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Impact assessment of ionising radiation on wildlife: Meeting the requirements of the EU birds and habitats directives

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Abstract. In the UK, research funded by the Environment Agency/English Nature has provided a series of spreadsheet-based assessment tools for calculating doses received by biota in coastal, freshwater and terrestrial ecosystems. The approach uses the reference organism concept where the organism of interest (feature species) is equated to a particular reference organism (based on its physical geometry and ecology). This paper describes the stages followed to collate additional species-, and site-, specific data and to undertake assessments to determine whether Natura 2000 sites are adequately protected from authorised releases of ionising radiation. The feature species used for the assessment were species listed under the EC Birds and Habitats Directives. The paper will describe the overall assessment process followed by the UK Environment Agency, demonstrating the staged assessment process adopted; how each feature species is mathematically aligned with the most appropriate reference organism geometry; and provide an example of the assessment conducted for the Natura 2000 sites located in the Humber Estuary, UK.

1. INTRODUCTION

The UK Environment Agency has a duty to comply with the EU Birds and Habitats Directives (Council Directives 79/409/EEC on the conservation of wild birds and 92/43/EEC on the conservation of natural habitats, and wild flora and fauna) when planning and undertaking all of its regulatory and operational activities within England and Wales. These European Directives were introduced into UK legislation by the Conservation (Natural Habitats) Regulations 1994, as amended in 2000. Under these Regulations the Agency has obligations to review relevant existing authorisations, consents, licences and permissions (hereafter collectively referred to as permissions) to ensure that no Agency authorised permission results in an adverse effect, either directly or indirectly, on the integrity of identified European Sites within England and Wales. In this context the sites consist of classified, or potential, Special Protection Areas (SPA) created under the Birds Directive and candidate, or designated, Special Areas of Conservation (SAC) under the Habitats Directive. These sites are collectively referred to as Natura 2000 sites. One of the stressors requiring assessment is ionising radiation, however, it should be noted that the need for this, is being driven by conservation pressure and not from a real or perceived radiological hazard in the environment. In order to assess whether radioactive substances released to the environment under authorisation have a significant impact, a staged assessment methodology was derived [1,2]. This paper describes the tiered assessment approach that has been applied to Natura 2000 sites in England and Wales [2]. Further developments to the

methodology will follow the framework outlined in the EC partly funded FASSET project (*Contract FIGE-CT-2000-00102*) and assessment tools being developed in the EC partly funded ERICA project (*Contract FI6R-CT-2003-508847*) [3,4]. The assessment approach is split into three component parts and each of these is described below.

2. OVERVIEW OF THE ASSESSMENT APPROACH

2.1 Stages 1 & 2 assessments

Stages 1 and 2 assessments have been used to determine the number of potentially impacted Natura 2000 sites following the approach described in [5]. The Stage 1 assessment filtered out applications and activities authorised by the Agency that by virtue of their nature or location, could not conceivably have an effect on the interest features of given European sites. This was conducted using simple rules to determine the likelihood of an authorised discharge reaching a Natura 2000 site so, for example atmospheric releases are only considered if they occur within 1km of the Natura 2000.

Having identified a number of potentially impacted sites in Stage 1, the Stage 2 assessment then reviewed the maximum permissible radioactive discharge levels from authorised sites and compared these to defined screening levels [6]. Research conducted by Copplestone *et al*. [1] was used to underpin the derivation of the discharge screening levels. This approach used the concept of reference organisms, which have been defined as "*a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects. It is important that they are not a direct representation of any identifiable animal or plant*" [7]. The reference organism concept therefore provides a series of organism types, which can be considered representative of different trophic levels (see Table 1). In each case it is possible to determine relevant ecological parameters for a species representative of the reference organism (for example, for a pelagic fish you might select a salmon). The ecological parameters provide information on prey, predators and the time spent in different compartments of the ecosystem, for example for a duck, how much time is spent on sediment, surface of the water, flying etc.. It is also possible to define a simplified geometry (usually as an ellipsoid) for the purposes of dosimetric calculations (full details are provided in [1]). For each reference organism a concentration factor has been defined relative to soil, water or air depending upon the type of assessment (freshwater, estuarine/marine or terrestrial) and radionuclide. Figure 1 provides an overview of the assessment methodology [1] process.

