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RADIATION EXPOSURE OF INHABITANTS IN RUSSIA AND BELARUS DUE TO FALLOUT FORM THE CHERNOBYL REACTOR

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***Abstract*:** The radiation exposure of the inhabitants in some nearby villages in south-western Russia and eastern Belarus has been surveyed. The results from the Russian villages are based on individual external and internal effective dose estimates over nearly two decades using conventional TLDs and NaI(Tl) measurements. In Belarus, ordinary household salt (NaCl) was tested as a dosimeter for external radiation exposure, in combination with ordinary TLDs and ambient survey instruments.

After more than two decades after the Chernobyl accident, the effective dose from the event is comparable to the annual effective dose from natural sources (cosmic radiation and ^{40}K in the body) around the world: 0.5 mSv y^{-1}. In addition, it has been shown that NaCl has useful dosimetric properties also when used in the environment.

***Keywords*:** Chernobyl, internal- & external exposure, OSL, TL.

1. Introduction

The Chernobyl accident occurred on 26 of April 1986 in the Ukrainian SSR (now Ukraine). It was the worst nuclear power plant accident/disaster ever, and is one of two events being classified as a level 7 event on the International Nuclear Event Scale (INES). The other one being the disaster at the nuclear power plant in Fukushima, Japan, following the earthquake and tsunami on 11 March 2011. Events rated as level 7 on the INES scale involve major releases of radioactive material with widespread health and environmental effects requiring implementation of planned and improvised countermeasures [1] which may be needed during a long period of time. Hence, a large number of individuals are expected to be exposed to high levels of radiation and disturbances in the society might follow. The consequences of such an event must therefore be followed for an extensive period of time.

During the initial period following a major radiological or nuclear accident (or serious incident) it is important to assess the exposure level of the exposed individuals to facilitate medical follow up and correct information to the concerned society. Later on, the exposure situation changes due to physical decay and natural processes such as weathering and downward migration of the deposited material in the soil. It is however, important to continue to survey the exposed population groups for proper remedial action also in remote periods after such major accidents and not just rely on models based on early assessments of the exposure situation.

In this paper the temporal behavior of the exposure situation in some Russian villages in the Bryansk region will be presented. The yearly external and internal effective doses have been assessed between 1991 to 2008 using conventional thermoluminescent LiF dosimeters (TLDs) and measurements of the whole body burdens of ^{137}Cs by means of NaI(Tl) detectors. An alternative method for retrospectively (and prospectively) estimate radiation doses is also presented. In a parallel project dosimeters of sodium chloride (NaCl), read by optically stimulated luminescence (OSL), were positioned in a village in the Gomel region in Belarus. Similar measurements were repeated in 2008, 2009 and 2010. Results from these surveys are discussed and future possibilities for OSL in NaCl are suggested.

2. Material and methods

The villages considered in this paper were all located within a radius of a few tenths of km within the Bryansk-Gomel spot. This was one of the most heavily contaminated areas after the Chernobyl accident with ^{137}Cs levels ranging from 0.8 MBq m^{-2} to 2.7 MBq m^{-2} (in the specific villages). Internal and external radiation doses were measured in a number of Russian villages (usually the same) and NaCl dosemeters were later tested to assess the external radiation exposure in a single Belarusian village.

2.1. External and internal effective doses in some Russian villages

As a part of a long-term Soviet-Nordic collaboration [2-5] the external and internal exposure to radiation of the inhabitants in some Russian villages in the Bryansk region have been assessed yearly from 1991 to 2000, except in 1999. This project was later re-initiated and two more assessments were carried out in 2006 and 2008.

A few villages, usually the same, were visited in September or October during each survey. All villages were similar in size (< 1000 inhabitants) and had initial ^{137}Cs contamination levels ranging from 0.9 – 2.7 MBq m^{-2}. Some of the inhabitants agreed to get their external radiation exposure measured (Fig. 1). These participants were given individual dosimeters of LiF: Mg, Ti (TLD-100; Harshaw, USA) and were advised to wear the dosimeters during about two months. The effective dose was calculated from the absorbed dose to the body surface, *i.e.* the TLD reading, using dose conversion factors according to *e.g.* [10]. A correction was also made to the dosimeters for natural background radiation and for exposure during transportation and storage. Hence, the doses referred to hereafter, are the Chernobyl related signals measured *in situ*.

All inhabitants were also offered to get their whole body burden of radiocaesium measured (Fig. 1). The assessments were carried out *in vivo* using portable 75 mm(Ø) × 75 mm NaI(Tl) detectors (ORTEC, USA). The individual effective dose from internal exposure was calculated based on the measured activity of caesium and the age dependent metabolic and dosimetric parameters from ICRP publications 56 and 67 [6, 7] according to [8].

Fig. 1. Measurements in Russia. To the left: participants wearing TLDs in a cord around the neck. To the right: measurement of the ^{137}Cs body burden using NaI(Tl) detectors in a sitting position.

