Long-Term Radiation Exposure of Inhabitants in the Bryansk Region in South-western Russia

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Abstract. Since 1990 the effective doses from external and internal irradiation to residents in the Bryansk area, Russia, have been followed. In the 1990s field surveys in a number of villages took place annually and after 1998 more irregularly. All surveys were carried out in September-October, The individual doses of the inhabitants were assessed using TL-dosemeters and *in vivo* measurements of ^{134,137}Cs. Twenty years after the Chernobyl accident, the average effective dose rate from internal and external exposure of ^{137}Cs to the inhabitants of the surveyed settlements – due to Chernobyl - was estimated to 0.6 mSv year^{-1}. This additional dose contribution is comparable with the yearly dose from cosmic radiation and naturally occurring radionuclides in the human body. During the first three years of the survey (1990-1993), the temporal variation in the effective dose rate from external irradiation can be described by a 20% annual decrease and then slowing down to a 12% decrease per year up to 1998. After that, there is a much slower decrease. In 2006 the fraction of the total effective dose rate associated with external exposure, was in the order of 0.4 mSv year^{-1}, which is twice as high as the dose from exposure of internal ^{137}Cs sources. The temporal variation in the internal exposure of $^{134,\ 137}$Cs is much more complex and related to several environmental and social factors. Hence, large variations are observed during different years and also between villages and within a specific village. In the present paper, results from all the field surveys are compared and the temporal evolution of the radiation environment during 20 years is discussed.

KEYWORDS: Caesium-134, 137, Chernobyl fallout, Bryansk, effective dose.

1. Introduction

In 1990, a joint Russian-Nordic program was initiated in order to carry out estimates of the effective doses to individuals living in a number of rural settlements around the town of Novozybkov in Bryansk, in the southwestern part of Russia. The intention of the project was to provide the population with independent dose estimates from researchers outside the Soviet Union. The region was highly affected by the Chernobyl accident in 1986 as a huge amount of radionuclides was deposited over the area in combination with heavy precipitation between 28 and 30 April. The ground deposition levels of ^{137}Cs in the area (locally up to 2700 kBq m^{-2}) were among the highest measured outside the 30 km zone around the reactor [1]. The villages were classified by the USSR Ministry of Health according to their soil contamination and the estimated average annual effective dose (AAED) to the inhabitants [2]. Villages with a ^{137}Cs soil contamination above 555 kBq m^{-2} were later classified as “controlled areas” and areas with contamination levels above 1480 kBq m^{-2} were classified as unfit for human habitation [3]. Later, the same authority imposed restrictions on consumption of locally produced food. In some of the villages decontamination of public areas was carried out as well, *e.g.* in and around kindergartens, schools and some of the dwellings.

The external- and internal effective doses to individuals living in some of these, non-decontaminated and partly- or fully decontaminated, villages in the Bryansk area have been studied during the month of September (and sometimes extending to October) each year from 1990 to 1998, in 2000 and 2006. During these field surveys individual dose assessments have been carried out using LiF TL-dosimeters and *in vivo* measurements of ^{137}Cs using NaI(Tl)-detectors.

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2. Material and Methods

Each year in September or October from 1990 to 1998 [4-6], and in 2000 [7], a number of rural villages in the Bryansk region (Russia) were visited by a team of Russian and Nordic (mainly Swedish) physicists for an assessment of the effective doses from external- and internal exposure to the inhabitants. During the most recent expedition in 2006 the four villages: Demenka, Starye Bobovichi, Starye Vyshkov and Yalovka were visited. These villages are all located within 40 km from the regional centre Novozybkov, close to the Belarusian border and about 200 km from Chernobyl.

Table 1: Deposition levels and extent of decontamination in the surveyed villages.

	Village			
	Demenka	Starye Bobovichi	Starye Vyshkov	Yalovka
Estimated mean deposition of ^{137}Cs [kBq m^{-2}] in 1986	1200	1100	1500	2700
Extent of decontamination	N.D.[a]	P.D.[b]	P.D.[b]	F.D.[c]

(a) Non-decontaminated (no systematic measures have been carried out to reduce the radiation level)
(b) partly decontaminated (mainly unpaved roads were covered with gravel)
(c) fully decontaminated (removal of topsoil around public buildings and roads and covering with asphalt as well as cleaning some of the buildings

During the expedition in 2006 the villages in Table 1 were visited and thermoluminescent dosemeters (TLD) of LiF were distributed to the residents to measure the effective dose from external exposure. The internal dose was determined by *in vivo* measurements of the whole body contents (WBC) of ^{137}Cs using portable NaI(Tl)-detectors.

