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Screening for ^{137}Cs Body Burden Due to the Chernobyl Accident in Korosten City, Zhitomir, Ukraine: 1996–2008

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Chernobyl nuclear power plant/Internal irradiation dose/Whole body counter/^{137}Cs.

During the Chernobyl Nuclear Power Plant (CNPP) accident on 26 April 1986, large amounts of radionuclides were released and spread to vast areas. Inhabitants residing around CNPP have been exposed to external and internal irradiation due to the long half-life of ^{137}Cs (30 years). In this study, we screened for internal whole-body ^{137}Cs concentration using a whole-body counter in the Zhitomir state of Ukraine. The total number of participants was 144,972 (96,149 females and 48,823 males). The median body burden of ^{137}Cs per body weight decreased from 1996 to 2008. In particular, after 2003, more than half of subjects had internal exposure doses below the detectable level. A weak seasonal effect was found in measurement data from 1997 to 1999, but no such effects were observed in later years. We also calculated annual dose for each year and confirmed that doses have been decreasing gradually. In particular, after 2003, the annual effective dose decreased to 0.1 mSv y^{-1} for 95% of the participants. Only two persons were found to have received more than 5 mSv y^{-1} since 2007. Although the health effects of ^{137}Cs body burden due to the Chernobyl accident remain uncertain, further screening is needed to monitor the health status and to allay the anxiety of inhabitants in the contaminated areas around CNPP.

INTRODUCTION

The accident at the Chernobyl Nuclear Power Plant (CNPP) on 26 April 1986 released large amounts of radionuclides. These spread to vast areas including the Republic of Belarus, Ukraine, and the Russian Federation, and the populations of these areas were therefore exposed to internal and external radiation.[1)] According to the World Health Organization report issued in 2006, there are four components of radiation dose to the human body, particularly to the thyroid gland: 1) internal irradiation resulting from intake of ^{131}I; 2) internal irradiation resulting from intake of short-lived radio-iodines, such as ^{132}I, ^{133}I, and ^{135}I; 3) external irradiation resulting from the deposition of radionuclides on the ground and other materials; and 4) internal irradiation resulting from intake of long-lived radionuclides such as ^{134}Cs and ^{137}Cs.[2)]

Contamination by such radionuclides was remarkable in the regions to the northwest and west of the power plant site. In Ukraine, the highest level of ^{137}Cs contamination was observed in the region of Kiev and the Zhitomir and Rivne regions. Among the various radioactive nuclides released from CNPP, radio-iodines such as ^{131}I had the highest radioactivity.[2)] Because most of the inhaled ^{131}I specifically accumulates in the thyroid gland, this caused a marked increase in pediatric thyroid cancer and thyroid dysfunction. On the other hand, ^{137}Cs accumulates non-specifically in the body, except for weak accumulation in the muscle and bone. Although the radioactivity of ^{137}Cs is weaker than that of ^{131}I, the environmental contamination has continued for a long time because the radioactive half-life of ^{137}Cs is 30 years. Hence, soil contamination with ^{137}Cs results in the contamination of food, such as farm produce, and causes internal radiation exposure. The relationship between whole-body ^{137}Cs concentrations and the concentrations in the soil of family farms and foods has been investigated.[3)] In that report, the whole-body ^{137}Cs counting results were significantly correlated with the measured soil radioactivity and

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meal contamination.

Previous studies have reported on internal-exposure dose assessment in the area surrounding Chernobyl.[4–6] The extent of soil and food contamination and the internal radiation exposure dose of the district around Chernobyl have so far been evaluated using ^{137}Cs, with whole-body ^{137}Cs concentrations most commonly measured throughout the contaminated zones. In this study, we screened for internal whole-body ^{137}Cs concentrations using a whole-body counter (WBC) in the Zhitomir state of Ukraine.

