SETTING AND USING BENCHMARKS IN RADIOLOGICAL ASSESSMENTS OF THE ENVIRONMENT

Objective of this briefing note

This document aims to provide a basic overview of what benchmarks are and how they are derived and applied within radiological assessments of the environment. Benchmarks are used in all the available assessment tools (ERICA, RESRAD-BIOTA, R&D128 etc.) and so these notes are not specific to a particular assessment tool. More information will be provided in the course lecture and key references are given below for further reading.

Why do we need a benchmark and how are they used in an assessment?

Benchmarks, or some form of criteria (usually numeric), allow the outputs of environmental assessments to be placed into context and aid decisions on the need for further assessment or regulatory/remedial action.

For radiological protection of the environment, these benchmarks are often referred to as the Predicted No Effect Dose Rate (PNEDR). The next section describes methods to derive a PNEDR, the approaches used are often consistent with those used in the risk assessment of chemicals.

A benchmark should:

- have a clearly intended meaning and use;
- be coupled to a protection goal (that is what is the assessment being used for);
- be robust and fit for purpose (i.e. actually screen out sites where there is genuinely no cause for concern and identify those that are);
- be derived using a clearly documented and transparent methodology.

Often benchmark values fall into two types:

- Screening values; where exceeding the values means that additional analyses/work are needed to better understand and quantify the risk. These are frequently liked to tiered risk assessment schemes and serve primarily as a trigger for further investigation. That is, exceeding the screening value at an early (simple, conservative) tier might change to an output where the predicted dose rates are below the screening value at later tiers as a result of additional analyses/work to refine the exposure assessment.
- Legally binding criteria or standards that must be met to answer a given regulation (for example as Environmental Quality Standards (EQSs) under the EC Water Framework Directive, or USDOEs dose rate limits for wildlife). In these cases, exceeding the values may result in legal or regulatory action.

Screening values in radiological assessments are often referred to as the Predicted No Effect Dose Rate (PNEDR). The methods used to derive PNEDRs are outlined below; these approaches are often consistent with those used in the risk assessment of chemicals.

For radiological environmental risk assessments the benchmark may be in the form of a dose rate or be back-calculated using the available tools to environmental concentrations for each radionuclide that would give rise to the predicted no effect dose rate. These environmental concentrations (known as Environmental Media Concentration Limits (EMCLs) in the ERICA Tool, or Biota Concentration Guides (BCGs) in RESRAD-BIOTA) can be compared directly to measured or model predicted environmental media concentration values and subsequently used to determine a 'risk quotient' (see below). The use of calculated environmental concentration benchmark values are usually applied at earlier tiers or stages of a risk assessment for identifying (or screening out) sites where there is negligible risk of potential impact.

What is a risk quotient?

A risk quotient (RQ) provides a simple means of assessing risk by integrating the exposure and effects data to determine the likelihood of an ecological risk occurring. It is calculated from the quotient of the estimated exposure and a numeric benchmark (in the case of radiological assessments of the environment this will be in the form of a dose rate or activity concentration). The benchmark dose rate is a dose rate which is assumed to be environmentally 'safe'. The RQ is defined as:

$$RQ = \frac{predicted \;\; environmental \; dose \; rate}{benchmark \;\; dose \; rate \;\; assumed \;\; to \, be \, environmentally \, 'safe'}$$

Where the resulting RQ is less than one, then it would generally be considered that no further effort or action would be required. Where the RQ is greater than one, then the assessment would likely need further work (such as collecting more data, refining the exposure assessment, or taking action to reduce the risk). The key here is that the more robust and transparent the derivation of the benchmark being used, the easier it is to communicate the risk estimates.

How are benchmarks derived?

There are three methods commonly used to derive numeric criteria in ecotoxicology in general:

- Deterministic – based on the application of assessment (or safety) factors to the most restrictive single sensitivity value observed;
- Probabilistic – based on Species Sensitivity Distribution (SSD) modelling;
- A weight of evidence approach – typically using data from field exposures, such as *in situ* measurements of biodiversity indices co-occurring with stressor levels.

Over the last few years the first two approaches have been applied to radiological assessment. The third method has not been widely used to derive benchmarks for use in radiological assessments of the environment although there are examples for specific sites (e.g. uranium

mining, Thompson et al 2005). Historically the derivation of radiological benchmarks for environmental assessment has relied upon 'expert judgement' and has not been totally transparent.

The first two approaches are based on the guidance provided by the European Technical Guidance Document (TGD) (EC, 2003) for chemical risk assessment. The benchmark produced by both approaches is designed to ensure protection of ecosystem structure and function.

