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RESUSPENSION OF RADIONUCLIDES AND THE CONTAMINATION OF VILLAGE AREAS AROUND CHERNOBYL

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Abstract—A series of deposition measurements have been undertaken in 1988 around a decontaminated village close to the Chernobyl nuclear power plant. The results indicate that the spread of contamination into decontaminated areas via resuspension processes is likely to be slow. Deposition rates within the village were higher than those a short distance away and might reflect the importance of traffic-generated resuspension. Agricultural operations in the area were found to have a measurable effect on the spread of contamination up to a few hundred metres, but were unlikely to result in a major regional spread of contamination.

1. INTRODUCTION

Following a major contamination event, it is necessary to take into consideration factors which may affect the lateral migration of deposited material, in order to assess the effectiveness of possible clean-up or decontamination activities. Such migration might include processes of resuspension and subsequent deposition, as well as migration in surface or drainage water.

Resuspension can occur via both natural and anthropogenic processes (e.g. Sehmel, 1980; Nicholson, 1988a). Wind speed, surface moisture and the presence and type of vegetation are important influences on natural resuspension (Nicholson, 1988a). Resuspension has been found by many authors to increase in proportion to a power of wind speed (e.g. Garland, 1983; Nicholson, 1993), which might be typically in the range of 1–6 (Sehmel, 1984). Consequently, the occurrence of high wind speed events could lead to episodic resuspension. Anthropogenic activities which induce resuspension include traffic activity (Sehmel, 1973; Nicholson and Branson, 1990), agricultural activity (Milham *et al.*, 1976) and various cleaning operations, such as sweeping (e.g. Fish *et al.*, 1967). The wide range of environmental conditions and anthropogenic activities, that have been studied, have led to a wide range of resuspension results (Sehmel, 1980).

The effects of resuspension are two-fold. Firstly, an inhalation hazard might occur and, secondly, there might be a resulting spread of surface contamination. The relative importance of the two effects is strongly dependent on particle size. The radiological consequences of the inhalation of radionuclides decreases with particle size for particles larger than a few micrometre diameter, whilst large particles which have high deposition velocities (Nicholson, 1988b) are dominant in the spread of contamination. It is important to note that resuspended contamination is often associated with other surface material (Sehmel, 1978) and is not, consequently, related to the size distribution of the contaminant species prior to deposition.

In the current study, measurements of the deposition of radionuclides have been carried out in a decontaminated village near the Chernobyl nuclear reactor. The results have been considered in relation to the role of resuspension in the spread of surface contamination. In a second experimental study, the importance of agricultural activity in the resuspension process has been assessed.

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2. EXPERIMENTAL

The current study was undertaken in August to October 1988, around the village of Jaseny (Bragin District, Gomel Region, Byelorussia), approximately 45 km north-northwest of the Chernobyl nuclear power plant. The inhabitants of this village were evacuated shortly after the reactor accident in 1986 and the village was subject to various decontamination activities during the first part of 1988 (although some activity still remained). It was, thus, considered a suitable site for the investigation of the spread of contamination from the surrounding area. In particular, the study was conducted when agricultural activity in the nearby fields was at a maximum and the surface conditions were dry.

The contamination in the region of study includes radionuclides in the form of fuel fragments (hot particles) and, in the case of ^{134}Cs and ^{137}Cs, also in the form of condensation products (i.e. formed by condensation on to pre-existing aerosols). This was demonstrated by autoradiography of soil samples. The ^{134}Cs and ^{137}Cs to ^{144}Ce ratios, where ^{144}Ce is a tracer of core fragments, indicated that around 82–94% of the Cs originated from condensation.

An analysis of soil samples by gamma-spectrometry showed that there was a strong horizontal concentration gradient in the region, with the farmland in the south having radionuclide levels several times higher than in Jaseny, prior to decontamination (see Fig. 1). The contamination in the region originated via dry deposition and the sharp concentration gradient would be due to the region being on the edge of the plume.

Deposition measurements have been made at 14 locations within Jaseny, at the side of quiet roads (up to 10 vehicles passing per day). These locations are shown in Fig. 1. The deposition collectors which were used consisted of 0.2 m × 0.2 m exposed areas of Petryanov cloth (a type of muslin), which were held in metal frames. Each collector was positioned