MATERIALS AND METHODS

Measurements of ^{137}Cs body burden were conducted using a WBC from September 1996 to August 2008 at Korosten Inter-Area Medical Diagnostic Center in Korosten city, Zhitomir state, Ukraine. This area is located to the southwest of Chernobyl and was strongly affected by the accident at CNPP (Fig. 1).

We investigated the inhabitants of the northern area of Zhitomir state. The inhabitants were referred to Korosten Inter-Area Medical Diagnostic Center for regular health screening, including blood examination and thyroid ultrasound. The annual numbers of study participants are shown in Table 1. The total number of participants accumulated from 1996 to 2008 was 144,972 participants (96,149 females and 48,823 males).

A γ-spectrometer, model 101 equipped with a collimator (Aloka Co., Ltd.), was used to measure ^{137}Cs body burden. The counter was equipped with a NaI (Tl) detector, 7.6 cm in diameter and 7.6 cm in thickness, with a 5-cm-thick lead shield. The participant sat on a sliding chair and the height and angle of the detector were adjusted so that it faced his or her abdomen. The back and the seat of the chair were shielded with lead plates. Gamma rays emitted from the body were counted by the detector and analyzed with a 240-channel spectrometer. The detectable ^{137}Cs body burden was 270 Bq. In accordance with the manufacturer's instructions, ^{137}Cs body burden was calculated and obtained values were corrected for body weight. The annual exposure dose was estimated based on the effective dose coefficient of 2.5×10^{-3} mSv y^{-1} per Bq kg^{-1}.[4] To assess the seasonal effect, the measurement periods were divided into four seasons (i.e. March–May for spring, June-August for summer, September–November for autumn, December-February for winter). The differences between seasons were evaluated using the analysis of variance followed by the Tamhane test. Because we collected data from September 1996 to August 2008, we excluded data of 1996 and 2008 from this analysis.

Data are expressed as median (25th–75th percentile) or mean (SD). All statistical analyses were performed using SPSS software, v.17.0 for Windows (SPSS Japan, Tokyo, Japan). *P* values less than 0.05 were considered indicative of statistical significance.

RESULTS

The median age of participants in each year was 16–39 years, and women accounted for 60% to 70% of the total. The sex ratio and mean weights of the participants were

Fig. 1. Location of the Zhitomir region, Ukraine.

Table 1. Population, age, and weight distribution of study participants from 1996 to 2008

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
No.	11151	20908	8551	10873	6774	6323	10433	10679	11348	13267	13504	13022	8139
Age													
Median	36	31	29	16	32	28	33	34	34	35	37	39	35
25th	13	14	14	12	19	15	17	18	19	20	21	22	20
75th	58	51	55	39	48	47	50	50	51	51	52	53	52
Female													
No.	6442	13061	4815	6753	4760	4152	7206	7307	7949	9447	9362	9021	5874
(%)	(57.8)	(62.5)	(56.3)	(62.1)	(70.3)	(65.7)	(69.1)	(68.4)	(70)	(71.2)	(69.3)	(69.3)	(72.2)
Mean weight													
kg	69.4	61.2	61.7	56.5	65.9	63.1	65.6	67.5	67.8	68.7	70.4	71.8	69.4
SD	20.3	20.9	20.1	20.0	17.9	19.8	19.4	19.5	19.8	19.7	19.4	19.2	20.3