The assessment approach was developed for the following radionuclides for different ecosystems: terrestrial only: ^{35}S, ^{41}Ar, ^{85}Kr, ^{226}Ra; aquatic only: ^{99}Tc, ^{125}I, ^{210}Po; both terrestrial and aquatic: ^{3}H, ^{14}C, ^{32}P, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{129}I, ^{131}I, ^{137}Cs, ^{234}Th, ^{238}U, ^{239}Pu and ^{241}Am.

Table 1. Reference organisms as listed in [1].

Freshwater	Estuarine/marine	Terrestrial	
Bacteria	Bacteria	Bacteria	Bee
Macrophyte	Macrophyte	Lichen	Woodlouse
Phytoplankton	Phytoplankton	Tree	Earthworm
Zooplankton	Zooplankton	Shrub	Herbivorous Mammal
Benthic Mollusc	Benthic Mollusc	Herb	Carnivorous Mammal
Small Benthic Crustacean	Small Benthic Crustacean	Seed	Rodent
Large Benthic Crustacean	Large Benthic Crustacean	Fungus	Bird
Pelagic & Benthic Fish	Pelagic & Benthic Fish	Caterpillar	Bird Egg
Amphibian	Fish Egg	Ant	Reptile
Duck	Seabird		
Aquatic Mammal	Seal & Whale		

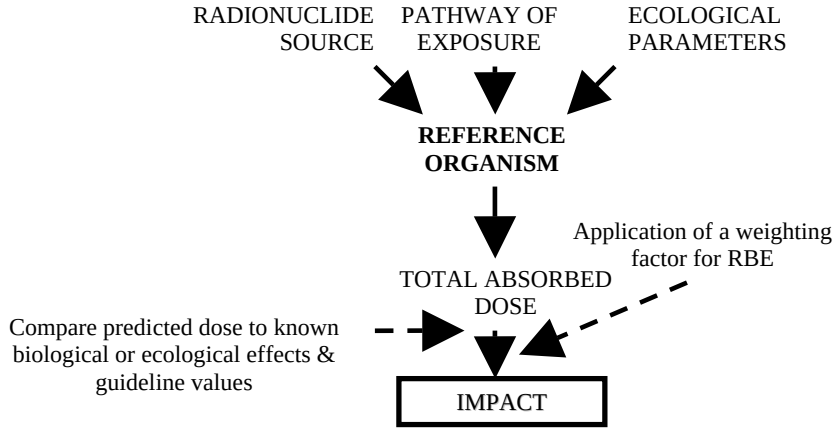

Figure 1. Overview of the assessment process given in [1].

As a result of Stage 2 and a screening level of 5 μGyh^{-1}, against approximately 100 authorisations were identified as potentially impacting on a total of 51 Natura 2000 sites and these thus require further assessment (Stage 3). One of the main reasons that an authorisation fails the screening level is because of the selection of a suitable radionuclide analogue for use in the assessment. This is because not all radionuclides authorised for release are included in the list of radionuclides used in [1]. For example ^{99m}Tc is released from medical institutions in relatively large quantities but it has a short (6 hour) half-life. It is usually released into the sewer system, which means that there will be a time delay in the ^{99m}Tc reaching any Natura 2000 site and hence radioactive decay will reduce the activity concentration arriving at the site. Furthermore, the short half-life means a rapid reduction in activity concentration of any ^{99m}Tc that reaches the Natura 2000 site. However ^{99m}Tc was not included in the original list of radionuclides used in [1] and so has to be represented by an analogue. In the case of the Stages 2 and 3 assessments this has been done using another gamma emitting radionuclide, ^{137}Cs, which has a 30-year half-life. As a consequence the dose rate from ^{99m}Tc to the organisms are over estimated.

