Cs-137 contamination of 555 kBq/m^2, show an increase in various diseases and death rates and a decrease in the number of healthy children (Resolution, 2006; see also Chapter II).

5. High levels of the accumulation of Cs-137 have been found in a significant number of children in the Lel'chitsy District (Figure 12.6), the El'sk District (Figure 12.7), and the Chechersk District (Figure 12.8) of Gomel Province. Maximum levels of accumulation of Cs-137 (6,700–7,300 Bq/kg) have been found in a significant number of children in the Narovlya District of Gomel Province. In many villages in this district up to 33% of children have dose levels exceeding the officially permissible 1 mSv/year (Figure 12.9).

6. The level of radionuclide incorporation is significantly different for different organs (Table 12.8).

7. Average Sr-90 concentration in the bodies of inhabitants of Gomel Province noticeably

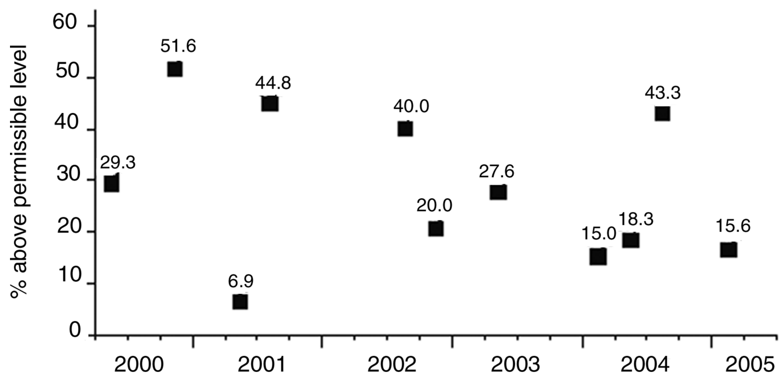

Figure 12.4. Percentage of foodstuffs exceeding permissible levels of Cs-137 for the years 2000 to 2005, Valavsk Village, Gomel Province, Belarus (BELRAD data). The horizontal axis shows the year divided into quarters; the vertical axis indicates the percentage of foodstuffs in which levels exceeded the norm.

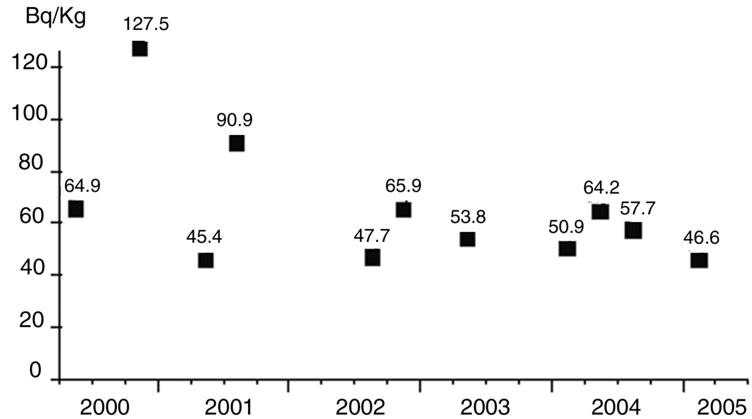

Figure 12.5. Average specific activity of Cs-137 (Bq/kg) in children from Valavsk Village, Gomel Province, Belarus, from 2000 to 2005 (BELRAD data).

increased from 1991 to 2000 (Borysevich and Poplyko, 2002).

8. The Pu body contamination of Gomel citizens 4–5 years after the Chernobyl accident is on average three to four times higher than global levels (Hohryakov *et al.*, 1994).

12.2.2. Other Countries

1. DENMARK. Sr-90 and Cs-137 contamination occurs in humans, with Sr accumulating along with Ca and Cs occurring in the same tissues as K. The Sr-90 mean content in adult human vertebral bone collected in 1992 was 18 Bq (kg Ca)$^{-1}$. Whole body measurements of Cs-137 were resumed after the Chernobyl accident. The measured mean level of Cs-137 in 1990 was 359 Bq (kg K)$^{-1}$ (Aarkrog *et al.*, 1995).

2. FINLAND. Peak body burdens in Finland in 1986 were 6,300 and 13,000 Bq for Cs-134 and for Cs-137, respectively (Rahola *et al.*, 1987). The average Cs-137 body burden 17 years after the catastrophe for the entire country was about 200 Bq; for inhabitants of Padasyoki

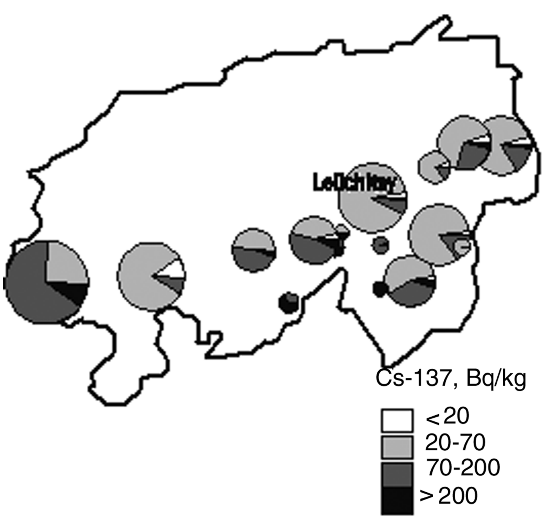

Figure 12.6. Cs-137 levels in children of Lel'chitsy District, Gomel Province, Belarus (Nesterenko, 2007).

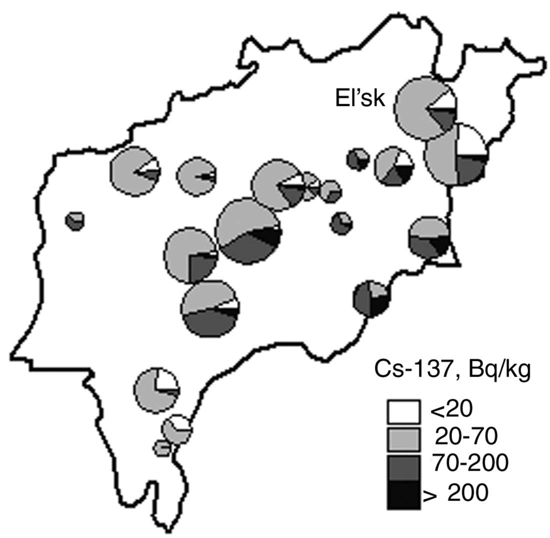

Figure 12.7. Cs-137 levels in children of El'sk District, Gomel Province, Belarus (Nesterenko, 2007).

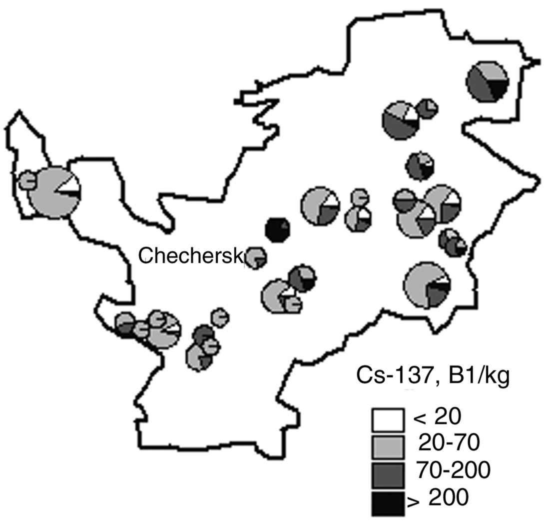

Figure 12.8. Cs-137 levels in children of Chechersk District, Gomel Province, Belarus (Nesterenko, 2007).

City it was 3,000 Bq (the maximum figure was 15,000 Bq). At the end of 1986 the mean Cs-134 body burden was 730 Bq. The Cs-137 mean body burden increased from 150 to 1,500 Bq in December 1986. The maximum levels of body burdens for Cs-134 and C-137 were

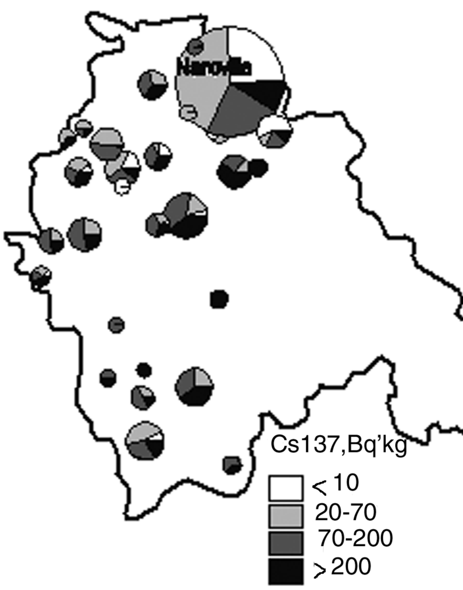

Figure 12.9. Cs-137 levels in children of Narovlya District, Gomel Province, Belarus (Nesterenko, 2007).

TABLE 12.8. Concentration (Bq/kg) of the Cs-137 in Autopsied Organs (56 Persons), Gomel Province, 1997 (Bandazhevsky, 2003)

Organ	Concentration
Thyroid	2,054 ± 288
Adrenal glands	1,576 ± 290
Pancreas	1,359 ± 350
Thymus	930 ± 278
Skeletal muscle	902 ± 234
Spleen	608 ± 109
Heart	478 ± 106
Liver	347 ± 61

6,300 and 13,000 Bq, respectively (Rahola *et al.*, 1987).

3. JAPAN. Before the Chernobyl accident Cs-137 body burdens were about 30 Bq, rising the year following 1986 to more than 50 Bq with values still increasing in May 1987. This compares to body burdens in England of 250–450 Bq (Uchiyama *et al.*, 1998). Peak concentrations of I-131 in urine increased to 3.3 Bq/ml in adult males (Kawamura *et al.*, 1988). Before the Chernobyl catastrophe Cs-137 body burdens were about 30 Bq, rising to more than 50 Bq in 1986 with values continuing to increase in May 1987 (Uchiyama and Kobayashi, 1988).

4. ITALY. Average I-131 thyroid incorporation for 51 adults was 6.5 Bq/g from May 3 to June 16, 1986 (Orlando *et al.*, 1986). Peak urinary excretion of Cs-137 occurred 300 to 425 days after the main fallout cloud had passed on May 5, 1986: pv 15–20 Bq/day (Capra *et al.*, 1989).