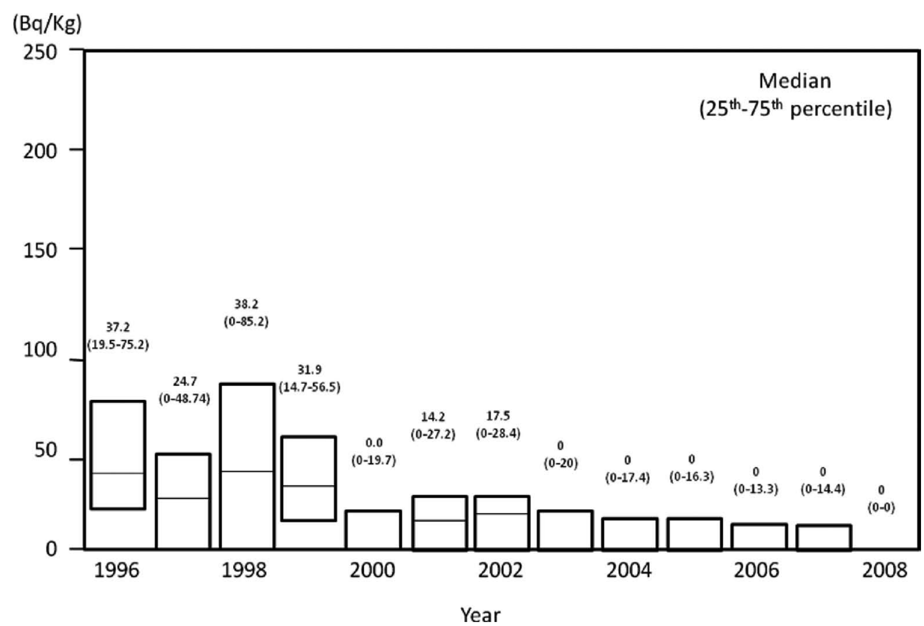

Fig. 2. Box plot diagram of ^{137}Cs concentrations evaluated by a whole-body counter.

essentially uniform for each year (Table 1).

^{137}Cs concentrations between 1996 and 2008 in Zhitomir state are shown in Fig. 2. The body burden of ^{137}Cs has constantly decreased during these years. The median values of ^{137}Cs body burden were negatively correlated with measurement years (r = – 0.56, $P < 0.001$, Spearman's rank correlation). In 2000, the median value of ^{137}Cs concentrations was lower than in other years. In particular, after 2003, the median of body burden was undetectably low. The median body burden of ^{137}Cs per body weight showed a constant decrease over the entire measurement period in both men and women, but median internal-exposure dose was slightly higher in men than in women in every year (data not shown).

The seasonal effects in ^{137}Cs concentration from 1997 to 2007 are shown in Table 2. As shown in the table, weak seasonal changes were found from 1997 to 2000. ^{137}Cs concentration was the highest in autumn (September–November) from 1997 to 2000. Although the ratio of median internal body burden in autumn to that in spring was 1.6 in 1997, 4.5 in 1998, 1.6 in 1999, and 1.4 in 2000, no such pattern was observed from 2000 to 2007. The ^{137}Cs concentrations in autumn were significantly higher than other seasons from 1997 to 1998 ($P < 0.001$). In 1999, the ^{137}Cs concentration in autumn was significantly higher than spring and summer ($P < 0.001$, analysis of variance followed by the Tamhane test).

Table 3 shows the calculated annual internal exposure dose. Median annual internal exposure doses during 1996 to

Table 2. Seasonal differences in ^{137}Cs body burden (Bq kg^{-1}) for each year

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Spring	24.2 (ND-593.9)	16.5 (ND-1641.7)	30.3 (ND-9018.8)	4.7 (ND-691.5)	20.7 (ND-1906.3)	20.1 (ND-810.4)	2.9 (ND-1230.2)	0.03 (ND-793.8)	1.1 (ND-15362.5)	0.01 (ND-353.5)	0.003 (ND-16763.9)
Summer	17.5 (ND-551.9)	26.6 (ND-3303.1)	15.1 (ND-1607.3)	5.2 (ND-248.0)	16.7 (40.7-198.4)	14.7 (ND-210.4)	0.1 (ND-400.9)	1.0 (ND-2145.0)	0.01 (ND-572.5)	0.01 (ND-1196.5)	3.9 (ND-251.4)
Autumn	37.8 (ND-1325.7)	74.8 (ND-40828.1)	47.0 (ND-1304.1)	6.5 (ND-2158.0)	15.6 (ND-521.5)	16.4 (ND-355.5)	8.9 (ND-377.8)	0.7 (ND-383.3)	0.01 (ND-578.0)	0.01 (ND-64658.8)	0.01 (ND-320.2)
Winter	29.2 (ND-3603.2)	17.0 (ND-12042.5)	29.2 (ND-3412.6)	0.5 (ND-476.6)	2.1 (ND-1906.3)	19.8 (ND-20315.8)	14.5 (ND-711.7)	6.9 (ND-33315.0)	1.0 (ND-12534.5)	0.01 (ND-426.1)	0.01 (ND-64616.0)