2.2 Stage 3 assessment

Stage 3 assessments are ongoing to determine the significance of any effect resulting from a single permission or combination of permissions on the Natura 2000 site(s) identified by Stages 1 and 2. There is a particular need to assess the potential impact on listed species present in the legislation. The legislation requires that these habitat assessments are completed by 2008.

In order to achieve this all the listed species that may be present at the 51 Natura 2000 sites potentially impacted by the 100 authorisations identified in Stage 2 needed to be stylised and represented by one of the reference organism geometries described in Copplestone *et al*. [1]. In addition, efforts were made to identify species representative of the habitats listed in the legislation. For example, one of the habitat types listed in the legislation is “estuaries”. This covers a multitude of possibilities but the project team eventually decided that the “estuary” habitat could be represented by the following keystone species: reef building worm (*Sabellaria spinulosa*), brittlestar (*Ophiothrix fragellis*), crustaceans, ascidians and rare sponges.

The first part of the Stage 3 assessment is to identify information associated with the Natura 2000 site, so for example Table 2 lists the 81 species that were identified as needing protection [2]. Having identified the feature species present, then the occupancy factors (time spent in different compartments of the ecosystem), and concentration factors (for each radionuclide/species combination) should be determined. Section 2.2.1 gives further details on how concentration factors were determined. Section 2.2.2 then considers how to link the geometry of the feature species to that of the reference organism geometries [1] which are used as the basis of the dosimetric method.

Table 2. Feature species (only common names given) identified at the 51 Natura 2000 sites potentially impacted by the Stage 2 screened authorisations. The number of species is given in brackets. Those species marked with * are found in the Humber Estuary Natura 2000 sites.

Bird species (55)	Avocet*, Bar-tailed Godwit*, Bewicks Swan, Bittern*, Black-tailed Godwit*, Brent goose, Chough, Common Scoter, Common Tern, Cormorant, Curlew*, Dartford Warbler, Dunlin*, Gadwall*, Gannet, Golden Plover*, Great Crested Grebe, Grey plover*, Guillemot, Hen Harrier*, Honey Buzzard, Kittewake, Knot*, Lapwing*, Lesser Black-backed Gull, Little Tern*, Manx Shearwater, Marsh Harrier*, Mediterranean Gull, Nightjar, Oystercatcher*, Peregrine, Pink-footed Goose, Pintail, Puffin, Razorbill, Redshank*, Ringed Plover*, Ruff*, Sanderling*, Sandwich Tern, Scaup*, Shelduck*, Short-Eared Owl, Shoveler, Snipe*, Stone Curlew, Storm Petrel, Teal, Tufted Duck*, Turnstone, White-fronted Goose, Whooper Swan, Wigeon*, Woodlark
Plant species (4)	Early Gentian, Fen Orchid, Petal Wort, Shore Dock
Terrestrial invertebrates (2)	Southern Damselfly, Stag Beetle
Amphibians (2)	Great Crested Newt, Natterjack Toad
Terrestrial mammals (4)	Bechsteins Bat, Dormouse, Greater Horseshoe Bat, Lesser Horseshoe Bat
Aquatic mammals (3)	Common Seal, Grey Seal, Otter
Aquatic invertebrate	Desmoulins Whorl Snail
Fish species (8)	Allis Shad, Atlantic Salmon, Brook Lamprey, Bullhead, River Lamprey, Sea Lamprey, Spined Loach, Twaite Shad
Reptiles (2)	Sand Lizard, Smooth Snake

2.2.1 Derivation of concentration factor (CF) values

Probably the main source of uncertainty in the Stage 3 assessment results from the derivation of concentration factors (CFs) for the radionuclide/species combination. A review of the scientific literature revealed little data on the concentration of the radionuclides of interest in the feature species. This was not surprising given that most of the feature species are of conservation value and therefore unlikely to be included in routine sampling and monitoring programmes. Some CF data have been obtained from the literature and from species with a similar ecology but which are not of conservation value and that have been sampled.