2.1 Effective Dose from Internal Irradiation

In each of the four villages, the inhabitants were offered to get their total body burden of ^{137}Cs determined. The *in vivo* measurements were conducted in public buildings (schools and community offices) with thick (> 50 cm) walls of bricks. The shielding of the buildings from the surrounding ground contamination allowed measurements with two portable (63 mm (Ø) × 53 mm) NaI(Tl) detectors coupled to a multi channel analyzer (DigiDart, EG&G Ortec, USA). The subject was sitting with the detector in the knee pointing towards the abdomen in a so-called Palmer geometry [8]. The background count rate was determined and a correction for the shielding by the measured person was also carried out. Individual calibration factors (for mass and waist circumference) were used (see [9] for a detailed description).

In total, 317 residents of both sexes and of ages ranging from 2 to 80 years were subject to whole-body counting of ^{137}Cs in 2006. To calculate the effective dose from internal contamination of ^{137}Cs, the investigated subjects were divided in groups depending on age and weight. The age and weight dependent dose conversion factors published in ICRP publication 67 [10] were then applied to obtain the effective dose rate, $\dot{E}$ (mSv y^{-1}) according to Eq. 1 [9].

$$\dot{E} = r(m) \cdot A/m \quad (1)$$

where *r(m)* is the dose rate coefficient (mSv kg kBq^{-1} y^{-1}) in a human subject with body mass *m* (kg) and activity *A* (kBq) of ^{137}Cs in the body.

2.2 Effective dose from external irradiation

In each of the four villages, 16 – 24 LiF dosemeters were distributed to young and adult persons (6 – 79 yrs.) of both sexes. The TL-chips were square formed thin tablets of hot pressed/extruded LiF:Mg, Ti (Harshaw TLD-100) with dimensions of 3.2×3.2×0.9 mm^3. Before the transport to Russia, the chips were calibrated free-in air, in a ^{60}Co-beam. Thereafter, during transportation and storage, the chips were kept in a lead container until the night before the distribution to the individuals when the dosemeters were prepared and the chips were put into holders of PMMA (two chips in each). At the end of the measurement period (typically after 1.5 – 3 months), the dosemeters were collected by a local contact person and sent to St. Petersburg and from there back to Sweden. Within two weeks after the dosemeters arrived in Sweden they were read-out with a TL-reader (Toledo Pitman Ltd) and once again calibrated to include sensitivity changes in the dose response.

The absorbed dose to the TL-dosemeters, $D_{surface}$ (Gy) was converted to a corresponding effective dose, E (mSv), using air kerma factors (E/K_{air}), according to the relation below.

$$E = D_{surface} \cdot \left(\frac{K_{air}}{D_{surface}}\right) \cdot \left(\frac{E}{K_{air}}\right) \quad (2)$$

where $D_{surface}$ is the absorbed dose to the body surface (Gy), *i.e.* the TL-dosemeter reading, and K_{air} (Gy) is the air kerma. Monte Carlo simulation suggest that $K_{air}/D_{surface}$ = 1.11 Gy Gy^{-1} for adults (>15 yrs.) [11] and a value of 0.83 Sv Gy^{-1} for the E/K_{air} ratio (in a rotational invariant geometry) [12]. For children (<15 yrs.) the effective dose was calculated by multiplying the body surface dose with 0.95 Sv Gy^{-1} [13]. Experiments during the previous expeditions [6] have verified the product of these two factors (i.e. the $E/D_{surface}$ ratio). However, as recently pointed out by Golikov *et al.* [14], there is a tendency to overestimate the doses when using computer simulations compared to experimental investigations. They suggested a $E/D_{surface}$ ratio of 0.92 Sv Gy^{-1} for adults and 0.93 – 1.05 for the children, based on measurements on a Rando phantom in the same area during the summer-autumn between 1991 and 1993.

