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VARIATION IN GAMMA DOSE RATE IN DIFFERENT LOCATIONS FOLLOWING THE CHERNOBYL ACCIDENT

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Abstract: Radionuclides from the Chernobyl accident were released and dispersed during a limited period of time, but under different weather conditions. As a result the radionuclides were unevenly distributed on the ground. During the years the initial deposition has been altered at some locations by different processes, but remains relatively unchanged in others. Here we report on the current inhomogeneous radionuclide distribution, on both large- and small scales ($1 \text{ cm}^2 - 10^{\text{th}}$ of km^2), which on average varies a factor of 4.

Keywords: Chernobyl, ^{137}Cs , dose rate

1. Introduction

A huge amount of different radionuclides were released during the disaster at the Nuclear Power Plant in Chernobyl (ChNPP) on April 26, 1986. During the 10 days of active release from the power plant, a complex combination of the composition of the releases and the weather conditions resulted in a non-uniform pattern of localized radioactive zones [2]. More than $200,000 \text{ km}^2$ of Europe received ^{137}Cs levels above 37 kBq m^{-2} (a level implemented to define an area as contaminated). In the three most heavily affected countries, Belarus, Russia and Ukraine, a total area of more than $40,000 \text{ km}^2$ per country was subjected to a deposition of ^{137}Cs exceeding 37 kBq m^{-2} , corresponding to 70% of the total ^{137}Cs activity deposited over Europe [6]. In addition to some dry deposition, washing out of radionuclides from the atmosphere by precipitation was the dominating source of deposition. This rainout took place over the south western parts of Russia and the eastern parts of Belarus, now being the most heavily affected area outside the 30-km zone (often referred to as the Gomel-Bryansk spot). On a smaller scale, the initial activity concentration varied on different surfaces depending on the type of deposition. During wet deposition, in connection with heavy rain, the activity was transported over horizontal surfaces and was collected in pits, ditches etc. and around houses.

Deposition during dry conditions resulted in activity that attached to trees, bushes, lawns and roofs.

Depending on the magnitude of the contamination different countermeasures were applied (*e.g.* temporary relocation, mechanical decontamination, monitoring and replacement of food, agricultural countermeasures, different restrictions and recommendations). These measures were carried out with the ambition to reduce the exposure as much as possible and at the same time to be efficient with respect to economical, social and practical conditions. Mechanical decontamination of village areas included at first cleaning of public buildings (schools, hospitals, administration buildings etc.) and later residential areas by *e.g.* replacing some of the roofs, cover roads with asphalt, remove or redistribute surface soil layers. In combination with human activities, natural processes as rain, snow and wind have together redistributed the initial deposition pattern in the affected areas.

Limited efforts have been put into studying the general variation in the external gamma dose rate on a limited scale after the Chernobyl accident [2, 4, 5]. The aim of this paper is to investigate the irregularities of the radiation fields from Chernobyl ^{137}Cs in the Gomel-Bryansk spot and to make the reader aware of the effects of these inhomogeneities when estimating doses to people residing in such contaminated areas.

2. Material and Methods

A number of rural villages in Russia and Belarus were visited at various occasions in the period from 2006 to 2013 (*cf.* [1]). These villages were characterized by a mean ^{137}Cs surface deposition in the range of $0.8-2.7 \text{ MBq m}^{-2}$ [3, 7], immediately after the Chernobyl accident. The villages are located close to the border between Russia and Belarus at a distance of about 200 km north-northeast from ChNPP. As they are located only some tenths of kilometres apart they can be considered similar in terms of initial deposition (magnitude and weather conditions during the deposition), population characteristics (*i.e.* number of

inhabitants, average age, occupations) and environment (*i.e.* soil type, vegetation and extent of agriculture).

In order to survey the variation in the radiation fields in these village, a variety of radiation protection instruments were used. To map large areas such as gardens and inside of houses, a NaI(Tl) based survey meter was used (GR110; Exploranium, Canada). This instrument is based on a $38 \times 38 \times 50$ mm³ NaI(Tl) detector and was previously calibrated by a high pressure ionisation chamber (RSS131-ER; General Electric Energy, Reuter-Stokes, USA) for the specific radiation environment in the Gomel-Bryansk spot [1]. The high pressure ionisation chamber (HPIC), uses an 8 l spherical volume filled with argon gas (25 atm). It measures the ambient dose equivalent rate, $\dot{H}^*(10)$, at an accuracy of $\pm 5\%$ at $0.10 \mu\text{Sv h}^{-1}$. During the expedition in 2013 a mobile spectrometric system was used to make accurate iso-dose maps over different surfaces. This equipment is configured as a back-pack system containing a $76 \text{ mm} \times 76 \text{ mm}$ NaI(Tl) detector (ORTEC, USA), coupled to a GPS. A special software (Nugget, SSM, Sweden), enable direct data collection and creation of the iso-dose maps. All measurements were carried out at 1 m above the ground, if nothing else is stated.

