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Predicting the environmental risks of radioactive discharges from Belgian nuclear power plants

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ABSTRACT

An environmental risk assessment (ERA) was performed to evaluate the impact on non-human biota from liquid and atmospheric radioactive discharges by the Belgian Nuclear Power Plants (NPP) of Doel and Tihange. For both sites, characterisation of the source term and wildlife population around the NPPs was provided, whereupon the selection of reference organisms and the general approach taken for the environmental risk assessment was established. A deterministic risk assessment for aquatic and terrestrial ecosystems was performed using the ERICA assessment tool and applying the ERICA screening value of 10 μGy h^{-1}. The study was performed for the radioactive discharge limits and for the actual releases (maxima and averages over the period 1999–2008 or 2000–2009). It is concluded that the current discharge limits for the Belgian NPPs considered do not result in significant risks to the aquatic and terrestrial environment and that the actual discharges, which are a fraction of the release limits, are unlikely to harm the environment.

1. Introduction

Belgium operates two nuclear power plant (NPP) sites within its territory, producing 45.7 TW h^{-1} or about 50% of the total electricity supply of the country. The NPP sites are situated at Doel and Tihange. The Doel plant has 4 pressurized heavy water generating (PWR) reactors producing a combined power output of 2755 MWe. The first unit came into service in 1974 and the last in 1985. The Tihange station has 3 PWR units totalizing between 863 and 1015 MWe, which started up between 1975 and 1985. All sites are operated by GDF SUEZ (NEA, 2011).

The sites at Doel and Tihange routinely discharge radionuclides into the terrestrial and aquatic environments. The annual limits for discharges and emissions are specified by the Federal Agency of Nuclear Control (FANC), which is the National authority responsible for supervision of discharges, in such a way that the resulting doses to the population must not exceed 1 mSv per year for all pathways combined (art. 20 of the Royal Decree of 20 July 2001). This Royal Decree introduces also a notion of dose constraint (optimisation principle-ALARA): the discharge limits have to be based on a fraction of the limit of 1 mSv y^{-1} to members of the general public.

The current study presents the first comprehensive environmental risk assessment of radioactive discharges from Belgian NPPs. The key aim of the study was to evaluate if the actual Belgian NPP discharge limits set to protect humans do or do not harm the environment. A variety of fission and activation products released from the nuclear power plants into air or water were taken into account, with special emphasis on waterways like the river Scheldt at Doel and the river Meuse at Tihange, as well as on the immediately adjacent freshwater and terrestrial ecosystems.

1.1. Rationale for radiological environmental protection

Historically, radiation dose limits focused exclusively on human health protection but, in recent years, the demand for ecological risk assessment (ERA) has extended to non-human biota. The old tenet that if humans are protected from ionising radiation, all non-human biota are also protected is no longer accepted (Copplestone et al., 2007). Consequently, the environmental protection field has undergone considerable changes over the last decades with a body of international guidelines being developed (Andersson et al.,

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2008; ECB, 2003; Environment Canada, 1997; Howard et al., 2010; IAEA, 1992; ICRP, 2008; UNSCEAR, 1996). Beyond limiting risks from the nuclear industry to human populations, the need for investigating potential radiation risks to non-human biota and ecosystems is now internationally recognised (IAEA, 2005; ICRP, 2003, 2007).

As the international system of radiological protection of the environment continues to emerge, several national bodies and international projects have already developed assessment methodologies, including the US Department of Energy (USDOE, 2002), Canadian agencies (Environmental Canada and Health Canada, 2003), the England and Wales Environment Agency/English Nature (Copplestone et al., 2001, 2003) and European Community (EC)-supported projects (Andersson et al., 2009; Beresford et al., 2007b; EPIC, 2003; Garnier-Laplace and Gilbin, 2006; Larsson et al., 2004). Some of the approaches developed include the 'R&D 128' method and associated extensions (Copplestone et al., 2001, 2003) (UK), the United States Department of Energy (USDOE) graded approach (USDOE, 2002) and the ERICA approach, developed under EU-sponsorship (Beresford et al., 2007b). A number of these methodologies are now being used in a regulatory context in some countries such as in Canada (Copplestone et al., 2004; Wismer et al., 2005), and elements of some of them are being routinely used in other countries (Beresford et al., 2008a; ICRP, 2008; Keum et al., 2011; Nedveckaite et al., 2010, 2011; Vives i Batlle et al., 2011).

1.2. General assessment approach

Methodologies for the assessment of ionising radiation impact to wildlife share the same basic *modus operandi*. The process involves five key steps: (1) indication and characterization of potentially affected ecosystems and wildlife species of interest; (2) assignment of geometries and occupancy factors within environmental media for the species of interest; (3) determination of the transfer of radionuclides to biota from their surrounding medium, (4) calculation of the absorbed dose rate for both internal and external exposure and (5) evaluation of effects to species and the ecosystem using dose–effects relationships. This process is implemented in whole or in part in software codes such as the ERICA assessment tool (Brown et al., 2008), the RESRAD-BIOTA model (Yu et al., 2004) and the 'R&D 128' aquatic and terrestrial ecosystem assessment models (Copplestone et al., 2001) among others.