5. GERMANY AND FRANCE. There are data concerning human contamination by Chernobyl radionuclides outside of the Former Soviet Union. Figure 12.10 shows body burden levels of Cs-137 in Germany and France.

6. GREAT BRITAIN. Average Cs-134 + Cs-137 body burden levels for adults in Scotland in 1986 after the catastrophe were: Cs-134, 172 Bq; Cs-137, 363 Bq; and K-40, 4,430 Bq. Peak concentrations were: Cs-134, 285 Bq and Cs-137, 663 Bq (Watson, 1986). The Cs-137 body

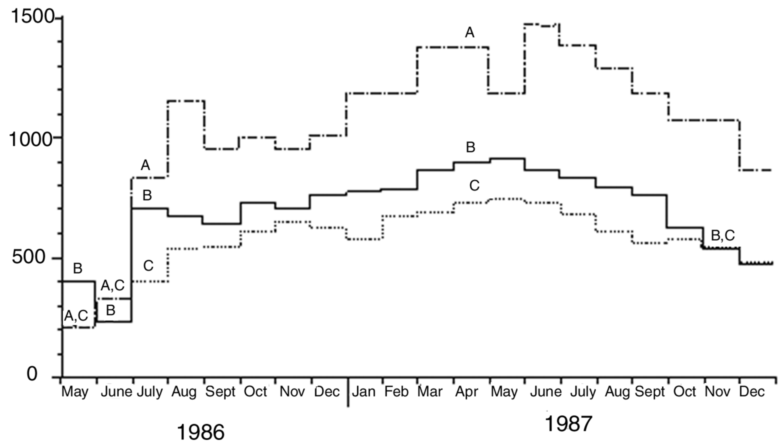

Figure 12.10. Body burden of Cs-137 (Bq) in humans in Munich, Germany: (A) males, (B) females); in Grenoble, France (C) adults (UNSCEAR, 1988).

burden in England in 1987 was 250–450 Bq (Uchiyama and Kobayashi, 1988). The thyroid I-131 burden measured in the neck region was up to 33 Bq in adults and up to 16 Bq in children in Britain (Hill *et al.*, 1986).

12.3. Conclusion

All people living in territories heavily contaminated by Chernobyl fallout continue to be exposed to low doses of chronic radiation. Human beings do not have sense organs to detect ionizing radiation because it cannot be perceived by sight, smell, taste, hearing, or touch. Therefore without special equipment to identify levels of environmental contamination, it is impossible to know what radionuclide levels are in our food and water or have been incorporated into our bodies.

The simplest way to ensure radiation safety in all areas contaminated by Chernobyl is to monitor food for incorporated radionuclides. Analysis of levels of incorporated gamma-radionuclides by individual spectrometry (IRC) and radioactive monitoring of local food in many Belarussian locations have demonstrated a high correlation between Cs-137 food contamination and the amount of radionuclides in humans and, most importantly, in children.

Chapter II of this volume detailed many cases of deterioration in public health associated with the Chernobyl radionuclide contamination. Many people suffer from continuing chronic low-dose radiation 23 years after the catastrophe, owing primarily to consumption of radioactively contaminated food. An important consideration is the fact that given an identical diet, a child's radiation exposure is three- to fivefold higher than that of an adult. Since more than 90% of the radiation burden nowadays is due to Cs-137, which has a half-life of about 30 years, contaminated areas will continue to be dangerously radioactive for roughly the next three centuries.

Experience has shown that existing official radioactive monitoring systems are inadequate (not only in the countries of the Former Soviet Union). Generally, the systems cover territories selectively, do not measure each person, and often conceal important facts when releasing information. The common factor among all governments is to minimize spending for which they are not directly responsible, such as the Chernobyl meltdown, which occurred 23 years ago. Thus officials are not eager to obtain objective data of radioactive contamination of communities, individuals, or food. Under such circumstances, which are common, an independent system of public monitoring is needed. Such an independent system is not a substitute for official responsibility or control, but is needed to provide regular voluntary monitoring of food for each family, which would determine the radionuclide level in each person.

We have to take responsibility not only for our own health, but for the health of future generations of humans, plants, and animals, which can be harmed by mutations resulting from exposure to even the smallest amount of radioactive contamination.

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13. Decorporation of Chernobyl Radionuclides

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Tens of thousands of Chernobyl children (mostly from Belarus) annually leave to receive treatment and health care in other countries. Doctors from many countries gratuitously work in the Chernobyl contaminated territories, helping to minimize the consequences of this most terrible technologic catastrophe in history. But the scale and spectrum of the consequences are so high, that no country in the world can cope alone with the long-term consequences of such a catastrophe as Chernobyl. The countries that have suffered the most, especially Ukraine and Belarus, extend gratitude for the help that has come through the United Nations and other international organizations, as well as from private funds and initiatives. Twenty-two years after the Chernobyl releases, the annual individual dose limit in heavily contaminated territories of Belarus, Ukraine, and European Russia exceed 1 mSv/year just because of the unavoidable consumption of locally contaminated products. The 11-year experience of the BELRAD Institute shows that for effective radiation protection it is necessary to establish the interference level for children at 30% of the official dangerous limit (i.e., 15–20 Bq/kg). The direct whole body counting measurements of Cs-137 accumulation in the bodies of inhabitants of the heavily contaminated Belarussian region shows that the official Dose Catalogue underestimates the annual dose burdens by three to eight times. For practical reasons the curative-like use of apple-pectin food additives might be especially helpful for effective decorporation of Cs-137. From 1996 to 2007 a total of more than 160,000 Belarussian children received pectin food additives during 18 to 25 days of treatment (5 g twice a day). As a result, levels of Cs-137 in children's organs decreased after each course of pectin additives by an average of 30 to 40%. Manufacture and application of various pectin-based food additives and drinks (using apples, currants, grapes, sea seaweed, etc.) is one of the most effective ways for individual radioprotection (through decorporation) under circumstances where consumption of radioactively contaminated food is unavoidable.

There are three basic ways to decrease the radionuclide levels in the bodies of people living in contaminated territories: reduce the amount of radionuclides in the food consumed, accelerate removal of radionuclides from the body, and stimulate the body's immune and other protective systems.

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13.1. Reducing Radionuclides in Food

Soaking in water, scalding, salting, and pickling foods such as mushrooms and vegetables and processing the fats in milk and cheeses can reduce the amount of radionuclides in some foods severalfold.

Stimulation of the body's natural defenses through the use of food additives that raise one's resistance to irradiation is also useful. Among such additives are the antioxidant vitamins A and C and the microelements I, Cu, Zn, Se, and Co, which interfere with free-radical formation. The additives prevent the oxidation of organic substances caused by irradiation (lipid peroxidation). Various food supplements can stimulate immunity: sprouts of plants, such as wheat, seaweed (e.g., *Spirulina*), pine needles, mycelium, and others.

Accelerating the removal of radionuclides is done in three ways (Rudnev *et al.*, 1995; Trakhtenberg, 1995; Leggett *et al.*, 2003; and many others):

- Increase the stable elements in food to impede the incorporation of radionuclides. For example, K and Rb interfere with the incorporation of Cs; Ca interferes with Sr; and trivalent Fe interferes with the uptake of Pu.
- Make use of the various food additives that can immobilize radionuclides.
- Increase consumption of liquids to "wash away" radionuclides—infusions, juices, and other liquids as well as enriched food with dietary fiber.

Decorporants (decontaminants) are preparations that promote the removal of incorporated radionuclides via excretion in feces and urine. Several effective decorporants specific for medical treatment of heavy radionuclide contamination are known (for Cs, Fe compounds; for Sr, alginates and barium sulfates; for Pu, ion-exchange resins, etc.). They are effective in cases of sudden contamination. In the heavily contaminated Belarussian, Ukrainian, and European Russian territories the situation is different. Daily exposure to small amounts of radionuclides (mostly Cs-137) is virtually unavoidable as they get into the body with food (up to 94%), with drinking water (up to 5%), and through the air (about 1%). Accumulation of radionuclides in the body is dangerous, primarily for children, and for those living in the contaminated territories where there are high levels of Cs-137 in local foodstuffs (see Chapter IV.12). The incorporation of radionuclides is now the primary cause of the deterioration of public health in the contaminated territories (see Chapter II for details), and all possible approaches should be employed to mitigate the consequences of that irradiation.

There is evidence that incorporation of 50 Bq/kg of Cs-137 into a child's body can produce pathological changes in vital organ systems (cardiovascular, nervous, endocrine, and immune), as well as in the kidneys, liver, eyes, and other organs (Bandazhevskaya *et al.*, 2004). Such levels of radioisotope incorporation are not unusual in the Chernobyl-contaminated areas of Belarus, Ukraine, and European Russia nowadays (see Chapter III.11 for details), which is why it is necessary to use any and all possible measures to decrease the level of radionuclide incorporation in people living in those territories. When children have the same menu as adults, they get up to five times higher dose burdens from locally produced foodstuffs because of their lower weight and more active processes of metabolism. Children living in rural villages have a dose burden five to six times higher than city children of the same age.

13.2. Results of Decontamination by the Pectin Enterosorbents

It is known that pectin chemically binds cations such as Cs in the gastrointestinal tract and thereby increases fecal excretion. Research and development by the Ukrainian Center of Radiation Medicine (Porokhnyak-Ganovska, 1998) and the Belarussian Institute of Radiation Medicine and Endocrinology (Gres' *et al.*, 1997) have led to the conclusion that adding pectin preparations to the food of inhabitants of the Chernobyl-contaminated regions promotes an effective excretion of incorporated radionuclides.

1. In 1981, based on 2-year clinical tests, the Joint Committee of the World Health Organization (WHO) and the U.N. Food and Agriculture Organization (FAO) on Food Additives declared the pectinaceous enterosorbents effective and harmless for everyday use (WHO, 1981).

2. In Ukraine and Belarus various pectin-based preparations have been studied as agents to promote the excretion of incorporated radionuclides (Gres', 1997; Ostapenko, 2002; Ukrainian Institute, 1997). The product based on the pectin from an aquatic plant (*Zostera*), known commercially as Zosterin-Ultra® is a mass prophylaxis agent used in the Russian nuclear industry. As it is a nonassimilated pectin, the injection of zosterine into the bloodstream does not harm nutrition, metabolism, or other functions. Zosterin-Ultra® in liquid form for oral administration was approved by the Ukrainian Ministry of Health (1998) and the Russian Ministry of Health (1999) as a biologically active (or therapeutic) food additive endowed with enterosorption and hemosorption properties.