The external radiation levels were investigated in the visited villages at different locations. The locations were selected based on where the inhabitants most frequently reside: residential houses and gardens (both decontaminated and non-decontaminated), schools, farmlands and forest areas were studied. Hence, both disturbed (human activities and natural redistribution) and undisturbed (natural redistribution only) areas were included, and studied on the following scales:

A) *Large scale (more than 1 km)*. On the scale of a typical village, including the surroundings, the initial deposition is often considered as fairly uniform and an average deposition level is normally adopted for such an area. However, on the countryside such a large area contains many different locations, from decontaminated school yards to untouched forests. Different processes tend to redistribute the radionuclide distribution by time, differently in different locations. In order to investigate these differences in terms of external gamma dose rate, a village in Belarus (including the surroundings) was investigated using the HPIC.

B) *Medium scale (less than 1 km)*. Areas on a scale comparable to a typical farmland, or a garden, were investigated inside the villages. Here natural processes (weathering, downward migration and re-suspension) have together with human activities (*e.g.* decontamination, processing and gardening) altered the initial deposition. To investigate the combined effect of this on the variations in the external gamma dose rate, several farmlands and about 40 houses were surveyed. Hand-held radiation protection instruments were used. The mobile spectrometric system was used to map a decontaminated schoolyard. The entire yard was investigated by walking with the back-pack in straight lines, with a few meters between each line.

C) *Small scale (less than 10 m)*. Hand-held radiation protection instruments were used to survey locations on a small scale. A pit (9×9 m²) on an open and undisturbed surface in Yalovka was investigated by surveying the pit in two perpendicular directions. The data from the survey was reconstructed using an interpolation algorithm to establish iso-dose maps. At the smallest scale considered, a surface soil sample from the village of Demenka was investigated by distributing a uniform 6 mm thick layer on a 24×30 cm² photostimulable image plate. The plate was exposed in darkness for one week before it was processed.

3. Results and Discussion

The radiation levels were investigated on large as well as on small scales in some similar villages close to the border between Russia and Belarus.

3.1 Large scale (several kilometers)

The variation in dose rate over different areas, in one specific village in the Gomel-Bryansk spot, can be seen in Fig. 1.

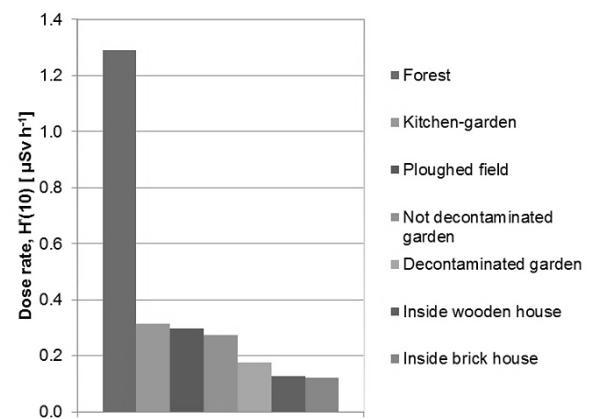


Fig. 1. Ambient dose rate, $\dot{H}^*(10)$, ($\mu\text{Sv h}^{-1}$), as measured using a high pressure ionisation chamber at different locations. The areas are located inside or outside the village of Svetilovichi in Belarus, 2010.

Due to the surrounding environment, ground surface structures and variations in the small scale meteorological conditions during the short deposition time, the fallout was dispersed differently in these different localities. This in combination with human activities has resulted in variations of a factor >6 , in average dose rate, on the outdoors open surfaces considered (or a factor 4 for the untouched surfaces). Highest dose rates are found in the forest where the influence of humans and the vertical migration is less than inside the village. It is also notable that the decontamination measures in the gardens (undertaken 20 years ago) have lowered the current radiation levels by about 40%, as compared to untouched gardens.

In Fig. 2 is an ISO-dose map of a partly decontaminated schoolyard in Starie Vyshkov. This data was collected by walking over the surface with a back-pack detector system, about 1.2 m above the ground.



Fig. 2. An approximately 70×100 m² schoolyard in the village of Starie Vyshkov (2013). The size of the squares indicate the ¹³⁷Cs activity (larger squares is equal to higher activity). Variations in the straight walking lines are mainly caused by the precision of the GPS-signal.

The schoolyard in Fig. 2 was partly decontaminated by removing the soil in the middle and replacing it with asphalt. At the time of the measurement (2013) the whole yard was covered with grass. Yet, there was an almost tenfold variation in ¹³⁷Cs activity concentration over this area, between the center (minimum) and the periphery (maximum) of the yard.

3.2 Medium scale (less than 1 km)

Table 1 shows the average results from surveying several different gardens (de-contaminated, not de-contaminated and abandoned) in the Gomel-Bryansk spot.