To assess the absorbed dose from exposure of man-made radiation (in our case from the Chernobyl fallout), the different contributions to the dosemeter reading must be considered and separated. The absorbed dose to the TL-dosemeters, $D_{surface}$, is composed of a number of components, but can be simplified as:

$$D = D_{person} + D_{bkg} \quad (3)$$

where D_{person} is the dose accumulated when the dosemeters are worn on the body (which includes contributions from pre-Chernobyl fallout as well as the background component from cosmic and terrestrial radiation), D_{bkg} is the dose from radiation, accumulated during transportation and storage. The D_{bkg} term is in turn composed of several contributions and the amount of each of these depends on how the dosemeters are handled (storage inside-/outside the lead container, usage, transportation etc.). The contributions to D_{bkg} can be described as:

$$D_{bkg} = \left(\frac{t}{T}\right) \cdot \left(D_{TL} - D_f\right) + D_f + D_{trans} \cdot (T - t) \quad (4)$$

where the first term accounts for the dose accumulated by the background dosemeters inside the lead container (corrected for the dose during air transportation, D_f), t is the time the TL-chips were inside the lead container and T is the total time between emptying of the dosemeters and read-out. D_{trans} is the average dose rate when the dosemeters were transported and stored outside the lead container. The different components of D_{bkg} was estimated and measured *in situ*, in the villages and during air transportation, using different dose rate and dose integrating instruments: SRV2000 (RADOS, Finland), a GR-100 (SAIC Exploranium, Canada) and an electronic dosemeter (Aloka, Mydose mini, PDM 101). A number of TL-dosemeters were also kept stationary in the lead container between the calibrations (*i.e.* during the measurement period) to assess a shielded TL-background.

A dose rate of 45 µSv month^{-1} [6,15] was adopted for the pre-Chernobyl dose rate contribution and corrected for in Eq. 2. Thereafter, the yearly effective dose from external exposure due to Chernobyl was multiplied by a factor of 0.94 to account for the shielding effect from snow during winter [6].

3. Results and Discussion

3.1 Internal Contribution to the Effective Dose - Body Burden of Caesium

The total body burden of caesium is highly dependent on food habits and especially on the amount of forest products available (such as mushrooms, game and wild berries) during the different years, since these foodstuffs have 10 to 100 times higher levels of radioactive caesium than local milk and meat [2]. Hence, a seasonal variation in the body burden is expected and has been confirmed (*e.g.* Jesko *et al.*) [16]. Our measurements were always carried out during the autumn, in order to minimize the interference of seasonal variations to the results. It should be mentioned though, that the observed ^{137}Cs levels in September/October are probably higher than the yearly mean value. In the following however, the September/October results were taken as representative for the yearly mean value.

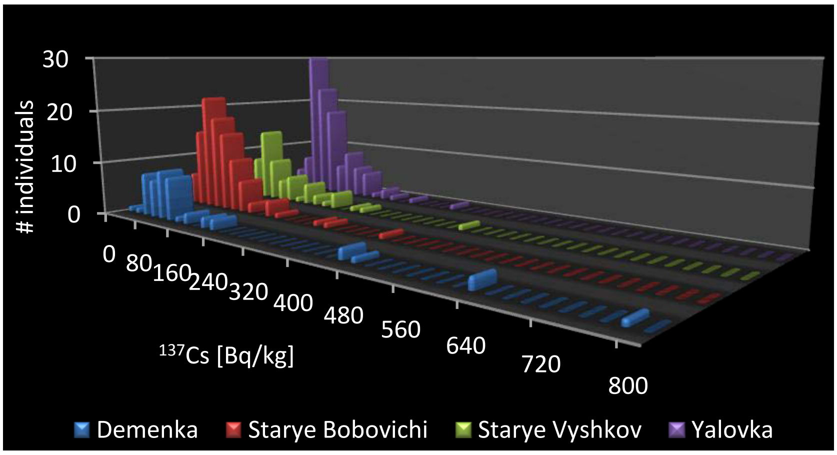
The whole-body concentrations of ^{137}Cs in the 317 individuals investigated are presented in Table 2, arranged after age and village.