3. In 1996, the BELRAD Institute initiated enterosorbent treatments based on pectin food additives (Medetopect®, France; Yablopect®, Ukraine) to accelerate the excretion of Cs-137. In 1999 BELRAD together with "Hermes" Hmbh (Munich, Germany) developed a composition of apple pectin additives known as Vitapect® powder, made up of pectin (concentration 18–20%) supplemented with vitamins B1, B2, B6, B12, C, E, beta-carotene, folic acid; the trace elements K, Zn, Fe, and Ca; and flavoring. BELRAD has been producing this food additive, which has been approved by the Belarussian Ministry of Health, since 2000.

4. In June–July 2001 BELRAD together with the association "Children of Chernobyl of Belarus" (France) in the Silver Springs sanatorium (Svetlogorsk City, Gomel Province) conducted a placebo-controlled double-blind study of 615 children with internal contamination who were treated with Vitapect (5 g twice a day) for a 3-week period. In children taking the Vitapect (together with clean food) Cs-137 levels were lowered much more effectively than in the control group, who had clean food combined with a placebo (Table 13.1 and Figure 13.1).

5. In another group of children the relative reduction in the specific activity of Cs-137 in the Vitapect-intake group was 32.4 ± 0.6%, and that of the placebo group was 14.2 ± 0.5% ($p > 0.001$), with a mean effective half-life for Cs-137 in a body of 27 days for the pectin group, as compared with 69 days without pectin. This was a reduction of the effective half-life by a factor of 2.4. These results mean that the pectin additive Vitapect with clean nutrition appears to be 50% more effective in decreasing the levels of Cs-137 than clean nutrition alone (Nesterenko *et al.*, 2004).

6. A clinical study of 94 children, 7 to 17 years of age, divided into two groups according to their initial level of Cs-137 contamination determined by whole body counting (WBC) and given Vitapect orally for 16 days (5 g twice a day) revealed both a significant decrease in incorporated Cs-137 and marked

TABLE 13.1. Decreased Cs-137 Concentration after Using Vitapect for 21 Days (Total 615 Children) in 2001 in the Silver Springs Belarussian Sanatorium (BELRAD Institute Data)

	Concentration of Cs-137, Bq/kg		
Group	Before	In 21 days	Decrease,%
Vitapect	30.1 ± 0.7	10.4 ± 1.0	63.6*
Placebo	30.0 ± 0.9	25.8 ± 0.8	13.9

*$p < 0.01$.

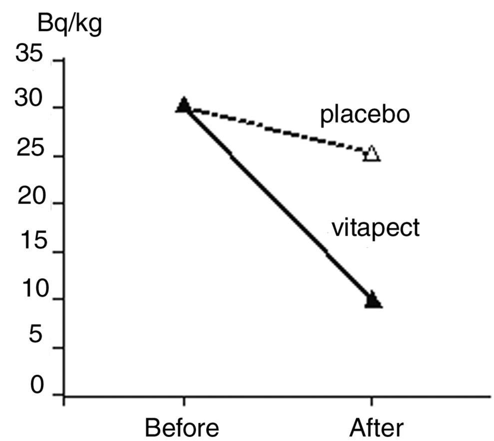

Figure 13.1. Decrease in levels of specific activity of Cs-137 in children's bodies after Vitapect intake (5 g twice a day) for 21 days (Nesterenko *et al.*, 2004).

TABLE 13.2. EKG Normalization Results in the Two Groups of Children Contaminated with Cs-137 Treated with Vitapect (Bandazevskaya *et al.*, 2004)

	Before		After 16 days	
Group	Normal EKG,%	Bq/kg	Normal EKG,%	Bq/kg
1	72	38 ± 2.4	87	23
2	79	122 ± 18.5	93	88

TABLE 13.3. Results of Treatment of 46 Children for 30 Days in France in 2004 (BELRAD Institute Data)

	Concentration, Bq/kg		Decrease, %
	Before	After	
Vitapect	39.0 ± 4.4	24.6 ± 3.4	37*
Placebo	29.6 ± 2.7	24.6 ± 2.1	17

*$p < 0.05$.

improvement in their electrocardiograms (EKG; Table 13.2).

7. From 2001 to 2003 the association "Children of Chernobyl in Belarus" (France), Mitterand's Fund (France), the Fund for Children of Chernobyl (Belgium), and the BELRAD Institute treated 1,400 children (10 schools serving 13 villages) in the Narovlyansky District, Gomel Province, in cycles in which the children received the pectin preparation Vitapect five times over the course of a year. The results demonstrated a three- to fivefold annual decrease in radioactive contamination in children who took the Vitapect. The results for one village can be seen in Figure 13.2.

8. There was concern that pectin enterosorbents remove not only Cs-137, but also vital microelements. Special studies were carried out in 2003 and 2004 within the framework of the project "Highly-Irradiated Belarus Children" with the support of the German Federal Office of Radiation Protection (BfS). Tests carried out in three Belarus sanatoriums (Timberland, Silver Springs, and Belarussian Girls) showed that Vitapect does not impair the positive balance of the K, Zn, Cu, and Fe in children's blood (Nesterenko *et al.*, 2004).

9. At the request of the "Chernobyl's Children" NGOs initiatives in Germany, France, England, and Ireland, the BELRAD Institute conducted measurements of Cs-137 in children before departure to and after their return from health programs in these countries. Children who only ate clean food during the 25–30 days showed a decrease in Cs-137 levels of some 20 to 22%, whereas children who also received a course of treatment with Vitapect showed an even further decrease in the level of Cs-137 incorporation (Tables 13.3 and 13.4).

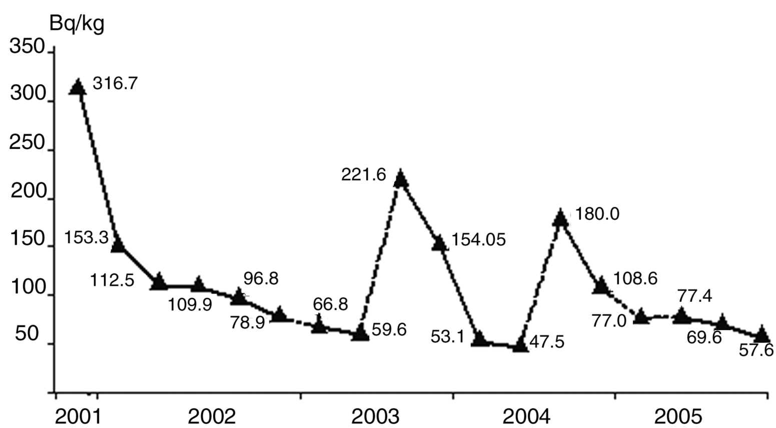

Figure 13.2. Changes in average specific activity of Cs-137 (Bq/kg) in the bodies of children of Verbovichi Village, Narovlyansky District, Gomel Province. Averages for these data are shown. Dotted line indicates the periods of Vitapect intake (Nesterenko *et al.*, 2004).

TABLE 13.4. Several Results of Vitapect Treatment of Belarussian Children (BELRAD Institute Data)

Concentration, Bq/kg		Decreasing,	
Before	After	%	Group data
30.0 ± 1.5	19.2 ± 1.4*	36	Germany, $n = 43$; Jul. 7 to Aug. 29, 2007
42.1 ± 5.1	19.6 ± 2.5*	53	Spain, $n = 30$; Jul. 2 to Aug. 30, 2007
26.4 ± 1.5	13.2 ± 0.8*	50	Canada, $n = 22$; Jun. 26 to Aug. 22, 2007
23.4 ± 2.0	11.8 ± 0.7*	49	Canada, $n = 15$; Jun. 24 to Aug. 22, 2007

*$p < 0.01$.

10. The frequency distribution of the activity reduction in one experiment is shown in Figure 13.3. The relative reduction of the specific activity for the pectin groups was 32.4% (arithmetic mean) and 33.6% (median), respectively, whereas the specific activity in the children who received placebos decreased only by 14.2% (arithmetic mean) and 13.1% (median), respectively. This corresponds to a reduction in the mean effective half-life of 27 days for the pectin groups, as compared with 69 days for the placebo groups.

11. The two calculated whole-body retention functions are shown in Figure 13.4 (for adults). The first curve represents the effect of replacing contaminated food by clean food effective from $t = 0$ and the second corresponds to clean food plus Vitapect, also effective from $t = 0$. The observed reduction of mean effective half-life (69→27 days) corresponds to a factor of 2.5.

12. From 1996 to 2007 a total of more than 160,000 Belarussian children received oral Vitapect (5 g twice a day) for an 18- to 25-day course of treatment. The results showed a decrease in Cs-137 levels after each course of treatment by an average of 30–40%.

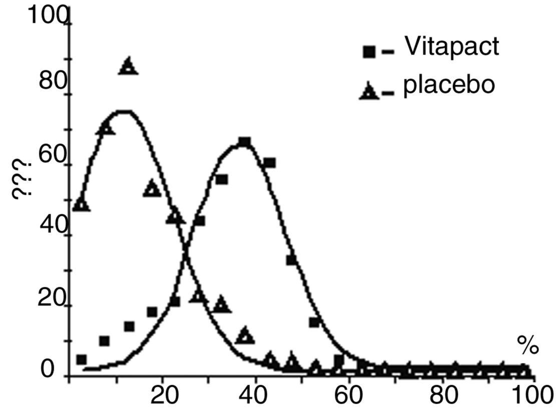

Figure 13.3. Frequency of occurrence of observed relative reduction of the Cs-137 body burden with Vitapect treatment in Belarussian children (Hill *et al.*, 2007).