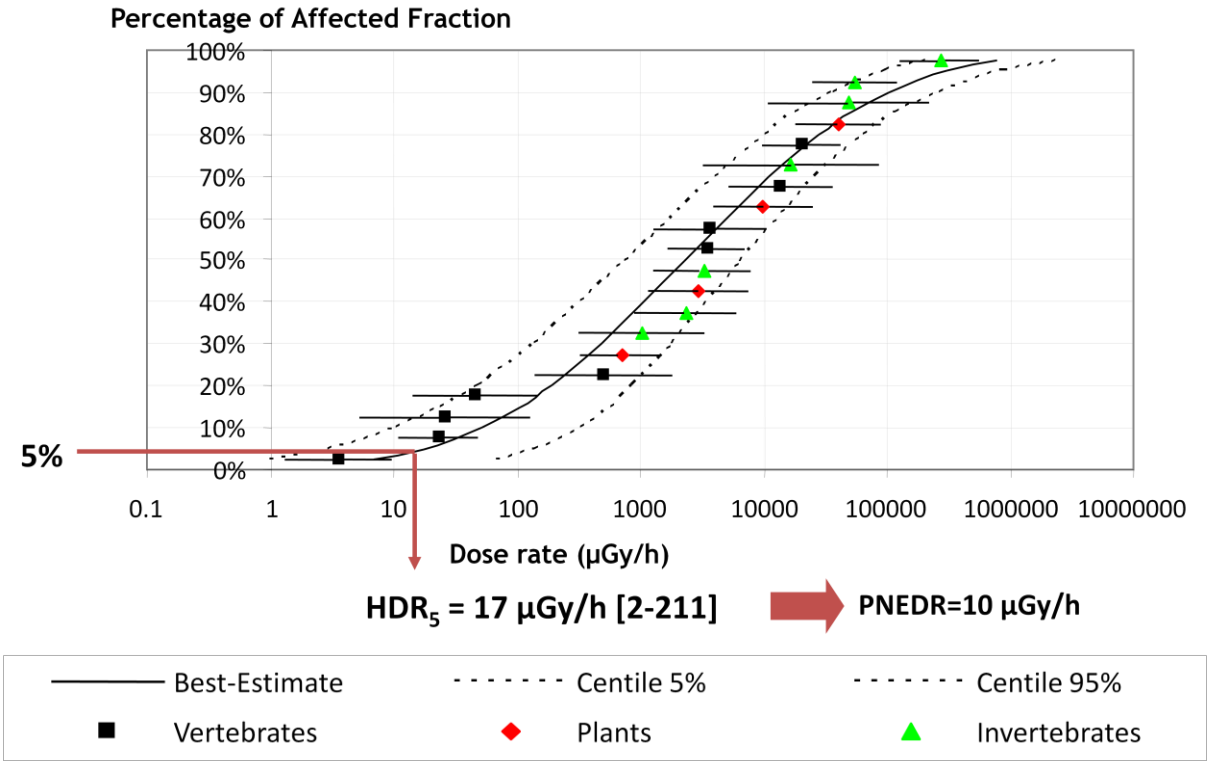
The deterministic approach, for example, takes the lowest dose rate observed to give a significant biological effect available for any tested species and divides it by a predefined assessment/safety factor ranging from 10 to 1000 (10000 for marine ecosystems) according to the quality and quantity of the data available. The assessment/safety factor is supposed to account for uncertainty.

In contrast, the probabilistic approach uses the available (quality-assured) ecotoxicology data to determine the level of radioactivity in a given medium giving a 10% effect resulting distribution for chronic exposure in the ecotoxicological data (the so called effective dose rate for a 10% effect (EDR_{10})). These EDR_{10} values are then plotted together for all species for which information exists and are used, as shown in the figure below, to identify (usually) the 5^{th} percentile from the species sensitivity distribution (SSD). To account for any residual uncertainty an assessment factor of between 1 and 5 is applied to the 5^{th} percentile value based on the available quality and quantity of the data in the SSD to produce the predicted no effect dose rate. This approach is described in full in Garnier-Laplace et al 2006, 2008 and 2010.

A freely available tool from http://www.rivm.nl/rvs/risbeoor/Modellen/ETX.jsp allows you to produce SSDs for yourself once you have identified the required biological effects data. A report (in English) which describes the tool is also available http://www.rivm.nl/bibliotheek/rapporten/601501028.html.