Due to the large biodiversity of most natural environments, it is impossible to consider all biota species in an assessment of radiation doses to wildlife. In order to narrow the problem of relating exposure to radiation dose, and relating dose to different categories of effect, use is made of reference organisms, a concept analogous to the reference man used in human dosimetry (ICRP, 1975). Reference organisms (along with their associated physical dimensions and occupancy factors) provide a basis for the estimation of the radiation dose rate to a range of organisms representative of a contaminated environment, based on criteria relating to ecological and radiation sensitivities.

The uptake of radionuclides by aquatic or terrestrial biota from their surrounding medium is a complex problem and few assessment tools address transfer dynamically (Vives i Batlle et al., 2008). The majority of models solve the problem by assuming equilibrium between the two phases. This assumption, only valid if discharges to the environment are continuous and uniform on an extended timescale, implies the use of compound transfer parameters (concentration factors and sediment/water distribution coefficients, or K_D values), a problem fraught with considerable uncertainty (Beresford et al., 2008b). Nevertheless, extensive compilations reflect several decades of work deriving transfer parameters for input into models, recognizing the state of equilibrium for the best use of these data in many situations (IAEA, 2010, 2011).

The key step in an assessment is the estimation of radiation dose rates for internal and external exposure, using the geometrical relationship between the radiation source(s) and the organism, organism shape, shielding properties of the medium, and the physico-chemical properties of the radionuclides present. A review of the different approaches used for wildlife is given elsewhere (Vives i Batlle et al., 2011). Briefly, in a homogeneous medium, internal and external exposures are defined by the energy-dependent absorbed fraction (AF), calculated as the fraction of energy emitted by a decaying atom that is absorbed within the organism. AFs are calculated by a Monte-Carlo or other type of numerically-based radiation transport code (Berger, 1968, 1971; Vives i Batlle et al., 2004; Waters, 2002). Most radionuclides emit a combination of radiations; this leads to the definition of dose conversion coefficients (DCCs) for the radionuclide, incorporating a summation of the absorbed fractions for all energies of each radiation, weighted by their corresponding yields. For external exposure, if the organism receives contributions from various environmental media, the approach needs to be generalized by summing these individual contributions.

Assessing the degree of protection of the environment requires eventually the evaluation of exposure in relation to effects. The dose rate is then compared with a no-effect benchmark level in order to assess the potential risk to the environment. There is information available on the biological effects produced by ionising radiation in wildlife, such as the FREDERICA radiation effects database (Copplestone et al., 2008). However, the available data tend to be limited in respect to chronic exposure to radionuclides, and continued research will be needed to systematically quantify the effects of chronic exposures of radiation on different biota in different habitats.

There is a general consensus on dose rate levels that are unlikely to cause effects to flora and fauna. Brown et al. (FASSET, 2003) concluded that only minor effects on biota are to be found for dose rates $<100\ \mu Gy\ h^{-1}$. The ERICA methodology proposes a screening dose rate at the ecosystem level of $10\ \mu Gy\ h^{-1}$ (Beresford et al., 2007b; Brown et al., 2008), further endorsed by the EU PROTECT project (Andersson et al., 2009). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concluded that dose rates up to $400\ \mu Gy\ h^{-1}$ to a small proportion of individuals in aquatic populations would not have a detrimental effect at the population level (UNSCEAR, 1996). The International Commission on Radiological Protection (ICRP) has proposed a 'derived consideration reference level' (DCRL) of $4–40\ \mu Gy\ h^{-1}$ for the most sensitive reference animals and plants (ICRP, 2008). A generic screening value of $10\ \mu Gy\ h^{-1}$ for chronic exposures is therefore deemed to be reasonably robust on the basis of current knowledge.

International examples of environmental impact assessment of radiation include studies in various England and Wales nuclear sites, Chernobyl, the freshwater environments in Norway and Finland and nuclear repositories in Finland and Sweden (Beresford et al., 2007a; 2008c; Hosseini et al., 2011; Smith et al., 2008; Torudd, 2011; Vetikko and Saxén, 2010; Wood et al., 2008). A handful of studies involve NPPs, including (a) Pickering and Darlington in Canada (Wismer et al., 2005), (b) Loire River in France (Beresford and Howard, 2005), carried out using the FASSET approach (FASSET, 2003) (c) Potter Point in Australia (research reactor) (Twining and Hughes, 2008), which used the EA R&D 128 methodology and (d) the Ignalina NPP cooling pond freshwater environment in Lithuania (Nedveckaite et al., 2011), performed using the ERICA approach. For all NPP discharge assessments, the