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

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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. 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.

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. 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. In that report, the whole-body $^{137}$Cs counting results were significantly correlated with the measured soil radioactivity and
meal contamination. Previous studies have reported on internal-exposure dose assessment in the area surrounding Chernobyl. 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 (TI) 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 $2.5 \times 10^{-3}$ mSv y$^{-1}$ per Bq kg$^{-1}$. 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

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**Fig. 1.** Location of the Zhitomir region, Ukraine.
essentially uniform for each year (Table 1).

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

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

$^{137}$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
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 2008. People with high internal doses, in excess of 5 mSv y\(^{-1}\), were also quite rare but regularly observed throughout the study period. The highest annual exposure dose that exceeded 1 mSv y\(^{-1}\) in 2008. People with very high internal doses, in excess of 10 mSv y\(^{-1}\), were also quite rare but regularly observed.

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. 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.

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. 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. Besides the physiological decay of \(^{137}\)Cs, changes in dietary patterns in this area, such as

### DISCUSSION

Although several studies have reported the evaluation of internal exposure dose by measuring whole body \(^{137}\)Cs in areas surrounding CNPP, 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.
consumption of imported foods and decreasing intake of locally produced foods, might contribute to weaken the season influence of foods.

After the Chernobyl accident, internal exposure was mainly caused by the gamma-emitting radionuclides $^{134,137}$Cs, 131,132I, $^{140}$Ba, 140La, $^{95}$Zr, $^{95}$Nb, $^{99}$Mo, $^{103,106}$Ru, $^{141,144}$Ce, and $^{131,132}$I, $^{137}$Cs. 2) $^{137}$Cs is the most commonly measured radionuclide throughout the contaminated zone, because ingestion of radioceium contained in locally produced foodstuffs became the main pathway of internal radiation exposure. Internal doses are 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.

REFERENCES