Table 2: Mean whole-body concentration of caesium-137 (Bq kg^{-1}) calculated as an average for each age group and village. The number of measured individuals in each group is given in the parentheses. M=Males and F=Females.

Village	**Age interval [yrs.]**				
	< 8	8 – 12	13 – 17	> 17	
				M	F
Demenka	40 (3)	53 (1)	77 (6)	152 (7)	129 (30)
Starye Bobovichi	40 (9)	53 (40)	77 (37)	- (0)	65 (15)
Starye Vyshkov	64 (9)	75 (14)	80 (24)	111 (3)	43 (8)
Yalovka	67 (14)	65 (34)	70 (30)	124 (13)	48 (20)

The mean whole-body concentration of ^{137}Cs is similar for individuals from the four villages. However, among the adults, women show large differences between the villages. Another observation is that the inhabitants of the most contaminated village, Yalovka, have on average the same or lower levels as in the other villages. As during the earlier expeditions (1991 – 1994) [17], there is no correlation between the whole-body contents of caesium and soil contamination. This can partly be explained by the selection of the measured people: In Yalovka most part of the adults were teachers and members of the local administration, who more carefully observed the recommendations on restriction of forest products consumption than the people measured in Demenka. Most measured persons in the latter village were agriculture workers and their families, who were more dependent on forest products for their daily food supply. This is also seen when comparing body burdens between individuals from urban settlements and larger cities where most of the consumed food comes from grocery stores (that import their food from outside the region). Another part of the explanation might be a generally higher awareness among the individuals from the villages with the highest contamination levels, due to the increased attention from the authorities to those villages.

Figure 1: Distribution of the whole body concentration of ^{137}Cs among the measured individuals within the villages. All age groups are included and a large fraction of the measured individuals are schoolchildren (except in Demenka).



The individual variation within a specific village is generally larger than the difference in the average body concentration between the villages (Fig. 1). However, among those individuals that were investigated there are a very small number of persons that have body concentrations that highly exceed the village mean.

3.2 External Contribution to the Effective Dose

The conversion coefficients (from dosemeter reading to effective dose) reported by Golikov *et al.* [14] were similar to those used during the previous expeditions and hence, the 2006 doses were calculated as during the previous years. The measured dose rates in the villages in September-October, calculated from the TL reading, are presented in Table 3. The mean effective dose rate in the four villages ranged from 5 – 57 µSv per month, with a coefficient of variation (C_v) of 62%. Over time, the mean external effective dose to the inhabitants is decreasing, but there are deviations in all villages from year to year.

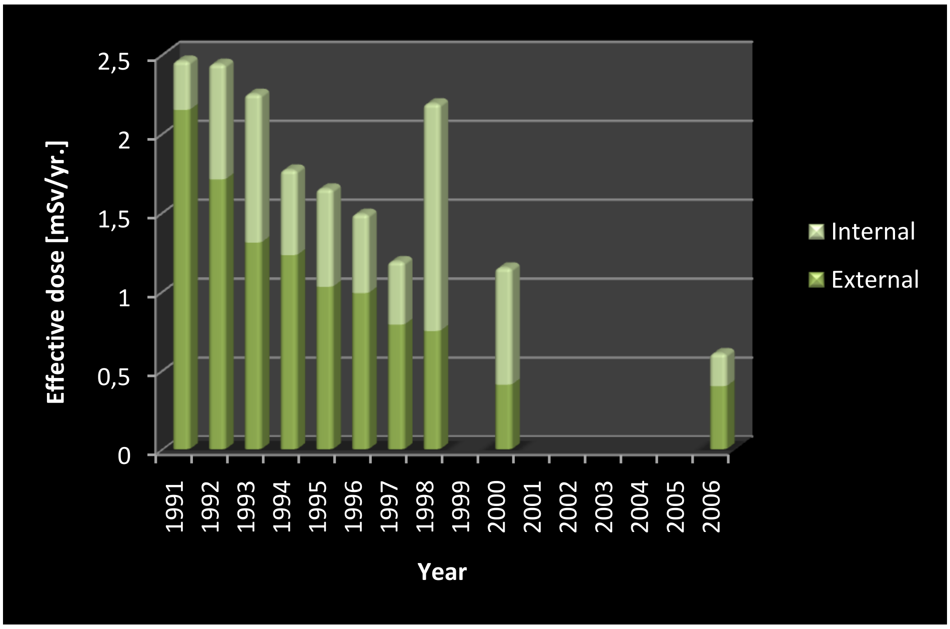
Table 3: Mean external dose rate to the inhabitants of the studied villages during the autumn of 2006, due to Chernobyl fall-out. Included are also the results from previous years, from similar villages in the same area.