In the absence of feature species and radionuclide specific CF values, an approach has been developed, which should be provide a consistent manner for selecting CF values for inclusion in the assessment. Essentially, the approach is as follows: determine if a CF is available for the species and radionuclide of interest. This is used if available. If not, a CF is selected from Copplestone *et al.* [1] for a reference organism with similar ecology. If this is not available, the CF and K_d (aquatic only) values for the radionuclide of interest are reviewed and expert judgement is used to determine which value should be recommended. Expert judgement is needed because, although the use of the K_d to

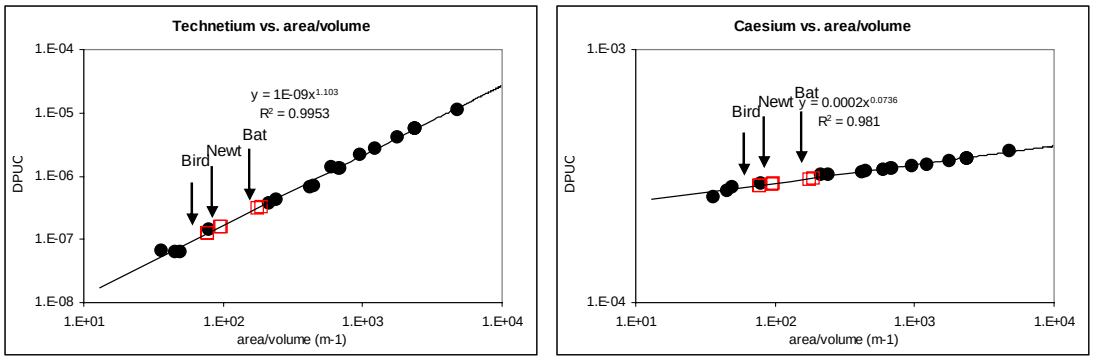

Figure 2. Plots of ^{99}Tc and ^{137}Cs as examples of the observed relationship between organism area/volume ratio and the DPUC values.

equate to CF can be viewed as generally conservative in aquatic ecosystems, certain radionuclides, e.g. ^{131}I, are known to accumulate in organisms and in these situations the use of the K_d is unlikely to be appropriate. Finally, where no CF is available for another plant or animal group, the CF for the Environment Agency recommended analogue radionuclide [5] has been used. It should be noted that this approach might produce some highly conservative CFs (as for example in the case of using ^{137}Cs as an analogue for ^{99m}Tc above). It is important to note the origins of the CFs used when interpreting the outputs of dose rate assessments. It is emphasised that the overall assessment must be supported by field measurements to produce site-specific data if there is any doubt over the results although this may be difficult if you have to measure the radionuclide content of a protected species.

2.2.2 Linking feature species geometry to that of reference organism geometries listed in [1]

In order to adapt the assessment methodology [1] to enable dose rates to be predicted for a number of species, a method to relate the geometry of the new species to the nearest reference organism geometry has been devised using an area/volume ratio. This assumes that both the feature species and the reference organism geometries are ellipsoids. Full details of the method are given elsewhere [2] but Figure 2 demonstrates the method graphically. It is important to note that the reference organism geometry in [1] is just a geometric shape. Therefore a benthic fish is actually a geometric shape of size 225mm x 43.5mm x 24.5mm with an area/volume ratio of 75.9 for the purposes of dosimetry and hence can be used to represent, for example, Guillemot with an ellipsoid shape of 207.5mm x 31.2mm x 31.2mm and an area/volume ratio of 76.4. Seventy-seven feature species identified were included in this mathematical assessment of area/volume ratios and were assigned to the appropriate reference organism geometry from [1]. The selection was conducted mathematically to give the best fit to the data [2]. It should be noted however that plants are not conducive to representation by means of an ellipsoid and hence were excluded from this process. Therefore any plant species should be represented by the macrophyte (for aquatic), shrub or herb (for terrestrial) geometries during Natura 2000 site assessments.

Ideally, absorbed doses for all new geometries should be calculated using the Monte Carlo absorbed fraction functional method [1] and conducted for all reference organism geometries. However, these calculations are onerous and, as the above approximations give rise to generally small errors in the dosimetric calculations (on average 3.5% and 7.5% for internal and external doses respectively), the area/volume approach seems an acceptable way of addressing the wide range of geometries of the identified feature species.