Based on long-term experience, the BELRAD Institute recommends that all children living in radioactive contaminated territories receive a quadruple course of oral pectin food additives annually along with their conventional food ration. Eleven years of BELRAD's activities in controlling levels of incorporated Cs-137 in more than 327,000 children has not caused alarm in the population or radiophobia and has led to the spread of knowledge concerning radiation protection and an

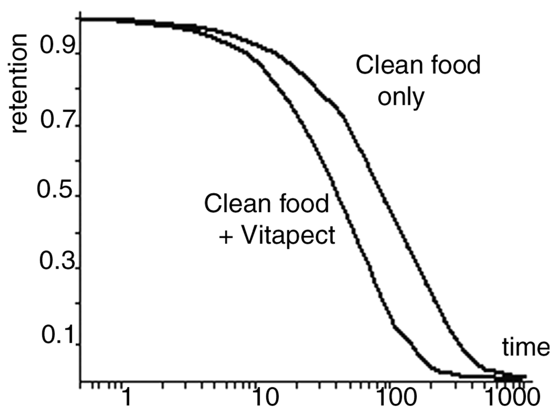

Figure 13.4. Theoretical retention functions for adults based on the model of Leggett *et al.* (2003). The upper curve shows the effect of clean food and the lower one illustrates the additional effect of blocking adsorption using Vitapect (Hill *et al.*, 2007).

increased sense of personal responsibility for one's health.

13.3. New Principles of Radiation Protection Based on Direct Measurements

The BELRAD Institute's 11 years of experience shows that for effective radiation protection in the contaminated territories, an intervention level—30% of the official dangerous limit (i.e., 15–20 Bq/kg)—must be established for children.

1. The direct whole body counting (WBC) measurements of Cs-137 accumulation in individuals in the heavily contaminated Belarussian regions showed that the official Dose Catalogue prepared on the basis of the Cs-137 concentrations in 10 milk samples and 10 potato samples underestimates the annual personal dose burden three- to eightfold and cannot be relied on for effective radiation protection.

2. It is obvious that a true dose catalogue of the contaminated population should be developed on the basis of the data obtained from the direct WBC measurements of Cs-137, which reflect the accumulated internal dose burden. This should be done via reliable sampling of inhabitants from each area of Belarus affected by Chernobyl.

3. Only by combining WBC measurements of Cs-137 accumulation in the body with medical evaluations can the causal relationship (dose dependence) between the increase in morbidity and incorporated radionuclides in the population be known. At this time, these data can only be obtained in the Chernobyl-contaminated regions of Belarus, Ukraine, and European Russia. This information can be an important factor in designing radiation protection and treating people, in persuading the world community of the need to help Belarus minimize radiation exposures, and in understanding the dimensions of the consequences of the Chernobyl catastrophe.

13.4. Where International Help for Chernobyl's Children Would Be Especially Effective

No country in the world is able to cope alone with the long-term consequences of a catastrophe of the magnitude of the meltdown in Chernobyl. The countries most severely affected, especially Ukraine and Belarus, which suffered greatly, are grateful for the help they get from the United Nations and other international organizations, as well as from private funds and initiatives.

Annually, tens of thousands of Chernobyl children go to other countries for treatment to improve their health. Doctors from many countries work pro bono in the Chernobyl-contaminated territories to help minimize the consequences of this most terrible technologic catastrophe in history. The scale and the range of the consequences are so great that there is always the question of how to make such help even more effective.

Experience from large-scale long-term programs to monitor foodstuffs and the levels of incorporated radionuclides in the bodies of those living in the contaminated territories is the basis for the following proposals to increase the efficacy of the international and national programs:

- Joint studies to determine the frequency and intensity of various diseases, especially in children, correlated with levels of incorporated radionuclides.
- Regular individual radiometric evaluation of the populations, especially children, in all contaminated territories. To accomplish this, Belarus will have to increase the number of mobile laboratories from eight to twelve or fifteen. Similar to the Belarussian system, independent, practical, science/clinical centers must be established in Ukraine and European Russia to use the results of such regular radiometric monitoring to identify critical groups with high radionuclide incorporation.

- Manufacture and administer various pectin-based food additives and drinks (based on apples, currants, grapes, seaweed, etc.) as one of the most effective ways of providing individual radiation protection (through decorporation) when circumstances make using contaminated food unavoidable.
- Independent radiation monitoring and radiation control of local foodstuffs, making use of the BELRAD Institute's experience in organizing local centers for radioactive control. This does not replace, but can add to the existing official system.
- Regular courses of oral pectin food additives for preventive maintenance.

Twenty-two years after the catastrophe the true situation in Chernobyl's heavily contaminated territories shows that the internationally accepted individual dose limit is in excess of 1 mSv/year because of the unavoidable consumption of local radioactively contaminated products. Thus the most advisable way to lower the levels of incorporated radionuclides is to consume only clean food. In those situations where clean food is not available, decorporant and sorbent additives should be used to remove as much as possible of the absorbed and incorporated radionuclides.

There are many more-or-less effective decorporants and sorbents: a wide spectrum of products with alginic acid-alginates (mostly from brown seaweed) promotes the reduction of Sr, iron and copper cyanides (e.g., ferrocyanide blue) promote the reduction of Cs. Activated charcoal, cellulose, and various pectins are also effective sorbents for incorporated radionuclides. For practical reasons the curative-like application of apple-pectin food additives may be especially helpful to effectively decorporate Cs-137.

What can be done:

- Reduce Cs-137 concentration in the main dose-forming product—milk—by feeding cows with mixed fodder containing sorbents and by separating the milk to produce cream and butter.
- Provide children and pregnant women with clean foodstuffs and with food additives to increase the elimination of radionuclides and heavy metals from their bodies.
- Inform the population about the levels of radionuclide contamination of the local foodstuffs and the radionuclide concentration in the bodies of the inhabitants (especially children), taking into consideration the existing available foods and the local way of life.
- Institute the practice of regular decorporation of radionuclides into the lifestyle as an effective measure of radiation protection for the population of the Chernobyl-contaminated regions.

The use of food additives, pectin preparations with a complex of vitamins and microelements, demonstrated a high efficiency in eliminating incorporated radionuclides.

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14. Protective Measures for Activities in Chernobyl's Radioactively Contaminated Territories

Alexey V. Nesterenko and Vassily B. Nesterenko

Owing to internally absorbed radionuclides, radiation levels for individuals living in the contaminated territories of Belarus, Ukraine, and Russia have been increasing steadily since 1994. Special protective measures in connection with agriculture, forestry, hunting, and fishing are necessary to protect the health of people in all the radioactively contaminated territories. Among the measures that have proven to be effective in reducing levels of incorporated radionuclides in meat production are food additives with ferrocyanides, zeolites, and mineral salts. Significant decreases in radionuclide levels in crops are achieved using lime/Ca as an antagonist of Sr-90, K fertilizers as antagonists of Cs-137, and phosphoric fertilizers that form a hard, soluble phosphate with Sr-90. Disk tillage and replowing of hayfields incorporating applications of organic and mineral fertilizers reduces the levels of Cs-137 and Sr-90 three- to fivefold in herbage grown in mineral soils. Among food technologies to reduce radionuclide content are cleaning cereal seeds, processing potatoes into starch, processing carbohydrate-containing products into sugars, and processing milk into cream and butter. There are several simple cooking techniques that decrease radionuclides in foodstuffs. Belarus has effectively used some forestry operations to create "a live partition wall," to regulate the redistribution of radionuclides into ecosystems. All such protective measures will be necessary in many European territories for many generations.

As a result of the Chernobyl catastrophe, millions of hectares of agricultural lands are dangerously contaminated with Cs-137 with concentrations higher than 37 kBq/m^2: in Belarus, 1.8 million hectares; in Russia, 1.6 million hectares; and in Ukraine, 1.2 million hectares. According to the Belarus Ministry of Agriculture, agricultural production now takes place on more than 1.1 million hectares of land contaminated with Cs-137 at a level from 37 to 1,480 kBq/m^2, and 0.38 million more hectares are similarly contaminated by Sr-90 at a level of more than 5.55 kBq/m^2. In Gomel Province 56% of all the agricultural land is contaminated, and in Mogilev Province that figure is 26%. Millions of hectares of Belarussian, Russian, and Ukrainian forests (more than 22% of all Belarussian woodlands) appear to be dangerously contaminated (National Belarussian Report, 2006). More than 5 million people live in the contaminated territories of Belarus, Ukraine, and Russia (see Chapter I for details). Moreover, some grasslands, forests, mountains, and lakes in Sweden, Norway, Scotland, Germany, Switzerland, Austria, Italy, France, and Turkey continue to show measurable contamination.

Over the 23 years since the catastrophe, owing to the devoted activities of many thousands of scientists and technical specialists, some methods and practical measures have been developed to decrease the risks from the contamination linked to the use of natural resources (agricultural, forestry, hunting, etc.). As a comprehensive review all these results would

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require a separate monograph. This short chapter simply outlines some basic techniques designed to achieve radiation protection for the resources utilized in the course of everyday living in the contaminated territories.

14.1. Measures for Radiation Protection in Agriculture

1. Where production with "permissible" amounts of radionuclides is impossible, agricultural lands have been taken out of use: in Belarus, 265,000 hectares; in Ukraine, 130,000 hectares; and in Russia, 17,000 hectares (Aleksakhin *et al.*, 2006).

2. Agricultural land with radioactive contamination is subject to obligatory monitoring of both soil and production processes for end-product control technology to ensure permissible levels of Cs-137 and Sr-90 in foodstuffs. This *permissible* level is established by calculating the combined individual average annual food intake so as to limit the effective equivalent radiation dose to less than 1 mSv/year. For beef and mutton the level of Cs-137 should be no higher than 500 Bq/kg in Belarus and 160 Bq/kg in Russia and Ukraine, flour and groats (buckwheat) should have no more than 90 Bq/kg, etc. (Bagdevich *et al.*, 2001). Each country has its own radioprotection policy.

3. Effective decreases in the levels of radionuclides in crops are achieved by applications of lime/Ca as antagonists of Sr-90, K fertilizers as antagonists of Cs-137, phosphoric fertilizers that form a hard soluble phosphate and precipitate Sr-90, plus zeolites, sapropel (gyttja), and other natural antagonists and absorbents (Aleksakhin *et al.*, 1992; and many others; Table 14.1).

4. Hayfields (meadows and pastures) used to support milk and meat production account for up to half of all contaminated agricultural land in Belarus. Disk tilling and replowing of hayfields incorporating an application of organic and mineral fertilizers reduces the levels of Cs-137 and Sr-90 accumulation three- to fivefold in herbage grown in mineral soils. Such radical treatment of hayfields on peat soils sharply reduces Cs-137, but is less effective for Sr-90. Owing to degradation of cultivated hayfields, repeated grassland renovation with an application of fertilizers is needed every 3 to 6 years.