Year	Village [µSv month^{-1}]						Average dose rate
	Demenka	Kusnetz	Starye Bobovichi	Starye Vyshkov	Veprin	Yalovka	
1990	-	-	195	138	-	-	167
1991	-	171	-	-	165	216	184
1992	-	162	105	-	152	219	160
1993	-	127	98	105	132	-	116
1994	-	119	68	120	101	130	108
1995	-	117	-	-	109	100	109
1996	-	84	54	107	95	111	90
1997	-	67	6	-	83	138	74
1998	-	51	28	62	89	68	60
2006	57	-	31	48	-	5	35

The monthly effective doses from external exposure are, on average, twice as high for the adults as for the children. The coefficient of variation (C_v) for the adults and the children are 71% and 45% respectively, indicating that the school-children are a more homogenous group in terms of dietary habits. As mentioned, there are large variations within the villages. This is particularly seen in Starye Bobovichi where the C_v was 110% and the highest individual dose was a factor of 4 higher than the median value for the village. However, the over all levels are low, the magnitude of the external radiation from Chernobyl ^{137}Cs is comparable to the natural background radiation level in 2006.

The mean external contribution to the effective dose in 2006, from Chernobyl fallout alone, was determined to 0.4 µSv year^{-1} (Fig. 2). This is close to the value reported in 2000, which would mean a reduction of only 4% in 6 years. Even if the vertical migration into the soil and the other human activities that redistribute the radiocaesium have stagnated or reached equilibrium, the reduction due to physical decay (2% per year) should result in a faster decrease of the dose rate. The observed stagnation in the dose rate may be an effect of increasing uncertainty associated with the very low signals obtained from the TLDs in 2000 and in 2006.

Figure 2: Effective dose from internal- and external sources as measured with portable NaI(Tl)-detectors and TL-dosemeters, respectively, during the expeditions between 1991 and 2006. *N.B.* the effective doses are averaged over all the villages visited during a specific year.



The decrease of the external dose can be described by a sum of exponential decay functions with different decay constants. During the first three years of the study there was a decrease of about 20% per year. After that period, there was a slower decrease of 12% per year between 1994 and 1998. This rate of decrease was extrapolated from 1998 to 2006 and this predicted (12% per year) line intersects the one between 2000 and 2006 in the middle. This illustrates the difficulties in determining doses close to the background radiation level. Another field survey in September 2008 will add useful information regarding these contradicting levels observed in 2000 and 2006.

From the time trend for the total effective dose, which have decreased with almost 75% (from 2.4 to 0.6 mSv year^{-1}) between 1991 and 2006, it is evident that the internal- and external contributions fluctuates over the years, although the main trend is decreasing. In general, the internal dose accounts for 30% of the total yearly dose, except during years with rich mushroom harvest as in 1998 and in 2000. It can be recognised from Fig. 2 that during the initial years after an accident, involving dispersion of radionuclides in to the environment, the external dose have a decisive influence on the total effective dose. Later, as countermeasures to reduce the radiation level is carried out and the radionuclides migrate down into deeper soil layers, the prolific years for forest products becomes more and more important due to the influence on the internal dose. As both the internal- and external dose decrease, with fairly the same rate, the total effective dose has a mean reduction of about 10% per year averaged over the whole measuring period.

4. Conclusion

In 2006, the observed yearly effective dose from Chernobyl ^{137}Cs to the residents was, on average, 0.6 mSv $year^{-1}$, which is comparable with the absorbed dose obtained annually from natural background radiation. Compared with 1991 this is a reduction with 75%. During the first years, the external component was dominating the total exposure, but the internal dose contribution has since gradually increased in importance, an increase that is largely governed by environmental and social factors (*i.e.* availability of forest products, economy and attitude to follow the food consumption recommendations).

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