Table 1. Representative values of the external dose rate (μSv h⁻¹) of village gardens in the Gomel-Bryansk spot. The variation of the dose rate in the gardens 1 m from the outer walls of the hoses is given as the coefficient of variation (C_v).

| | Max | Min | C _v |
|---------------------|------|------|----------------|
| De-contaminated | 0.35 | 0.12 | 26% |
| Not de-contaminated | 0.60 | 0.11 | 35% |
| Abandoned | 1.10 | 0.23 | 44% |

Table 1 shows that there still is a difference between de-contaminated, not de-contaminated and abandoned houses in terms of the maximum values and the inhomogeneity observed. In the abandoned house no human processes have altered the surroundings, only natural processes (during the initial period after the accident) are responsible for the variations as compared to the not de-contaminated houses where people still are living and continue to improve their houses and gardens.

3.3 Small scale (less than 10 m)

An example of an open and untouched surface is shown in Fig. 3. The surface was tilted downwards towards the middle, with a depth of about 0.5 m in the center.

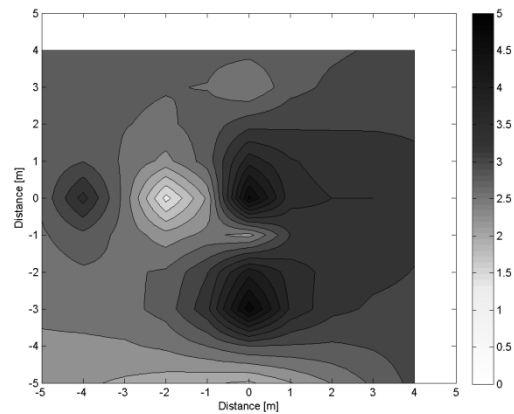


Fig. 3. Interpolated radiation levels as measured with a hand-held 72.2 cm³ NaI(Tl) detector at 0.1 m above the surface of a 9×9 m² pit. The pit is located in Yalovka and the measurements were done in 2008.

Over this small surface there are two pronounced hot-spots, as well as one warm and one cold spot. The count rate at 0.1 m over this surface (about 80 m²) varies a factor of 3.5, with a coefficient of variation (C_v) of 30%. It is noteworthy that the main part of the deposited caesium is collected at other positions than at the deepest part (center) of the pit. It is therefore suggested that these patterns represent the initial localized radionuclide deposition.

The surface soil sample taken in Demenka was exposed on a photostimulable image plate for one week, the read-out film is shown in Fig. 4.

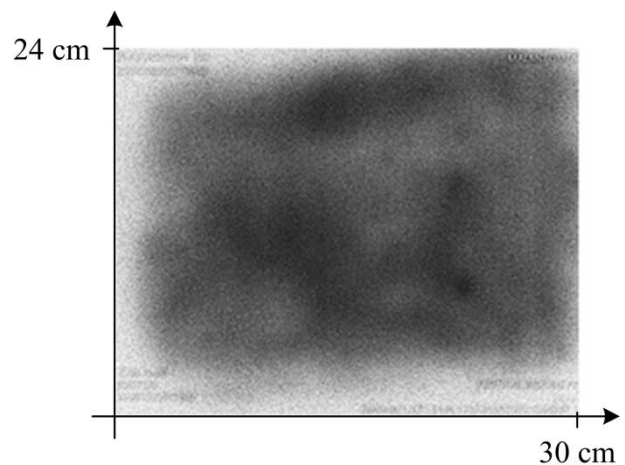


Fig. 4. Read-out of a photostimulable image plate after close contact during one week with an evenly thick (6 mm) layer of surface soil. The soil was collected in Demenka 2008.

As the film plate was not calibrated for activity quantification the interpretation of Fig. 4 may only be done visually. However, the variation in exposure over the film is associated with the varying activity distribution within the layer of soil. Several small spots with higher activity are seen. The pattern of variation is similar to the variation observed on larger scales.

4. Conclusions

Almost 30 years after the radionuclide fallout from the ChNPP, the external gamma dose rate is still highly non-uniform. Human activities, weathering and resuspension have together contributed to the current radionuclide distribution, both horizontally on the ground and vertically in the ground. These variations are observed on both large and small scales and correspond, on average, to a factor of 4. This must be considered when performing dose estimations, sampling of *e.g.* soil, and *in situ* gamma spectrometry. In order to do so, the areas must first be surveyed by *e.g.* scanning the surface with a sensitive ambient survey meter or mobile spectrometric system.

It should be noted that the results presented in this paper are valid for the specific locations investigated. They should be viewed as examples of the inhomogeneities in dose rate after a fallout event. However, the variations indicated are expected to be similar after other fallout events (*e.g.* the accident at Fukushima Daiichi, 2012). Hence, each situation must be investigated individually in order to understand the local variation in the radiation fields for proper prognosis and remedial actions for the people that continue to stay in the area.

Acknowledgements

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