TABLE 14.1. Efficiency of Agrochemical Measures to Reduce Cs-137 and Sr-90 Concentrations in Plant Production (Gudkov, 2006)

	Reduction factor	
Method	Cs-137	Sr-90
Lime	1.5–4	1.5–2.5
Higher level of:		
Phosphoric fertilizers	1.5–2	1.2–1.5
Potassium fertilizers	1.8	None
Organic fertilizers 40 tons/ha	1.5–3	1.5–2
Combined application of lime, mineral, and organic fertilizers	2–5	2–4
Mineral soil absorbents (zeolites, vermiculites, bentonites, etc.)*	1.5–2.5	1.5–2

*They were most effective during the first 5 years after the catastrophe (Kenik, 1998).

5. As noted above, radiation protection measures are effectively applied in large state-owned and collective farms. In small private-sector households and farms, which in Belarus account for more than 50% of agricultural production, these measures are incidental. Generally for each cow on a private Belarus farm there is about 1 hectare of hayfield and improved pasture. This is not sufficient to sustain the animal so the farmers have to get hay from grassy forest glades and unarable lands that are contaminated with higher levels of radioactivity than cultivated hayfields. Thus a significant number of settlements, even 23 years since the catastrophe, had inadequate radiation protection for agricultural production. There are more than 300 such settlements each in Belarus and Ukraine, and more than 150 in Russia (Kashparov *et al.*, 2005).

6. Twenty years after the catastrophe, some 10 to 15% of the milk on private Belarussian farms had a higher Cs-137 contamination than the permissible level. In 2006 there were

TABLE 14.2. Efficiency of Measures to Reduce Cs-137 and Sr-90 Concentrations in Animal-Breeding Production (Gudkov, 2006)

Measure	Reduction factor Cs-137	Sr-90
Improvement of meadows and pastures*	1.5–10	1.5–5
Food additives with ferrocyanide	2–8 (to 20)	None
Food additives with zeolites	2–4	None
Food additives with mineral salts	1.5–2	2–3
Month on clean fodder before slaughter	2–4	None

*Less effective on peat soils.

instances in which household milk contained Cs-137 at a value as high as 1,000 Bq/liter. In Gomel Province in 2004, some 12% of beef had Cs-137 levels above 160 Bq/kg (BELRAD Institute data).

7. There are some effective measures to reduce levels of incorporated radionuclides in meat production (Table 14.2) and food-processing technologies to reduce radionuclide content in foodstuffs (Table 14.3).

8. Table 14.4 presents the primary known antiradiation chemical and pharmacological measures to achieve clean animal breeding in the contaminated territories.

9. All the methods described to reduce radiation in agricultural production require additional material and labor; thus economic efficiency in the contaminated areas is compromised. In spite of measures taken and subsidies, agricultural production in radioactive contaminated areas continues to be difficult and the farmers often turn to specialized enterprises for cattle breeding for meat production, production of oils and industrial crops, etc.

TABLE 14.3. Efficiency of Measures to Reduce Cs-137 and Sr-90 Content in Foodstuffs (Gudkov, 2006)

Measure	Reduction factor Cs-137	Sr-90
Cleaning of cereals seeds	1.5–2	
Processing of potato to starch	15–50	
Processing carbohydrate-containing: Production to sugars	60–70	
Production to ethyl alcohol	Up to 1,000	
Processing of milk to cream	6–12	5–10
Processing of milk to butter	20–30	30–50
Culinary treatment of meat	2–4	None

TABLE 14.4. Chemical and Pharmacological Antiradiation Remedies (Based on Gudkov, 2006)

Radionuclide blockers and decontaminants	
Antagonists—competitors	Stable isotopes, chemical analogues
Enterosorbents	Activated charcoal, zeolite, Vitapect, Algisorb, etc.
Insoluble complexes	Ferrocyanides, alginates, pectins, phosphates
Soluble complexes	Natural (flavonoids: flavones, anthocyans, catechins) and synthetic (Zinkacyne, etc.)
Radioprotectants	
Antioxidants	Aminothiols; disulfides; thiosulfates; vitamins A, C, E
Stabilizers of DNA and membranes	Metal ions, chelates, flavonoids
Metabolism inhibitors	Cyanides, nitriles, azides, endotoxins
Adaptogenes	Immunostimulants, vitamins, microelements, etc.

14.2. Radiation Protection Measures for Forestry, Hunting, and Fisheries

Forestlands accumulated about 70% of the Chernobyl radionuclides that fell on Belarus. Shortly after the catastrophe most forest radionuclide contamination was on the surface of trees. Roots absorb Cs-137 and Sr-90 from the soil and transport them into the wood and other parts of the plant. Specific activity of Cs-137 can exceed 20 kBq/kg in forest berries and mushrooms, as much as 150 kBq/kg in dried mushrooms, and 250 kBq/kg in wild game meat. In predatory fish breeds in landlocked reservoirs the levels can reach 300 kBq/kg (see Chapter III for details).

1. In the exclusion zone, which in 1986–1987 was 30 km wide, as well as in the zone of involuntary resettlement, all forestry activities are forbidden where there is risk to an individual of a dose greater than 5.0 mSv. In this zone permanent housing is banned and economic activity is strictly limited. The zone of involuntary resettlement is an area outside the exclusion zone where the level of ground contamination from Cs-137 is above 15 Ci/km^2, that from Sr-90 is above 3 Ci/km^2, or that from Pu-239 and Pu-240 is above 0.1 Ci/km^2. The territories of involuntary resettlement also include some areas with low-level radioactivity where radionuclides migrate into plants from contaminated soil.

2. According to official Belarussian data, for several years after the catastrophe radiation levels in contaminated forest products (wild berries, mushrooms, firewood, etc.) exceeded those in domestic agricultural products (milk, bread, cereals, etc.).

3. Ten years after the catastrophe, the amount of radionuclides in underground parts of trees doubled and reached 15% of the total amount in forest ecosystems. Even now, in Belarus, owing to external radiation contamination, foresters are exposed to levels two to three times higher than agricultural workers.

4. Among the principal measures proposed to decrease radiation risk for forestry workers are: (a) shorten the length of stay in contaminated territory; (b) minimize manned technologies and maximize mechanization; (c) provide individual safety equipment and shielding for the driver's cabin on farm machines and devices for protection from gamma irradiation; (d) require special permission to enter the forests; and (e) impose seasonal regulations on forestry operations (Maradudin *et al.*, 1997).

5. Contamination is increasing and it appears that it will rise even more with the use of contaminated firewood as fuel and its radioactive ashes as fertilizer; all of these activities will increase individual radiation doses.

6. Among forest products, mushrooms, berries, and hazelnuts are the most contaminated. Up to 50% of all the mushrooms and berries that were measured exceeded the permissible level of Cs-137 (370 Bq/kg). Consumption of forest products accounts for up to 40% of the annual individual dose of internal radiation in Belarus. Persistence of Cs-137 in forest products exceeds the permissible level even in territories with soil contamination below 37 kBq/m^2 (<1 Ci/km^2).

7. The Belarus National Academy Forest Institute revealed that the forest can serve as "a live partition wall," by regulating redistribution of radionuclides in ecosystems. In test plots in sections of the Vetka and El'sk forests in Gomel Province the amounts of radionuclides in the roots of trees, in forest berries, and in mushrooms have been decreased up to sevenfold as a result of special forestry and reclamation measures (Ipat'ev, 2008).

8. To prevent dispersion of radionuclides from contaminated forest areas to adjoining territories as a result of water and wind erosion it is necessary to reforest eroded land. Universal efforts to prevent forest fires and improve fire-fighting efficiency are needed to stop radionuclide dispersion via wind currents several hundred or even thousands of kilometers away from contaminated territories. Unfortunately, this was not done during the fires that raged in 1992.

9. In zones with a Cs-137 level of more than 15 Ci/km^2 it is dangerous to consume wild game. Obligatory total control over all game production is needed in zones contaminated up to 15 Ci/km^2. In contaminated territories it is recommended to shoot wild boars and roe deer aged 2 years or older because they have lower levels of incorporated radionuclides than younger ones.

10. The situation with elk is the opposite. The level of radionuclide incorporation is significantly lower among young animals as compared to adults.

11. Radionuclide concentrations in the visceral organs of game mammals (heart, liver, kidneys, lungs, etc.) are significantly higher than in muscle tissue.

12. Decreasing levels of specific radioactive contamination of principal game species are as follows: wolf > fox > wild boar > roe deer > hare > duck > elk.

13. In contaminated territories the same species of fish taken from rivers and streams have significantly lower radionuclide levels than those from lakes and ponds. Phytophagous fish have three to four times lower radionuclide levels than predatory species (catfish, pike, etc.). Benthic fishes (crucian, tench, etc.) have several times more contamination than fish that live in the top water layers (small fry, chub, etc.).

14. There are some effective methods to significantly decrease radionuclide contamination in pond cultures by plowing from the pond bottom down to a depth up to 50 cm and washing with flowing water, applying potash fertilizers, and using vitamins and antioxidants (radioprotectants) as food additives for the fish (Slukvin and Goncharova, 1998).

14.3. Radiation Protection Measures in Everyday Life

Instructions for radiation protection and self-help countermeasures can be found in Ramzaev, 1992; Nesterenko, 1997; Beresdorf and Wright, 1999; Annenkov and Averin, 2003; Babenko, 2008; Parkhomenko *et al.*, 2008; and many others.

It is very important to avoid radionuclides in food and if they are consumed to try to eliminate them from the body as quickly as possible. In a baby, the biological half-life of Cs-137 is 14 days; for a 5-year old it is 21 days; for a 10-year old, 49 days; for teenagers, about 90 days; and for a young male, about 100 days (Nesterenko, 1997).

1. The most direct way of decreasing radionuclide intake is to avoid foods that are potentially heavily contaminated and to consume foodstuffs with lower levels. However, this is not easy to do because the average level of radionuclide bioaccumulation differs in each region owing to differences in soils, cultivars, agriculture techniques, etc.

Several examples of differing levels of contamination are presented below.

1.1. Vegetables: Order of decreasing Cs-137 in some areas of Belarus: sweet pepper > cabbage >potatoes > beetroot > sorrel > lettuce > radish > onion > garlic > carrots > cucumbers > tomatoes. Order of decreasing levels in Gomel Province: sorrel > beans > radish > carrots > been root > potatoes > garlic > sweet pepper > tomatoes > squash > cucumbers > cabbage (kohlrabi) > cauliflower > colewort (Radiology Institute, 2003).