2.2. External effective doses and test of NaCl as dosemeter in a Belarusian village

The village of Svetilovichi (0.8 MBq m^{-2} of ^{137}Cs in 1986) is located in the Vetka region on the Belarusian side of the border, some tenths of kilometers from the villages in the Bryansk region. To test the potential of ordinary household salt as a dosimeter for ionising radiation, special dosimeter kits containing regular Swedish household salt (Falksalt fint bergsalt; Hanson & Möhring, Sweden) and TLDs were manufactured. A number of light tight dosimeter kits were fastened on stationary positions inside and outside different houses in the village. After a monitoring period of about 2.5 months the dosimeter kits were collected. During distribution and collection the dose rate was measured using a radiation protection survey instrument based on a 75 cm^3 NaI(Tl) crystal (GR-110; Exploranium, Canada). Two independent comparisons to the salt dosimeters were therefore available. The specific calibration procedure and OSL read-out protocol use an automated TL/OSL-DA-15 reader (Risø National Laboratory, Denmark) and a pre-determined calibration factor, to convert the luminescence to a corresponding absorbed dose in salt. The details of the protocol are described elsewhere [9].

The radiation environment, in terms of ambient dose equivalent rate, H^*, 1 m above ground, was also studied using a high pressure ionisation chamber [HPIC (RSS-131ER; General Electric Energy, USA)] at some reference locations in the village (Fig. 2). Based on the measured ambient dose equivalent and the model described in Eq. 1 [10] the effective dose, E_k, to the inhabitants of Svetilovichi was estimated.

$$E_k = \sum_i OF_{i,k} \cdot CF_{i,k} \int \dot{D}(t) \cdot LF_i(t) \cdot dt \qquad (1)$$

where $OF_{i,k}$ is the occupancy factor for location i which accounts for the relative amount of time spent on location i by individuals of the kth population, $CF_{i,k}$ is a dose conversion factor from measurable to risk quantities, $\dot{D}(t)$ is the dose rate over an undisturbed reference area and LF_i is a location factor for area i which accounts for the dose rate reduction in the area compared to the reference area.

Fig. 2. *In situ* measurement of the ambient dose rate in a garden in the village of Svetilovichi.

3. Results and discussion

3.1. External and internal effective doses in some Russian villages

Due to the logistics between the Russian villages and Sweden, a significant background signal was added to the dosimeters. The influence of this (unwanted) dose is assumed to be the largest uncertainty in the effective dose calculations. In addition, no dosimeters were retrieved at all from one of the villages in 2008. The effective dose in this village was therefore estimated based on the TLDs used in 2006 and the average dose rate reduction as indicated by ambient survey meters in 2006 and 2008.

A total number of 316 persons in 2006 and 324 persons in 2008 measured their whole body concentration (WBC) of caesium in the villages visited. The WBC was found to be similar between persons of different ages. The distribution of the individual effective doses is log-normal, with some individuals exceeding the average value by a factor of 5. The average annual effective dose, from external and internal exposure due to Chernobyl, in the selected villages is shown in Fig. 3, for the period from 1991 to 2008.

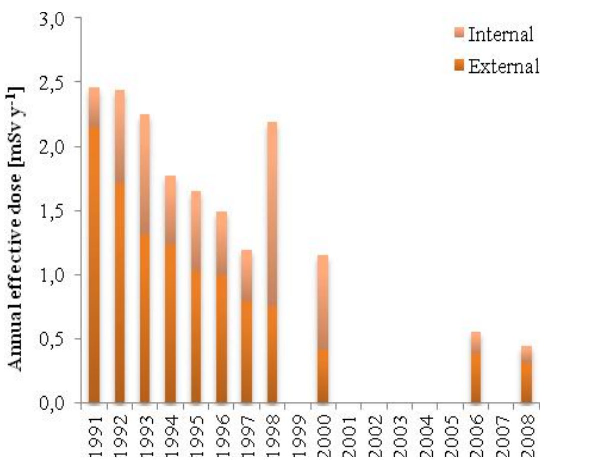

Fig. 3. Average annual effective dose (internal and external) from Chernobyl fallout only between 1991 and 2008. Each bar represents the mean value averaged over all population groups and villages.

The contribution from Chernobyl caesium to the total effective dose was determined to an average value of 0.5 mSv y^{-1} and 0.4 mSv y^{-1} in 2006 and 2008, respectively. This corresponds to a general decrease of the total effective dose by 1/5 over the monitoring period and the present day exposure is now comparable to the annual effective dose from cosmic radiation and ^{40}K in the human body. Over the years (1991-2008) the rate of decrease of the total effective dose has remained relatively constant, at a rate of about -10% y^{-1}. However, it is now indicated that in the recent years this decrease is much slower, a few percent per year. In addition, the reduction is a combined effect of the behavior of the external and internal effective dose components which depends on several different factors.

In terms of the external effective dose, it has reduced over time, but with a decreasing rate from year to year (Table 1) mainly due to caesium's physical decay and downward migration in the soil.

