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Review

Thirty years after the Chernobyl accident: What lessons have we learnt?

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ABSTRACT

April 2016 sees the 30th anniversary of the accident at the Chernobyl nuclear power plant. As a consequence of the accident populations were relocated in Belarus, Russia and Ukraine and remedial measures were put in place to reduce the entry of contaminants (primarily $^{134+137}Cs$) into the human food chain in a number of countries throughout Europe. Remedial measures are still today in place in a number of countries, and areas of the former Soviet Union remain abandoned.

The Chernobyl accident led to a large resurgence in radioecological studies both to aid remediation and to be able to make future predictions on the post-accident situation, but, also in recognition that more knowledge was required to cope with future accidents. In this paper we discuss, what in the authors' opinions, were the advances made in radioecology as a consequence of the Chernobyl accident.

The areas we identified as being significantly advanced following Chernobyl were: the importance of semi-natural ecosystems in human dose formation; the characterisation and environmental behaviour of 'hot particles'; the development and application of countermeasures; the "fixation" and long term bioavailability of radiocaesium and; the effects of radiation on plants and animals.

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1. Introduction

At 01:23 on 26th April 1986 an experiment was started at number 4 reactor of the Chernobyl nuclear power plant in northern Ukraine (then part of the USSR). The purpose of the experiment was to investigate reactor safety in the event of failure of the mains electricity supply to the plant. Less than a minute after the start of the experiment there was a steam explosion which blew the lid of the reactor and resulted in the largest accidental release of radioactivity into the environment in the history of nuclear power production. The exposed reactor core continued to burn for approximately 10 days with continued releases of radioactivity into the atmosphere over this period.

As well as high contamination in the local area, radioactive plumes were transported over large areas of Europe with the highest depositions of radioactivity at distances from the NPP being due to wet deposition in rainfall.

Between the 27th April (when the about 44,000 inhabitants of Pripyat approximately 3 km from the NPP were evacuated) and 6th May the entire population of what has become known as the '30 km exclusion zone' around the NPP were evacuated. Initially a total of approximately 116,000 people were evacuated from an area of about 3500 km^2. Subsequently the number of evacuees rose to 350,000 within affected areas of Ukraine, Belarus and Russia. Many of these evacuated areas remain abandoned today.

A population of about 6 million people in Ukraine, Belarus and Russia were living in areas which were officially designated as 'contaminated' (>37 kBq ^{137}Cs m^{-2}); 640 settlements with approximately 270,000 people had in excess of 555 kBq ^{137}Cs m^{-2} (Fesenko et al., 2006). Consequently, wide scale remedial actions were required in these former Soviet Union (fSU) countries both in food production systems (Fesenko et al., 2007) and also to decontaminate some settlements (IAEA, 2006). Outside the fSU, long-term remedial measures were put in place on animal production systems in a number of countries (Brynildsen et al., 1996; Åhman, 1999; Meredith et al., 1988; Wright et al., 2003). In Scandinavia the fallout necessitated a range of actions to protect the culture and lifestyle of the reindeer herding South Sámi people (Strand et al., 1989a; Stephens, 1987).

The Chernobyl accident led to a large resurgence in radioecological studies both to aid remediation and to be able to make future predictions on the post-accident situation, but, also in recognition that more knowledge was required to cope with future accidents. In this paper we discuss, what in the authors' opinions, were the advances made in radioecology as a consequence of the Chernobyl accident.

This review paper is accompanied by an on-line virtual special issue in which the authors have selected 30 key papers published in Journal of Environmental Radioactivity which demonstrate the contributions of post-Chernobyl research (Beresford et al., 2016; http://dx.doi.org/10.1016/j.jenvrad.2016.01.023[1]).

Descriptions of the Chernobyl accident and its consequences can be found in IAEA (2006) and Smith and Beresford (2005) (the latter being the source of information for the overview of the accident and aftermath given above).