1.2. Berries: Order of decreasing Cs-137 among some berries: blueberry (*Vaccinium myrtillus*), cowberry (*V. vitis-idaea*), red and black currants (*Ribes sp.*), and cranberry (*Oxycoccus*) usually accumulate more Cs-137 than strawberry (*Fragaria*), gooseberry (*Grossularia*), white currant, raspberry (*Rubus*), and mountainash (*Sorbus*).

1.3. Meat: Order of decreasing Cs-137 in some meats: poultry > beef > mutton > pork. Meats from older animals have more radionuclides that meat from younger ones owing to accumulation over time. Bones of young animals have more Sr-90. Among visceral organs the order of decreasing levels of Cs-137 is: lung > kidney > liver > fat.

1.4. Eggs: Order of decreasing levels: shell > egg-white > yolk.

1.5. Fish: Predatory and benthic fishes (pike, perch, carp, catfish, tench, etc.) are more contaminated, and fish living in rivers and streams are always less contaminated than those from lakes and ponds.

1.6. Mushrooms: The cap usually contains more Cs-137 than the pedicle. Agaric (Agaricales) mushrooms usually concentrate more radionuclides than boletuses (Boletus).

2. The biological properties of Cs-137 are similar to those of stable K and Rb, and Sr-90 and Pu are similar to Ca. These properties determine where they concentrate in the body so the use of stable elements may help to decrease the absorption of radionuclides.

Foods rich in K include potatoes, maize, beans, beets, raisins, dried apricots, tea, nuts, potatoes, lemons, and dried plums. Ca-rich foods include milk, eggs, legumes, horseradish, green onions, turnip, parsley, dill, and spinach. Green vegetables, apples, sunflower seeds, black chokeberries, and rye bread are rich in Fe; and Rb is found in red grapes.

3. A diet to protect against radioactive contamination should include uncontaminated fruits and vegetables, those rich in pectin, and those with high-fiber complexes to promote the rapid elimination of radionuclides.

4. High intake of fluids including fruit drinks helps promote excretion of contaminants in urine.

5. Daily addition of antioxidants (vitamins A, C, E, and the trace elements Zn, Co, Cu, and Se) is recommended.

6. Individuals exposed to radioactive contamination should consume special food additives such as Vitapect (see Chapter IV.13) and products made from apples, green algae (*Spirulinae*), fir-needles, etc.

7. There are several simple cooking techniques that decrease radionuclides: boil foods several times and discard the water, wash food thoroughly, soak some foods and discard the water, avoid the rinds of fruits and vegetables, salt and pickle some foods but throw away the pickling juice! Avoid eating strong bouillon, use rendered butter, etc.

Experiences from around the world after the catastrophe show that citizens of countries that did not provide information and methods to counter the effects of the radioactive fallout fared more poorly than those in countries that did provide such help. In 1986 the effective individual dose to the "average" person in Bulgaria, where there was no emergency protection was 0.7 to 0.8 mSv, or about threefold higher than the dose for the "average" Norwegian. The Norwegian government placed a prohibition against eating leafy vegetables and drinking fresh milk, destroyed contaminated meat, maintained cattle in stalls, deactivated pastures and reservoirs, and mandated that prior to slaughter the cattle be fed on clean forage, etc. This disparity in contamination doses occurred even though the level of contamination in Bulgaria was measurably lower than that in Norway (Energy, 2008).

Since 1994, radiation exposure of individuals living in the contaminated territories of Belarus, Ukraine, and Russia has continued to increase owing to internal absorption of radionuclides—the most dangerous form of radiation exposure despite natural radioactive decay.

Migration of Chernobyl radionuclides into soil root zones allows plants to absorb them, transport them to the surface, and incorporate them into edible portions of the plant. Agricultural and forest product radionuclides are introduced into food chains, significantly increasing the radiation danger for all who consume those foodstuffs. Today the most serious contaminating agents are Cs-137 and Sr-90. In coming years the situation will change and Am-241 will present a very serious problem (see Chapter I for details).

For at least six to seven generations, vast territories of Belarus, Russia, and Ukraine must take special measures to control radiation exposure in agriculture, forestry, hunting, and fishing. So too must other countries with areas of high radioactive contamination, including Sweden, Norway, Switzerland, Austria, France, and Germany. This means, that local economies will require external grants-in-aid and donations to minimize the level of radionuclides in all products because many areas simply do not have the funds to monitor, teach, and mandate protection. Thus the problem of contamination is dynamic and requires constant monitoring and control—for Cs-137 and Sr-90 pollution at least 150 to 300 years into the future. The contamination from the wider spectrum of radioisotopes is dynamic and will require constant monitoring and control essentially forever.

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15. Consequences of the Chernobyl Catastrophe for Public Health and the Environment 23 Years Later

Alexey V. Yablokov, Vassily B. Nesterenko, and Alexey V. Nesterenko

More than 50% of Chernobyl's radionuclides were dispersed outside of Belarus, Ukraine, and European Russia and caused fallout as far away as North America. In 1986 nearly 400 million people lived in areas radioactively contaminated at a level higher than 4 kBq/m^2 and nearly 5 million individuals are still being exposed to dangerous contamination. The increase in morbidity, premature aging, and mutations is seen in all the contaminated territories that have been studied. The increase in the rates of total mortality for the first 17 years in European Russia was up to 3.75% and in Ukraine it was up to 4.0%. Levels of internal irradiation are increasing owing to plants absorbing and recycling Cs-137, Sr-90, Pu, and Am. During recent years, where internal levels of Cs-137 have exceeded 1 mSv/year, which is considered "safe," it must be lowered to 50 Bq/kg in children and to 75 Bq/kg in adults. Useful practices to accomplish this include applying mineral fertilizers on agricultural lands, K and organosoluble lignin on forestlands, and regular individual consumption of natural pectin enterosorbents. Extensive international help is needed to provide radiation protection for children, especially in Belarus, where over the next 25 to 30 years radionuclides will continue to contaminate plants through the root layers in the soil. Irradiated populations of plants and animals exhibit a variety of morphological deformities and have significantly higher levels of mutations that were rare prior to 1986. The Chernobyl zone is a "black hole": some species may persist there only via immigration from uncontaminated areas.

The explosion of the fourth block of the Chernobyl nuclear power plant in Ukraine on April, 26, 1986 was the worst technogenic accident in history. The information presented in the first 14 parts of this volume was abstracted from the several thousand cited scientific papers and other materials. What follows here is a summary of the main results of this meta-analysis of the consequences of the Chernobyl catastrophe.

The principal methodological approach of this meta-review is to reveal the consequences of Chernobyl by comparing differences among populations, including territories or subgroups that had and have different levels of contamination but are comparable to one another in ethnic, biologic, social, and economic characteristics. This approach is clearly more valid than trying to find "statistically significant" correlations between population doses that are impossible to quantify after the fact and health outcomes that are defined precisely by morbidity and mortality data.

15.1. The Global Scale of the Catastrophe

1. As a result of the catastrophe, 40% of Europe was contaminated with dangerous

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radioactivity. Asia and North America were also exposed to significant amounts of radioactive fallout. Contaminated countries include Austria, Finland, Sweden, Norway, Switzerland, Romania, Great Britain, Germany, Italy, France, Greece, Iceland, and Slovenia, as well as wide territories in Asia, including Turkey, Georgia, Armenia, The Emirates, China, and northern Africa. Nearly 400 million people lived in areas with radioactivity at a level exceeding 4 kBq/m^2 ($\geq$0.1 Ci/km^2) during the period from April to July 1986.

2. Belarus was especially heavily contaminated. Twenty-three years after the catastrophe nearly 5 million people, including some 1 million children, live in vast areas of Belarus, Ukraine, and European Russia where dangerous levels of radioactive contamination persist (see Chapter 1).

3. The claim by the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and several other groups that the Chernobyl radioactive fallout adds "only" 2% to the natural radioactive background ignores several facts:

- First, many territories continue to have dangerously high levels of radiation.
- Second, high levels of radiation were spread far and wide in the first weeks after the catastrophe.
- Third, there will be decades of chronic, low-level contamination after the catastrophe (Fig. 15.1).
- Fourth, every increase in nuclear radiation has an effect on both somatic and reproductive cells of all living things.

4. There is no scientific justification for the fact that specialists from IAEA and the World Health Organization (WHO) (Chernobyl Forum, 2005) completely neglected to cite the extensive data on the negative consequences of radioactive contamination in areas other than Belarus, Ukraine, and European Russia,

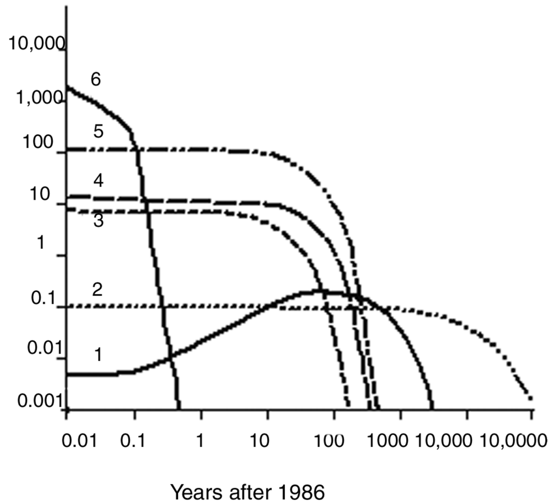

Figure 15.1. Total additional radioactivity (in petabequerels) in the global environment after the Chernobyl catastrophe: (1) Am-241, (2) Pu (239 + 240), (3) Pu-241, (4) Sr-90, (5) Cs-137, (6) I-131 (Mulev, 2008).

where about 57% of the Chernobyl radionuclides were deposited.

15.2. Obstacles to Analysis of the Chernobyl Consequences

1. Among the reasons complicating a full-scale estimation of the impact of the Chernobyl catastrophe on health are the following:

- Official secrecy and unrectifiable falsification of Soviet Union medical statistics for the first 3.5 years after the catastrophe.
- Lack of detailed and clearly reliable medical statistics in Ukraine, Belarus, and Russia.
- Difficulties in estimating true individual radioactive doses in view of: (a) reconstruction of doses in the first days, weeks, and months after the catastrophe; (b) uncertainty as to the influence of individual "hot particles"; (c) problems accounting for uneven and spotty contamination; and (d) inability to determine the influence of each of many radionuclides, singly and in combination.