Values are median values (minimum to maximum). ND: not detected.

Table 3. Number of participants according to annual internal exposure dose (mSv y^{-1})

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
< 0.1 mSv	5907	14158	4389	6569	6077	5493	9115	10084	10808	12672	13073	12574	7958
(%)	(52.97)	(67.72)	(51.33)	(60.42)	(89.71)	(86.87)	(87.37)	(94.43)	(95.24)	(95.52)	(96.81)	(96.56)	(97.78)
0.1 mSv ≤	5063	6616	4062	4249	690	824	1313	590	536	589	427	443	180
(%)	(45.40)	(31.64)	(47.50)	(39.08)	(10.19)	(13.03)	(12.59)	(5.52)	(4.72)	(4.44)	(3.16)	(3.40)	(2.21)
1 mSv ≤	169	130	92	51	6	6	4	5	2	4	2	3	1
(%)	(1.52)	(0.62)	(1.08)	(0.47)	(0.09)	(0.09)	(0.04)	(0.05)	(0.02)	(0.03)	(0.01)	(0.02)	(0.01)
5 mSv ≤	7	4	1	3	1	0	0	0	1	0	0	0	0
(%)	(0.06)	(0.02)	(0.01)	(0.03)	(0.01)	(0)	(0)	(0)	(0.01)	(0)	(0)	(0)	(0)
10 mSv ≤	5	0	7	1	0	0	1	0	1	2	2	2	0
(%)	(0.04)	(0)	(0.08)	(0.01)	(0)	(0)	(0.01)	(0)	(0.01)	(0.02)	(0.01)	(0.02)	(0)

2008 were between 0 and 0.1 mSv y^{-1}. The number of people with doses of 1 mSv y^{-1} decreased gradually and only seven inhabitants (0.1%) had an exposure dose that exceeded 1 mSv y^{-1} in 2000; in particular, only one inhabitant had an exposure dose that exceeded 1 mSv y^{-1} in 2008. People with high internal doses, in excess of 5 mSv y^{-1}, were quite rare (between 0% and 0.08%) during all years. On the other hand, people with very high internal doses, in excess of 10 mSv y^{-1}, were also quite rare but regularly observed throughout the study period. The highest annual exposure dose (161.6 mSv y^{-1}) was observed in 2004.

DISCUSSION

Although several studies have reported the evaluation of internal exposure dose by measuring whole body ^{137}Cs in areas surrounding CNPP,[3–6] data on the Zhitomir State of Ukraine have so far been limited.

In both men and women, ^{137}Cs concentration showed a constant decrease during the measurement period. In a previous study conducted at Bryansk Oblast, Russian Federation during 1991–1996, the ratio of the mean value of ^{137}Cs body burden per body weight in a large sample of resident children in 1991 to that in 1996 is 1.45, corresponding to the half-life of ^{137}Cs.[4]

As in previous reports, median internal-exposure dose was slightly higher in men than in women in every year of our study. This is likely to result from the difference in body size between men and women. The data on ^{137}Cs activity concentrations in horse tissue taken on 90th day after the beginning of radionuclide administration showed that the highest ^{137}Cs transfer is to spleen, lungs, heart, muscles, kidneys, intestine, skin, and bones.[7] Furthermore, the United Nations Scientific Committee on the Effects of Atomic Radiation (1988) reported that cesium is transferred with its chemical congener potassium to the soft tissues of animals, particularly muscle.[1] Because ^{137}Cs accumulates in muscle and bone, the dose in the body burden differs between individuals of various body sizes. This characteristic is found even if annual internal dose decreases.