2. Post-Chernobyl advances in radioecology

2.1. 'Hot particles'

The release of highly radioactive fuel particles (generally referred to as 'hot particles') into the environment was a distinguishing feature of the radioactive contamination following the Chernobyl accident (Bogatov et al., 1990; Konoplev and Bobovnikova, 1990; Victorova and Garger, 1990; Sandalls et al., 1993; Salbu et al., 1994; Kashparov et al., 1996). The fuel particles were of either dense or loose structure and were composed of uranium oxides. The radionuclide composition of the fuel particles was similar to the fuel composition in the damaged unit with some depletion of volatile nuclides (^{131}I, ^{134,137}Cs, ^{106}Ru, etc.). Sizes of deposited fuel particles ranged from hundreds of microns to a fraction of a micron (Sandalls et al., 1993). Within the 30-km exclusion zone, up to 10^5 particles m^{-2} were observed (Victorova and Garger, 1990). Deposition of fuel particles decreased with increasing distance from the reactor site (Sandalls et al., 1993).

As a result of the breakdown of fuel elements and annealing of nuclear fuel, large amounts of volatile fission products (isotopes of I, Cs and others) were released into the atmosphere and partly condensed on inert particle carriers (Konoplev and Bobovnikova, 1990; Kashparov et al., 1996). These "condensation particles" had a lower activity concentration compared with fuel particles (Konoplev et al., 1993; Kashparov et al., 1996) and were similar to those found in global fallout after nuclear weapon tests and, therefore, their environmental behaviour could, generally, be predicted relatively well. At the same time, the behaviour of fuel particles within the environment was unstudied before the Chernobyl accident and, therefore, presented a serious scientific problem (Sandalls et al., 1993; Salbu, 2001).

Fallout from nuclear weapons testing had more than 90% of ^{90}Sr and ^{137}Cs in water soluble and readily exchangeable forms (Pavlotskaya, 1974; Konoplev and Bobovnikova, 1990). After the Chernobyl accident close to the NPP, the fraction of water soluble and exchangeable forms in the fallout was much lower, because of the presence of water-insoluble fuel particles, and depended on the distance from the damaged unit (Konoplev and Bulgakov, 1995). For example, the fraction of non-exchangeable ^{137}Cs in the fallout near Chernobyl was about 75% (Konoplev and Bobovnikova, 1990; Bobovnikova et al., 1991), in the Bryansk region (Russia) it was 40–60% (Konoplev et al., 1996) and in Cumbria (UK) it was about 10% (Hilton et al., 1992). Because of the lower solubility of hot particles, the Chernobyl radionuclides had higher values of the distribution coefficient (K_d) in the "soil-water" system and, hence, slower migration and lower bioavailability in the area close to the NPP. Wash-off of dissolved ^{90}Sr with surface run-off in the 30-km zone in 1986–1987 was lower than that after Kyshtym accident or nuclear weapon testing (Konoplev and Bobovnikova, 1990).

Mobility and bioavailability of radiocaesium in Western Europe was higher, and similar to global nuclear weapons testing fallout, because the particles deposited there were mostly condensation particles (Hilton et al., 1992; Konoplev and Bulgakov, 1995; Smith et al., 2000).

Apart from the differences in radionuclide speciation between Chernobyl and nuclear weapons testing fallout, the radionuclides also differed in their rates of change in availability in the soil. The mobility of radionuclides from nuclear weapons testing decreased with time because of fixation by soil components, while in the zone near the Chernobyl NPP, in the first years after the accident, the predominant process was leaching of radionuclides from fuel particles, which led to increased migration, especially for ^{90}Sr (Konoplev et al., 1992; Kashparov et al., 1999, 2004; Konoplev and Bulgakov, 1999). In the first years after deposition, the uptake of ^{137}Cs by plants in areas where aerosol fallout dominated was 4–5 times higher than that in areas with considerable hot particle contamination. However, subsequent transfer in areas with considerable hot particles exceeded that in areas dominated by aerosol fallout by three to five times (Fesenko et al., 1997). This effect has implications for the design and timing of remediation

[1] The virtual special issue will be available on-line upto April 2017.