- Inadequacy of modern knowledge as to: (a) the specific effect of each of the many radionuclides; (b) synergy of interactions of radionuclides among themselves and with other environmental factors; (c) population and individual variations in radiosensitivity; (d) impact of ultralow doses and dose rates; and (e) impact of internally absorbed radiation on various organs and biological systems.

2. The demand by IAEA and WHO experts to require "significant correlation" between the imprecisely calculated levels of individual radiation (and thus groups of individuals) and precisely diagnosed illnesses as the only iron clad proof to associate illness with Chernobyl radiation is not, in our view, scientifically valid.

3. We believe it is scientifically incorrect to reject data generated by many thousands of scientists, doctors, and other experts who directly observed the suffering of millions affected by radioactive fallout in Belarus, Ukraine, and Russia as "mismatching scientific protocols." It is scientifically valid to find ways to abstract the valuable information from these data.

4. The objective information concerning the impact of the Chernobyl catastrophe on health can be obtained in several ways:

- Compare morbidity and mortality of territories having identical physiographic, social, and economic backgrounds and that differ only in the levels and spectra of radioactive contamination to which they have been and are being exposed.
- Compare the health of the same group of individuals during specific periods after the catastrophe.
- Compare the health of the same individual in regard to disorders linked to radiation that are not a function of age or sex (e.g., stable chromosomal aberrations).
- Compare the health of individuals living in contaminated territories by measuring the level of incorporated Cs-137, Sr-90, Pu, and Am. This method is especially effective for evaluating children who were born after the catastrophe.
- Correlate pathological changes in particular organs by measuring their levels of incorporated radionuclides.

The objective documentation of the catastrophe's consequences requires the analysis of the health status of about 800,000 liquidators, hundreds of thousands of evacuees, and those who voluntary left the contaminated territories of Belarus, Ukraine, and Russia (and their children), who are now living outside of these territories, even in other countries.

5. It is necessary to determine territories in Asia (including Trans-Caucasus, Iran, China, Turkey, Emirates), northern Africa, and North America that were exposed to the Chernobyl fallout from April to July 1986 and to analyze detailed medical statistics for these and surrounding territories.

15.3. Health Consequences of Chernobyl

1. A significant increase in general morbidity is apparent in all the territories contaminated by Chernobyl that have been studied.

2. Among specific health disorders associated with Chernobyl radiation there are increased morbidity and prevalence of the following groups of diseases:

- Circulatory system (owing primarily to radioactive destruction of the endothelium, the internal lining of the blood vessels).
- Endocrine system (especially nonmalignant thyroid pathology).
- Immune system ("Chernobyl AIDS," increased incidence and seriousness of all illnesses).
- Respiratory system.
- Urogenital tract and reproductive disorders.
- Musculoskeletal system (including pathologic changes in the structure and

composition of bones: osteopenia and osteoporosis).
- Central nervous system (changes in frontal, temporal, and occipitoparietal lobes of the brain, leading to diminished intelligence and behaviorial and mental disorders).
- Eyes (cataracts, vitreous destruction, refraction anomalies, and conjunctive disorders).
- Digestive tract.
- Congenital malformations and anomalies (including previously rare multiple defects of limbs and head).
- Thyroid cancer (All forecasts concerning this cancer have been erroneous; Chernobyl-related thyroid cancers have rapid onset and aggressive development, striking both children and adults. After surgery the person becomes dependent on replacement hormone medication for life.)
- Leukemia (blood cancers) not only in children and liquidators, but in the general adult population of contaminated territories.
- Other malignant neoplasms.

3. Other health consequences of the catastrophe:

- Changes in the body's biological balance, leading to increased numbers of serious illnesses owing to intestinal toxicoses, bacterial infections, and sepsis.
- Intensified infectious and parasitic diseases (e.g., viral hepatitis and respiratory viruses).
- Increased incidence of health disorders in children born to radiated parents (both to liquidators and to individuals who left the contaminated territories), especially those radiated *in utero*. These disorders, involving practically all the body's organs and systems, also include genetic changes.
- Catastrophic state of health of liquidators (especially liquidators who worked in 1986–1987).
- Premature aging in both adults and children.
- Increased incidence of multiple somatic and genetic mutations.

4. Chronic diseases associated with radioactive contamination are pervasive in liquidators and in the population living in contaminated territories. Among these individuals polymorbidity is common; that is, people are often afflicted by multiple illnesses at the same time.

5. Chernobyl has "enriched" world medicine with such terms, as "cancer rejuvenescence," as well as three new syndromes:

- "Vegetovascular dystonia"—dysfunctional regulation of the nervous system involving cardiovascular and other organs (also called autonomic nervous system dysfunction), with clinical signs that present against a background of stress.
- "Incorporated long-life radionuclides"—functional and structural disorders of the cardiovascular, nervous, endocrine, reproductive, and other systems owing to absorbed radionuclides.
- "Acute inhalation lesions of the upper respiratory tract"—a combination of a rhinitis, throat tickling, dry cough, difficulty breathing, and shortness of breath owing to the effect of inhaled radionuclides, including "hot particles."

6. Several new syndromes, reflecting increased incidence of some illnesses, appeared after Chernobyl. Among them:

- "Chronic fatigue syndrome"—excessive and unrelieved fatigue, fatigue without obvious cause, periodic depression, memory loss, diffuse muscular and joint pains, chills and fever, frequent mood changes, cervical lymph node sensitivity, weight loss; it is also often associated with immune system dysfunction and CNS disorders.
- "Lingering radiating illness syndrome"—a combination of excessive fatigue, dizziness, trembling, and back pain.
- "Early aging syndrome"—a divergence between physical and chronological age

with illnesses characteristic of the elderly occurring at an early age.

7. Specific Chernobyl syndromes such as "radiation in utero," "Chernobyl AIDS," "Chernobyl heart," "Chernobyl limbs," and others await more detailed definitive medical descriptions.

8. The full picture of deteriorating health in the contaminated territories is still far from complete, despite a large quantity of data. Medical, biological, and radiological research must expand and be supported to provide the full picture of Chernobyl's consequences. Instead this research has been cut back in Russia, Ukraine, and Belarus.

9. Deterioration of public health (especially of children) in the Chernobyl-contaminated territories 23 years after the catastrophe is not due to psychological stress or radiophobia, or from resettlement, but is mostly and primarily due to Chernobyl irradiation. Superimposed upon the first powerful shock in 1986 is continuing chronic low-dose and low-dose-rate radionuclide exposure.

10. Psychological factors ("radiation phobia") simply cannot be the defining reason because morbidity continued to increase for some years after the catastrophe, whereas radiation concerns have decreased. And what is the level of radiation phobia among voles, swallows, frogs, and pine trees, which demonstrate similar health disorders, including increased mutation rates? There is no question but that social and economic factors are dire for those sick from radiation. Sickness, deformed and impaired children, death of family and friends, loss of home and treasured possessions, loss of work, and dislocation are serious financial and mental stresses.

15.4. Total Number of Victims

1. Early official forecasts by IAEA and WHO predicted few additional cases of cancer. In 2005, the Chernobyl Forum declared that the total death toll from the catastrophe would be about 9,000 and the number of sick about 200,000. These numbers cannot distinguish radiation-related deaths and illnesses from the natural mortality and morbidity of a huge population base.

2. Soon after the catastrophe average life expectancy noticeably decreased and morbidity and mortality increased in infants and the elderly in the Soviet Union.

3. Detailed statistical comparisons of heavily contaminated territories with less contaminated ones showed an increase in the mortality rate in contaminated European Russia and Ukraine of up to 3.75% and 4.0%, respectively, in the first 15 to 17 years after the catastrophe.

4. According to evaluations based on detailed analyses of official demographic statistics in the contaminated territories of Belarus, Ukraine, and European Russia, the additional Chernobyl death toll for the first 15 years after the catastrophe amounted to nearly 237,000 people. It is safe to assume that the total Chernobyl death toll for the period from 1987 to 2004 has reached nearly 417,000 in other parts of Europe, Asia, and Africa, and nearly 170,000 in North America, accounting for nearly 824,000 deaths worldwide.

5. The numbers of Chernobyl victims will continue to increase for several generations.

15.5. Chernobyl Releases and Environmental Consequences

1. Displacement of the long half-life Chernobyl radionuclides by water, winds, and migrating animals causes (and will continue to cause) secondary radioactive contamination hundreds and thousands of kilometers away from the Ukrainian Chernobyl Nuclear Power Station.

2. All the initial forecasts of rapid clearance or decay of the Chernobyl radionuclides from ecosystems were wrong: it is taking much longer than predicted because they recirculate. The overall state of the contamination in water, air,

and soil appears to fluctuate greatly and the dynamics of Sr-90, Cs-137, Pu, and Am contamination still present surprises.

3. As a result of the accumulation of Cs-137, Sr-90, Pu, and Am in the root soil layer, radionuclides have continued to build in plants over recent years. Moving with water to the above-ground parts of plants, the radionuclides (which earlier had disappeared from the surface) concentrate in the edible components, resulting in increased levels of internal irradiation and dose rate in people, despite decreasing total amounts of radionuclides from natural disintegration over time.

4. As a result of radionuclide bioaccumulation, the amount in plants, mushrooms, and animals can increase 1,000-fold as compared with concentrations in soil and water. The factors of accumulation and transition vary considerably by season even for the same species, making it difficult to discern dangerous levels of radionuclides in plants and animals that appear to be safe to eat. Only direct monitoring can determine actual levels.

5. In 1986 the levels of irradiation in plants and animals in Western Europe, North America, the Arctic, and eastern Asia were sometimes hundreds and even thousands of times above acceptable norms. The initial pulse of high-level irradiation followed by exposure to chronic low-level radionuclides has resulted in morphological, physiological, and genetic disorders in all the living organisms in contaminated areas that have been studied—plants, mammals, birds, amphibians, fish, invertebrates, bacteria, and viruses.

6. Twenty years after the catastrophe all game animals in contaminated areas of Belarus, Ukraine, and European Russia have high levels of the Chernobyl radionuclides. It is still possible to find elk, boar, and roe deer that are dangerously contaminated in Austria, Sweden, Finland, Germany, Switzerland, Norway, and several other countries.

7. All affected populations of plants and animals that have been the subjects of detailed studies exhibit a wide range of morphological deformities that were rare or unheard of prior to the catastrophe.