In our study, a weak seasonal effect of ^{137}Cs was shown from 1997 to 1999, but no such effects were noted after 2000. These seasonal effects might be attributed to a seasonal change in the contamination levels of locally produced foods. A study in Northern Ukraine revealed extremely high ^{137}Cs concentrations in mushrooms.[4] Although mushrooms and wild berries represent only a small part of the daily diet, these foods contributed 95% of the total ^{137}Cs ingestion of inhabitants.[8] Besides the physiological decay of ^{137}Cs, changes in dietary patterns in this area, such as increasing consumption of imported foods and decreasing intake of locally produced foods, might contribute to weaken the seasonal influence of foods.

After the Chernobyl accident, internal exposure was mainly caused by the gamma-emitting radionuclides ^{132}Te, ^{131,132}I, ^{140}Ba, ^{140}La, ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103,106}Ru, ^{141,144}Ce, and ^{134,136,137}Cs.[2] ^{137}Cs is the most commonly measured radionuclide throughout the contaminated zone, because ingestion of radiocesium contained in locally produced foodstuffs became the main pathway of internal radiation exposure. ^{137}Cs is also the main contributor to the radiation doses to organs other than the thyroid, from either internal or external irradiation, which will continue for several decades at low dose rates around CNPP.[2] On the other hand, except for the most contaminated areas, internal doses are decreasing, in accordance with a decline in ^{137}Cs availability for plant root uptake. For remote forest settlements in the Russian Federation, there is a linear dependence between internal dose normalized to the density of contamination and the proportion of peat soils surrounding the settlements.[9]

In this study, annual doses were less than 0.1 mSv y^{-1} in most participants, which is equivalent to those produced by a single chest X-ray. The number of people with doses of 1 mSv y^{-1}, which is the ICRP dose limit for the general public,[12] decreased gradually and only two participants were found to have received more than 5 mSv y^{-1} in Korosten city since 2007. People with high internal doses, in excess of 5 mSv y^{-1}, were quite rare (between 0% and 0.08%) during all years. However, on the other hand, people with very high internal doses, in excess of 10 mSv y^{-1}, were regularly observed throughout the study period. The highest annual exposure dose (161.6 mSv y^{-1}) was observed in autumn 2004 in a 35-year-old woman whose body weight was 56 kg. Furthermore, this study investigated the inhabitants who were referred to the Center for regular health screening. It is difficult for inhabitants who live in contaminated rural areas to reach the Center due to transportation limitations. Hence, further screening is expected to identify those individuals with a relatively high body burden, especially in contaminated rural areas of Ukraine.

There are several limitations of this study. Because this study is cross-sectional, we could not deny the possibility of duplicate study participants. We could not evaluate the dietary habits of study participants. Furthermore, we did not investigate the address, occupation, or daily activities of participants. After such investigation, we could advise inhabitants with a high body burden regarding dietary habits and living environment. In previous studies, the dose was greater for individuals who spent most of their time outdoors in areas such as forests, and was also greater for those living in rural areas than for those living in urban areas.[10,11] Because the health risks of internal exposure to ^{137}Cs remain unclear, it may be necessary to compare the health status of inhabitants who currently live in high contamination areas with that of evacuated people. If the safety of ^{137}Cs is revealed, the inhabitants can be given some relief.

In conclusion, we revealed that the ^{137}Cs body burden is continuously decreasing in Zhitomir region, Ukraine. Further evaluation of ^{137}Cs body burden is needed to clarify the effect on health and to appropriately deal with concerns of inhabitants around CNPP.

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