Table 1. Rate of decrease of the external effective dose from Chernobyl ^{137}Cs in the period 1991-2008. *N.B.* physical decay of ^{137}Cs corresponds to -2.3 % y^{-1}.

Period (years)	Average reduction rate
1991-1993	-20% y^{-1}
1994-1998	-12% y^{-1}
1998-2008	-9% y^{-1}
2000-2008	-3% y^{-1}

A similar behavior of the rate of decrease is not observed for the internal effective dose component. The reason for this is that the internal effective dose is related to a number of other factors, that may vary from year to year, *e.g.* amount of forest food available (mushrooms, berries, game), selection of investigated persons (occupation, attitude to food restrictions, economics and possibility to self-supply of food). The largest year-to-year variations are therefore seen in the internal effective dose component, which indicates that in the future, most attention should be paid in reducing this contribution to the total effective dose.

3.2. External effective doses and test of NaCl as dosemeter in a Belarusian village

In total, 250 dosimeter kits were used at different positions in 2008-2010. Among these, 26 OSL dosimeters (OSLD) could not be used (in 2010) due to a large signal loss related to insufficient packaging of the dosimeter kits. A transportation dose rate of 0.10 µSv h^{-1} was used for the background correction, but no correction for normal (pre-Chernobyl) background radiation have been carried out in these calculations. The results of the dosimeter kits should therefore be viewed as a comparison of the different detectors. Fig. 4 shows the correlation between the signals from the OSLD (NaCl) and TLD (LiF) used in each kit and year.

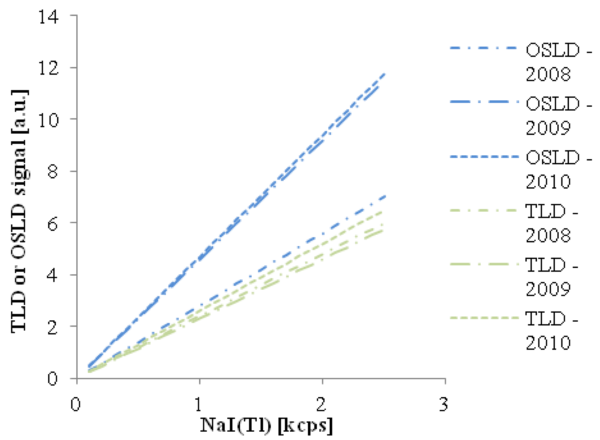

Fig. 4. OSLD or TLD dose response relative to NaI(Tl) at the position of the dosimeter kits. The average regression line in each year represents 56, 69 and 99 positions/dosimeter kits in 2008, 2009 and 2010, respectively.

As shown in Fig. 4 the TLD signals correlates to the NaI(Tl) detector readings similarly in all three years. It is also evident that the OSLDs in 2008 have a similar dose response as the TLDs. The same correlation is not observed for the OSLDs used in 2009 and 2010.

Nevertheless, the OSLDs in 2009 and 2010 have an almost identical dose response relative to the NaI(Tl) detector. The explanation for this is that salts from two different packages (but from the same brand) were used during the years. When applying the general calibration factor mentioned previously, it will not account for the differences between salts of the same brand but from different packages *e.g.* manufacturing date, grain size distribution, history of ambient conditions etc. However, one way to overcome this is to individually calibrate each salt dosimeter after the read-out. One such method is the single-aliquot regenerative-dose protocol (SAR). By using a recently update version of this protocol [12] it is possible to retrieve doses within ±5% and with a high throughput of measured samples.

The external effective dose to the inhabitants in the Belarusian village Svetilovichi was estimated using the HPIC measurements and the model described in Eq. 1. The annual effective dose ranged from 0.9 mSv y^{-1} to 1.4 mSv y^{-1}, depending of residential house type (brick/wood) and indoor vs. outdoor occupation. Slightly higher estimates were made based on the dosimeter kits (1 mSv y^{-1} to 1.5 mSv y^{-1}) associated with an uncertainty in the background dose correction, as well as the conversion factors from measured value to effective dose.

4. Conclusions

The radiation exposure more than twenty years post-accident in some of the most Chernobyl affected villages in Russia and Belarus has been surveyed and new OSL dosimeters tested *in situ*. Ten to fifteen years after the accident, the yearly decline in the total exposure from Chernobyl ^{137}Cs has leveled out to an almost constant rate of only a few percent per year. The observed year-to-year variations are mainly due to a varying internal effective dose component. In 2006 and 2008 the average annual effective dose were around 0.5 mSv y^{-1} in the Russian villages. A similar, but slightly higher, value of the effective dose was observed in the Belarusian village, although the estimates were based on model calculations and no pre-Chernobyl background correction was carried out. It has also been shown that the OSL in household salt may be used for dosimetry when handled as ordinary dosimeters in the environment during extended periods of time. However, some fading properties and sampling strategies will be necessary to investigate further in order to fully use the potential of NaCl as a retrospective dosimeter after future events such as those in Chernobyl and Fukushima.

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