3. THE HUMBER ESTUARY ASSESSMENT – A CASE STUDY

The Humber catchment drains approximately 40% of the land surface of England and receives a number of authorised discharges of radioactive substances. 94 permits have been identified within the catchment where the discharges are likely to reach the Natura 2000 sites, which are located mainly around the mouth of the estuary. The list of radionuclides that may be released into the estuary are given in Figure 3. Table 2 lists the 24 feature species, all birds, were identified in the Natura 2000 sites in the Estuary.

Figure 3 shows the predicted dose rates to the reference organisms and selected examples from the feature species identified in the Humber Natura 2000 sites. A worst-case dose rate of 81.2 μGyh^{-1} has been predicted for most of the listed bird species (e.g. lapwing). Comparing this dose rate of 50 μGyh^{-1}, which has been summarised from the biological effects work of the FASSET project, suggests that effects may be observed above 100 μGyh^{-1}. Given that the predicted dose rates exceed that level, further assessment may be required at the Natura 2000 sites in the Humber Estuary. However there are large uncertainties associated with the two largest contributors to dose namely ^{14}C and other alpha. These account for 86% of the total dose rate and are both likely to be significant over-estimates due to the assumptions made over the source/discharge rates of ^{14}C and the conservative use of a ^{238}U analogue for the other alpha category. Further work is required to address this, possibly including fieldwork to generate site-specific data.

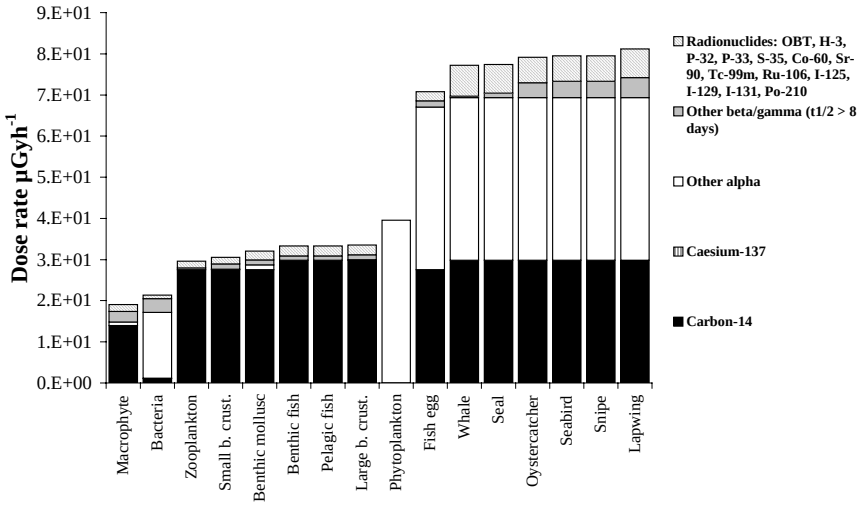

Figure 3. Predicted dose rates to the reference organisms and selected feature species in the Humber case study.

4. SUMMARY

This paper describes the staged assessment approach being used in England and Wales to determine the significance of authorised releases of ionising radiation on Natura 2000 sites under the current legislation. As mentioned previously, the pressure for this assessment comes from the needs of conservation and not because of a perceived or actual radiological hazard in the environment. The approach is being used by Agency staff between now and 2008 to conduct assessment of the Natura 2000 sites. 100 permissions, which discharge to 51 Natura 2000 sites, have been identified in Stage 2 as needing further assessment. 81 species listed under the legislation as requiring protection are recorded at one or more of the 51 Natura 2000 sites. For each of the 81 species the organism dimensions have been determined along with data on occupancy factors and concentration factors. As outlined in Section 2.2, a method of stylising each feature species as one of the reference organism geometries listed in Copplestone *et al.* [1] has been derived and an example assessment has been provided in Section 3 using the Humber estuary as a case study.

Acknowledgments

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