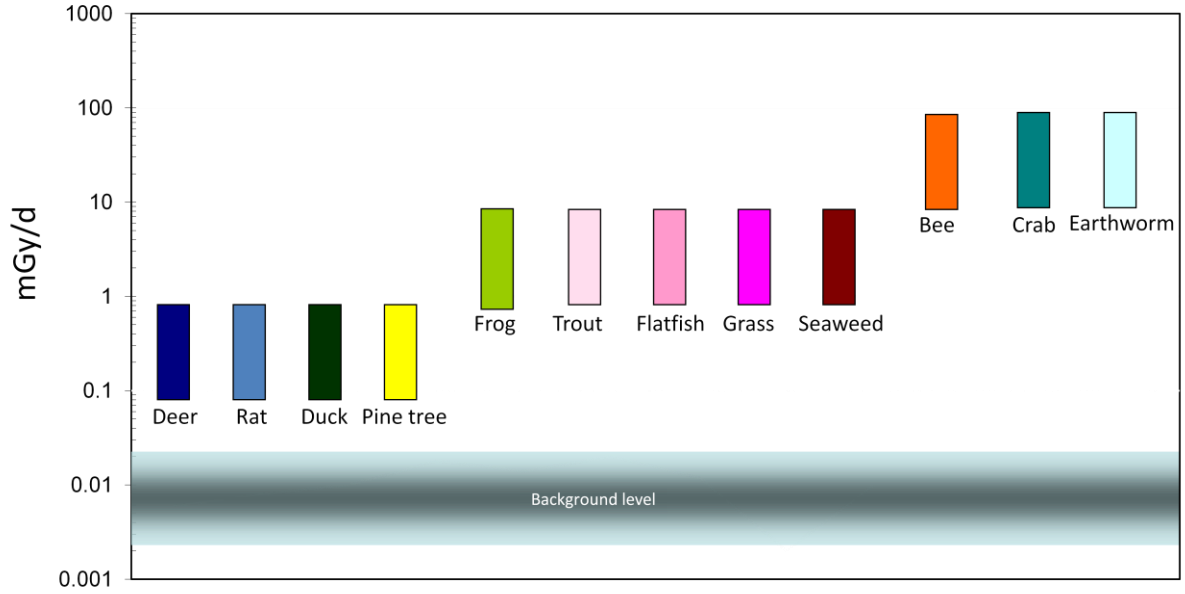
In all cases, the available ecotoxicity data for exposure to ionising radiation is the source of the information. During the EC funded FASSET, ERICA and EPIC projects, data on the biological effects of ionising radiation on wildlife from the literature were compiled into a single database called the FREDERICA radiation effects database which is available on line (www.frederica-online.org) and described in Copplestone et al 2008.

The SSD approach was used to derive the default ERICA screening dose rate (10 μGy h^{-1}) and the FREDERICA database provides effects data within the Tool.



ICRP's Derived Consideration Reference Levels

The ICRP has outlined its framework for radiological protection of the environment in its Publication 108 (ICRP, 2008) and described its use of Reference Animals and Plants. Within Publication 108, the RAPs and expert judgement have been used to produce Derived Consideration Reference Levels (DCRL) (see following figure) for each RAP. The DCRLs are defined as *a band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of RAP (derived from a knowledge of expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimise the level of effort expended on environmental protection, dependent upon the overall management objectives and the relevant exposure situation*. The ICRP is now working on guidance to show how to use the DCRLs in actual assessments.



Taxonomic screening levels

One thing that is clear from the DCRLs for each RAP figure is that the bands in which biological effects may be expected reflect the radiosensitivity of the different RAPs. The EC funded PROTECT project attempted to produce taxonomic screening levels (i.e. screening levels that reflected the radiosensitivity of different species or groups of species) but found it difficult to do this using the SSD approach because of a lack of available biological effects data. The PROTECT project also highlighted the need for the international community to consider what to do if the screening level is exceeded (in terms of provision of advice on how to evaluate the dose rates that are being predicted against the available biological information). This will be discussed further during the lecture.

References

Some useful **references** are:

Copplestone D, Hingston JL and Real A (2008) The development and purpose of the FREDERICA radiation effects database. J. Environ. Radioact. 99 1456-1463

EU (2003) Technical Guidance Document in support of Commission Directive 93/67/EEC on Risk Assessment for new notified substances, Commission Regulation (EC) No 1488/94 on Risk Assessment for existing substances and Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market. (Luxebourg: Office for Official Publication of the European Commission). Available from: http://ecb.jrc.ec.europa.eu/tgd/

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Garnier-Laplace J., Della-Vedova C., Andersson P., Copplestone D., Cailes C., Beresford N.A., Howard B.J., Howe P. and Whitehouse P. (2010) A multi-criteria weight of evidence approach to derive ecological benchmarks for radioactive substances. Journal of Radiological Protection. 30, 215-233

ICRP (International Commission on Radiological Protection) (2008) Environmental protection: the concept and use of reference animals and plants. Ann. ICRP 108 (4-6)

Thompson PA. Kurias J and Mihok S (2005) Derivation and use of sediment quality guidelines for ecological risk assessment of metals and radionuclides released to the environment from uranium mining and milling activities in Canada. Environ. Monit. Assess. 100 71-85