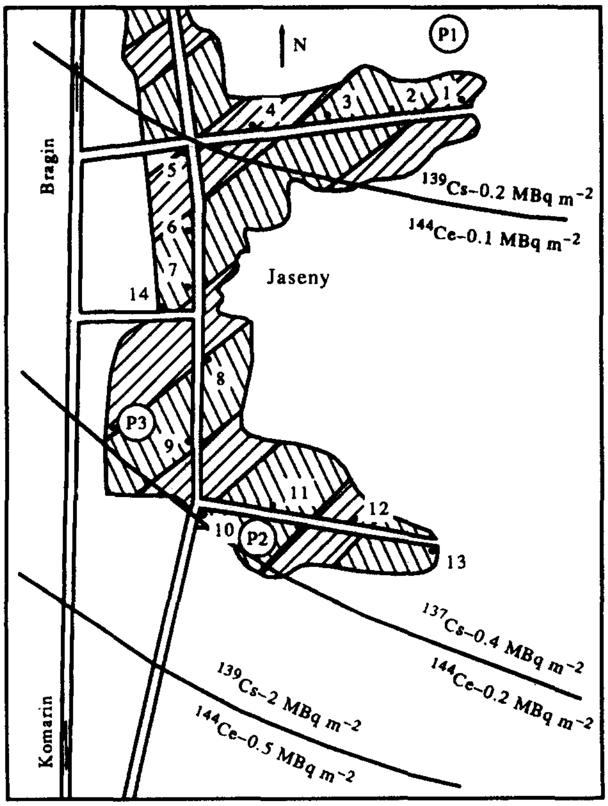

Fig. 1. Sampling locations and surface concentration contours prior to decontamination (the hatched area shows the extent of Jaseny village).

horizontally at 1 m above ground level. In addition to these deposition measurements, deposition some distance from the roadway was measured at three locations using soil deposition plots (P1, P2 and P3 in Fig. 1). These consisted of a 0.7 m × 0.7 m area of Petryanov cloth placed over the central part of a 2 m × 2 m area of uncontaminated soil (achieved by the removal of the top 20 cm of soil). Also at these three locations, deposition flux was measured at a height of 1 m using a collector with an exposed Petryanov cloth of area 0.7 m × 0.7 m.

There were three measurement intervals during the period of study (31/8/88–27/10/88).

In a second part of the study, deposition to Petryanov cloth collectors (0.7 m × 0.7 m), positioned at 1 m above ground level, was measured at various distances downwind of agricultural activity. This experiment was undertaken during dry soil conditions (soddy podzolic/sandy-loam soil of moisture content equal to 12%) with a wind speed equal to 7 $m\,s^{-1}$. The agricultural activity consisted of a tractor ploughing soil over a period of 4 h, passing the samplers a total of 23 times.

Radionuclide analysis of all collected samples was by gamma-spectrometry. In addition, some autoradiography was carried out, in order to identify the presence of hot particles.

3. EXPERIMENTAL RESULTS

A summary of the deposition fluxes measured at roadside locations is given in Table 1. Also included in Table 1 are estimated external dose rates at each of the sampling locations. The measured deposition fluxes of ^{137}Cs were of the order of 1–6 $Bq\,m^{-2}\,day^{-1}$. This clearly constitutes a small fraction of the original deposition in Jaseny (around 0.3 $MBq\,m^{-2}$). There are two factors which could account for such low deposition fluxes. Firstly, it is possible that much of the deposited material was inefficiently collected by the collection surfaces, due to either the bounce-off and blow-off of large particles, or their poor collection efficiencies for, especially, small particles. Secondly, it is possible that resuspended material may only travel short distances in the atmospheres, so that deposition of material that is advected into the region from surrounding areas that were not decontaminated, is small. Thus, it seems that agricultural operations in the surrounding countryside, including cultivation, sowing of crops and harvesting, did not lead to a significant spread of contamination into the village.

It is interesting to note the gradual decrease in the mean measured deposition flux throughout the experimental period (Table 1). Whilst it is tempting to consider this in

Table 1. Deposition flux measurements to roadside collectors

Collector number*	External dose rate ($\mu Sv\,h^{-1}$)	Deposition flux to roadside collectors ($Bq\,m^{-2}\,day^{-1}$) 31/8–15/9/88 ^{137}Cs	31/8–15/9/88 ^{144}Ce	15/9–5/10/88 ^{137}Cs	15/9–5/10/88 ^{144}Ce	5–27/10/88 ^{137}Cs	5–27/10/88 ^{144}Ce
1	1.25	1.2±0.4	<	<	<	0.7±0.2	<
2	1.50	5.6±0.7	1.7±0.8	2.9±0.6	1.2±0.6	2.7±0.7	0.9±0.5
3	1.50	1.0±0.4	<	1.0±0.3	0.6±0.5	0.6±0.2	<
4	1.60	1.5±0.5	1.2±0.6	1.4±0.3	<	0.8±0.2	<
5	1.20	0.9±0.3	<	4.9±0.6	4.5±0.6	2.4±0.6	10±2.0
6	1.95	2.8±0.5	3.1±0.9	1.0±0.3	0.8±0.4	1.0±0.2	<
7	1.80	4.1±0.6	<	2.7±0.5	<	1.0±0.2	<
8	2.20	5.7±0.7	3.6±0.9	0.7±0.2	<	1.0±0.2	<
9	2.35	1.7±0.4	<	2.4±0.5	7.0±1.0	0.7±0.2	<
10	2.70	15±1.0	5.0±1.0	3.2±0.5	0.9±0.5	4.7±0.8	<
11	3.40	1.0±0.4	<	1.2±0.3	<	0.8±0.2	<
12	2.60	0.8±0.3	<	1.3±0.3	0.7±0.5	0.8±0.2	<
13	3.20	1.3±0.4	<	1.8±0.4	<	1.2±0.3	<
14	2.30	3.1±0.6	<	2.9±0.5	1.4±0.6	1.4±0.3	<
mean	—	3.2	—	2.1	—	1.4	—