8. Stability of individual development (determined by level of fluctuating symmetry—a specific method for detecting the level of individual developmental instability) is lower in all the plants, fishes, amphibians, birds, and mammals that were studied in the contaminated territories.

9. The number of the genetically anomalous and underdeveloped pollen grains and spores in the Chernobyl radioactively contaminated soils indicates geobotanical disturbance.

10. All of the plants, animals, and microorganisms that were studied in the Chernobyl contaminated territories have significantly higher levels of mutations than those in less contaminated areas. The chronic low-dose exposure in Chernobyl territories results in a transgenerational accumulation of genomic instability, manifested in cellular and systemic effects. The mutation rates in some organisms increased during the last decades, despite a decrease in the local level of radioactive contamination.

11. Wildlife in the heavily contaminated Chernobyl zone sometimes appears to flourish, but the appearance is deceptive. According to morphogenetic, cytogenetic, and immunological tests, all of the populations of plants, fishes, amphibians, and mammals that were studied there are in poor condition. This zone is analogous to a "black hole"—some species may only persist there via immigration from uncontaminated areas. The Chernobyl zone is the microevolutionary "boiler," where gene pools of living creatures are actively transforming, with unpredictable consequences.

12. What happened to voles and frogs in the Chernobyl zone shows what can happen to humans in coming generations: increasing mutation rates, increasing morbidity and mortality, reduced life expectancy, decreased intensity of reproduction, and changes in male/female sex ratios.

13. For better understanding of the processes of transformation of the wildlife in the

Chernobyl-contaminated areas, radiobiological and other scientific studies should not be stopped, as has happened everywhere in Belarus, Ukraine, and Russia, but must be extended and intensified to understand and help to mitigate expected and unexpected consequences.

15.6. Social and Environmental Efforts to Minimize the Consequences of the Catastrophe

1. For hundreds of thousands of individuals (first of all, in Belarus, but also in vast territories of Ukraine, Russia, and in some areas of other countries) the additional Chernobyl irradiation still exceeds the considered "safe" level of 1 mSv/year.

2. Currently for people living in the contaminated regions of Belarus, Ukraine, and Russia, 90% of their irradiation dose is due to consumption of contaminated local food, so measures must be made available to rid their bodies of incorporated radionuclides (see Chapter IV.12–14).

3. Multiple measures have been undertaken to produce clean food and to rehabilitate the people of Belarus, Ukraine, and European Russia. These include application of additional amounts of select fertilizers, special programs to reduce levels of radionuclides in farm products and meat, organizing radionuclide-free food for schools and kindergartens, and special programs to rehabilitate children by periodically relocating them to uncontaminated places. Unfortunately these measures are not sufficient for those who depend upon food from their individual gardens, or local forests, and waters.

4. It is vitally necessary to develop measures to decrease the accumulation of Cs-137 in the bodies of inhabitants of the contaminated areas. These levels, which are based upon available data concerning the effect of incorporated radionuclides on health, are 30 to 50 Bq/kg for children and 70 to 75 Bq/kg for adults. In some Belarus villages in 2006 some children had levels up to 2,500 Bq/kg!

5. The experience of BELRAD Institute in Belarus has shown that active decorporation measures should be introduced when Cs-137 levels become higher than 25 to 28 Bq/kg. This corresponds to 0.1 mSv/year, the same level that according to UNSCEAR a person inevitably receives from external irradiation living in the contaminated territories.

6. Owing to individual and family food consumption and variable local availability of food, permanent radiation monitoring of local food products is needed along with measurement of individual radionuclide levels, especially in children. There must be general toughening of allowable local food radionuclide levels.

7. In order to decrease irradiation to a considered safe level (1 mSv/year) for those in contaminated areas of Belarus, Ukraine, and Russia it is good practice to:

- Apply mineral fertilizers not less than three times a year on all agricultural lands, including gardens, pastures, and hayfields.
- Add K and soluble lignin to forest ecosystems within a radius up to 10 km from settlements for effective reduction of Cs-137 in mushrooms, nuts, and berries, which are important local foods.
- Provide regular individual intake of natural pectin enterosorbents (derived from apples, currants, etc.) for 1 month at least four times a year and include juices with pectin daily for children in kindergartens and schools to promote excretion of radionuclides.
- Undertake preventive measures for milk, meat, fish, vegetables, and other local food products to reduce radionuclide levels.
- Use enterosorbents (ferrocyanides, etc.) when fattening meat animals.

8. To decrease the levels of illness and promote rehabilitation it is a good practice in the contaminated areas to provide:

- Annual individual determination of actual levels of incorporated radionuclides using a whole-body radiation counter (for children, this must be done quarterly).
- Reconstruction of all individual external irradiation levels from the initial period after the catastrophe using EPR-dosimetry and measurement of chromosomal aberrations, etc. This should include all victims, including those who left contaminated areas—liquidators, evacuees, and voluntary migrants and their children.
- Obligatory genetic consultations in the contaminated territories (and voluntary for all citizens of childbearing age) for the risks of severe congenital malformations in offspring. Using the characteristics and spectra of mutations in the blood or bone marrow of future parents, it is possible to define the risk of giving birth to a child with severe genetic malformations and thus avoid family tragedies.
- Prenatal diagnosis of severe congenital malformations and support for programs for medical abortions for families living in the contaminated territories of Belarus, Ukraine, and Russia.
- Regular oncological screening and preventive and anticipatory medical practices for the population of the contaminated territories.

9. The Chernobyl catastrophe clearly shows that it is impossible to provide protection from the radioactive fallout using only national resources. In the first 20 years the direct economic damage to Belarus, Ukraine, and Russia has exceeded 500 billion dollars. To mitigate some of the consequences, Belarus spends about 20% of its national annual budget, Ukraine up to 6%, and Russia up to 1%. Extensive international help will be needed to protect children for at least the next 25 to 30 years, especially those in Belarus because radionuclides remain in the root layers of the soil.

10. Failure to provide stable iodine in April 1986 for those in the contaminated territories led to substantial increases in the number of victims. Thyroid disease is one of the first consequences when a nuclear power plant fails, so a dependable system is needed to get this simple chemical to all of those in the path of nuclear fallout. It is clear that every country with nuclear power plants must help all countries stockpile potassium iodine in the event of another nuclear plant catastrophe.

11. The tragedy of Chernobyl shows that societies everywhere (and especially in Japan, France, India, China, the United States, and Germany) must consider the importance of independent radiation monitoring of both food and individual irradiation levels with the aim of ameliorating the danger and preventing additional harm.

12. Monitoring of incorporated radionuclides, especially in children, is necessary around every nuclear power plant. This monitoring must be independent of the nuclear industry and the data results must be made available to the public.

15.7. Organizations Associated with the Nuclear Industry Protect the Industry First—Not the Public

1. An important lesson from the Chernobyl experience is that experts and organizations tied to the nuclear industry have dismissed and ignored the consequences of the catastrophe.

2. Within only 8 or 9 years after the catastrophe a universal increase in cataracts was admitted by medical officials. The same occurred with thyroid cancer, leukemia, and organic central nervous system disorders. Foot-dragging in recognizing obvious problems and the resultant delays in preventing exposure and mitigating the effects lies at the door of nuclear power advocates more interested in preserving the status quo than in helping millions of innocent people who are suffering through no fault of their own. It need to change official agreement between WHO and IAEA (WHO, 1959) providing hiding from public of any

information which can be unwanted of nuclear industry.

15.8. It Is Impossible to Forget Chernobyl

1. The growing data about of the negative consequences of the Chernobyl catastrophe for public health and nature does not bode well for optimism. Without special large-scale national and international programs, morbidity and mortality in the contaminated territories will increase. Morally it is inexplicable that the experts associated with the nuclear industry claim: "It is time to forget Chernobyl."

2. Sound and effective international and national policy for mitigation and minimization of Chernobyl's consequences must be based on the principle: "It is necessary to learn and minimize the consequences of this terrible catastrophe."

15.9. Conclusion

U.S. President John F. Kennedy speaking about the necessity to stop atmospheric nuclear tests said in June 1963:

> . . . The number of children and grandchildren with cancer in their bones, with leukemia in their blood, or with poison in their lungs might seem statistically small to some, in comparison with natural health hazards, but this is not a natural health hazard—and it is not a statistical issue. The loss of even one human life or the malformation of even one baby—who may be born long after we are gone—should be of concern to us all. Our children and grandchildren are not merely statistics toward which we can be indifferent.

The Chernobyl catastrophe demonstrates that the nuclear industry's willingness to risk the health of humanity and our environment with nuclear power plants will result, not only theoretically, but practically, in the same level of hazard as nuclear weapons.

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Conclusion to Chapter IV

In the last days of spring and the beginning of summer of 1986, radioactivity was released from the Chernobyl power plant and fell upon hundreds of millions of people. The resulting levels of radionuclides were hundreds of times higher than that from the Hiroshima atomic bomb.

The normal lives of tens of millions have been destroyed. Today, more than 6 million people live on land with dangerous levels of contamination—land that will continue to be contaminated for decades to centuries. Thus the daily questions: how to live and where to live?

In the territories contaminated by the Chernobyl fallout it is impossible to engage safely in agriculture; impossible to work safely in forestry, in fisheries, and hunting; and dangerous to use local foodstuffs or to drink milk and even water. Those who live in these areas ask how to avoid the tragedy of a son or daughter born with malformations caused by irradiation. Soon after the catastrophe these profound questions arose among liquidators' families, often too late to avoid tragedy.

During this time, complex measures to minimize risks in agriculture and forestry were developed for those living in contaminated territories, including organizing individual radiation protection, support for radioactive-free agricultural production, and safer ways to engage in forestry.

Most of the efforts to help people in the contaminated territories are spearheaded by state-run programs. The problem with these programs is the dual issue of providing help while hoping to minimize charges that Chernobyl fallout has caused harm.

To simplify life for those suffering irradiation effects a tremendous amount of educational and organizational work has to be done to monitor incorporated radionuclides, monitor (without exception) all foodstuffs, determine individual cumulative doses using objective methods, and provide medical and genetic counseling, especially for children.

More than 20 years after the catastrophe, by virtue of the natural migration of radionuclides the resultant danger in these areas has not decreased, but increases and will continue to do so for many years to come. Thus there is the need to expand programs to help people still suffering in the contaminated territories, which requires international, national, state, and philanthropic assistance.