*See Fig. 1.

relation to the time dependence of resuspension noted by other authors (e.g. Anspaugh *et al.*, 1975; Garland, 1979), little change would be expected over the duration of the current study. Rather, it seems likely that environmental factors including, perhaps, surface moisture, could have played an important role and may have been expected to change during the measurement period.

Mostly, ^{144}Ce deposition levels were below the limits of analytical detection due to the relatively short half-life of this radionuclide (284 days) in comparison to ^{137}Cs (30 years). It is important to note, however, that for both ^{137}Cs and ^{144}Ce, there were some samples which contained relatively high levels in comparison to most other samples and this could suggest the occurrence of hot particles. Autoradiographic analyses of some samples supported this suggestion, indicating a small number of active particles which would contribute significantly to the overall activity. It is evident from Table 1 that there is no clear relationship between deposition flux and external dose rate, which might reflect variations in exposure of the collectors to traffic generated resuspension, as well as the confounding influence of advection from upwind sources.

The deposition flux measurements for the collectors located away from the roadside are listed in Table 2. The values are lower than those measured at the roadside and this might indicate the importance of vehicle-induced resuspension contributing to deposition at roadside locations, even in a village where there is a very low traffic density.

The measured deposition fluxes at ground level were generally greater than at 1 m height (see Table 2). This could reflect the presence of large material which is moving in saltation (i.e. skipping across the ground surface) and which is mostly contained below 1 m height. Alternatively, the measured deposition fluxes might be indirect measurements of atmospheric concentration and a decrease in this with increasing height would be expected in the occurrence of resuspension (Shinn *et al.*, 1983). In either case, the source of contamination is likely to be mostly local.

The results of the second experiment, which involved the measurement of deposition at various distances away from an agricultural source, are shown in Table 3. The source was a tractor carrying out ploughing operations and could be considered to be a line source. A

Table 2. Deposition flux measurements to collectors at remote locations

Collector reference* and height	Deposition flux to collectors at remote locations ($Bq\,m^{-2}\,day^{-1}$)					
	31/8–15/9/88		15/9–5/10/88		5/10–27/10/88	
	^{137}Cs	^{144}Ce	^{137}Cs	^{144}Ce	^{137}Cs	^{144}Ce
P1 (0 m)	0.4±0.1	0.4±0.2	0.7±0.1	0.3±0.2	0.3±0.1	<
P1 (1 m)	—	—	0.5±0.1	0.2±0.1		—
P2 (0 m)	0.4±0.1	0.4±0.2	0.4±0.1	0.4±0.2	0.3±0.1	<
P2 (1 m)	0.3±0.1	0.4±0.2	0.3±0.1	<	0.7±0.2	<
P3 (0 m)	0.5±0.1	0.3±0.2	0.7±0.1	0.7±0.2	—	—
P3 (1 m)	0.2±0.1	0.3±0.2	0.3±0.1	0.2±0.1	—	—

*See Fig. 1.

Table 3. Deposition of ^{137}Cs according to distance from an agricultural source (duration of experiment: 4 h)

Distance from source (m)	Total deposition of ^{137}Cs ($Bq\,m^{-2}$)
10	21±2
50	19±4
200	11±1
500	5.6±0.4

decline in measured deposition of ^{137}Cs is apparent with increasing distance from the agricultural operation, although this might be partly explained by upward diffusion of resuspended material. It is probable that such agricultural operations could lead to a significant spread of contamination to a distance of at least a few hundred metres. The level of deposition of ^{137}Cs at 500 m from the agricultural source (34 $Bq\,m^{-2}\,day^{-1}$) is greater than the values listed in Tables 1 and 2, although it must be added that the agricultural experiments took place in dry conditions when resuspension was most likely.

The experimental results indicate that resuspension, including the effects of both wind and agricultural activity, are only likely to result in a slow spread of deposited activity on a regional basis. The measurements suggest an annual deposition rate of the order of several hundred $Bq\,m^{-2}$, throughout most of Jaseny, which is insignificant in comparison to the original deposition of up to 0.4 $MBq\,m^{-2}$, for ^{137}Cs. However, the contamination of food crops by resuspended radionuclides might still present an important consideration.

4. SUMMARY

A number of measurements of dry deposition have been carried out in order to evaluate the spread of contamination resulting via resuspension. The results suggest that the spread of contamination into decontaminated areas is likely to be slow, even including the effects of agricultural activities. However, such operations might be important in determining local transport and the contamination of food crops.

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