Workshop: *Thirty years after the Chernobyl accident what do we know about the effects of radiation on the environment?*

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How are current benchmarks used in radiological assessments derived?

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CONTENT

- What is a benchmark?
- Why are the benchmarks needed? What are they used for?
- Aspects that need to be considered to derive a benchmark value:
  - ✓ Protection goal
  - ✓ Data on effects produced by ionising radiation in wildlife
  - ✓ Method to derive the benchmark values
- Approaches used to derive benchmark values
- Benchmark values proposed by different "groups"
  - ✓ Comparison of the benchmark values proposed by different groups
  - ✓ Comparison with natural background levels
  - ✓ Comparison with dose rates producing observable biological effects

WHAT IS A BENCHMARK?

- A benchmark is “a value that is used for comparison purposes”.
- In radiation protection of the environment, the benchmarks generally refers to a predefined dose rate value assumed to be safe for the object of protection.
- A benchmark can also refer to a dose or a concentration activity

WHY ARE THE BENCHMARKS NEEDED? WHAT ARE THEY USED FOR?

- The benchmark values are needed to judge the level of risk for wildlife due to the presence of radioactivity n the environment
- To evaluate the risk, the estimated dose rates received by animals and plants are compared with the dose rate benchmark values.
- The benchmark values can be applied as:
  - ✓ **Screening value**. To identify situations of "no concern", from the radiological point of view. If the value is exceeded additional analyses (site-specific) are needed, to better understand and quantify the risk.
  - ✓ **Legally binding criteria or standard.** To answer a given regulation (e.g., Environmental Quality Standards under the EC Water framework Directive). Exceeding the values may result in legal or regulatory actions.

WHAT ARE THE BENCHMARKS USED FOR?

- Benchmark values = Screening values:
  - ✓ Allow to put into context the outputs of the environmental assessments and aid decisions on the need for further assessment or regulatory/ remedial action.
  - ✓ Optimise the amount of effort invested to protect the environment. Focus the effort on those scenarios where a potential risk exists.

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- The benchmark value(s) derived will be influenced by several factors:
  - ✓ Protection goal
  - ✓ Data on effects produced by ionising radiation on wildlife
  - ✓ Method used to derive the benchmark

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- **Protection goal**

✓ The protection goal must be precise and measurable.

✓ The benchmark value is only applicable for the protection goal defined

✓ Most commonly used goal: Protect the sustainability of populations of the vast majority of species, to ensure the ecosystem function.

✓ For rare or protected species, there is a need to ensure the protection of individuals (but the protection goal remains at the population level)

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- **Data on effects produced by ionising radiation in wildlife**
  - ✓ The selection of the data (relevancy, quality and quantity) to be used to derive benchmark values is of major importance, because the will greatly influence the value derived.
  - ✓ For radioactive substances there is not an standardized ecotoxicity test: wide range of heterogeneity in species tested, exposure conditions, observed effects, range of dose or dose rate, etc.
  - ✓ Most benchmark values are intended to protect populations, but the majority of the data available refers to effects on individuals: consider biological endpoints in individuals that are relevant for population maintenance.

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- Data on effects produced by ionising radiation in wildlife

FREDERICA Radiation Effects Database
www.frederica-online.org

Contains around 1,500 references; 22,000 data (FRED + EPIC + EMRAS-II):

- Ecosystem: around 75% terrestrial
- Exposure regime: Chronic 40%; Acute 55%; Transitory 5%
- "Route" of exposure: External 96%; Internal 4%
- Type of study: Laboratory 70%; Field 18%; Controlled field 12%

Effects after chronic irradiation

- Chronic exposure

	Mortality	Reproduction	Morbidity	Mutation
Amphibians				
Aquatic invertebrates				
Aquatic plants				
Bacteria				
Birds				
Crustaceans				
Fish				
Fungi				
Insects				
Mammals				
Molluscs				
Moss/lichen				
Plants				
Reptiles				
Soil fauna				
Zooplankton				

Effects after chronic irradiation

- Chronic exposure: **dose rates < 24 mGy/d**

	Mortality	Reproduction	Morbidity	Mutation
Amphibians				
Aquatic invertebrates		X		
Aquatic plants			X	
Bacteria				
Birds		X		
Crustaceans			X	
Fish				
Fungi			X	
Insects	X	X	X	
Mammals				
Molluscs	X			
Moss/lichen				
Plants				
Reptiles				
Soil fauna				
Zooplankton				

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- **Methods used to derive the benchmark values:**
  - ✓ Varying degrees of expert judgement (UNSCEAR, IAEA, ICRP, USA, UK EA):
  - ✓ Methodologies used for chemical risk assessments: EU, TGD 2003 (ERICA, PROTECT, Environmental Canada):
    - Deterministic: Based on the application of Safety Factors (SF) to ecotoxicity data. The PNEC value is obtained by dividing the lowest critical data by an appropriate SF ranging from 10 to 1000 (depending on the available data).
    - Probabilistic: Based on statistical extrapolation model (Species Sensitivity Distribution, SSD) to address variation between species in their sensitivity to a stressor.

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- **Deterministic method**: For radioactive compounds/ ionising radiation, to obtained the PNEDR the EDR_{10} (dose rate that produced 10% effect) is used.

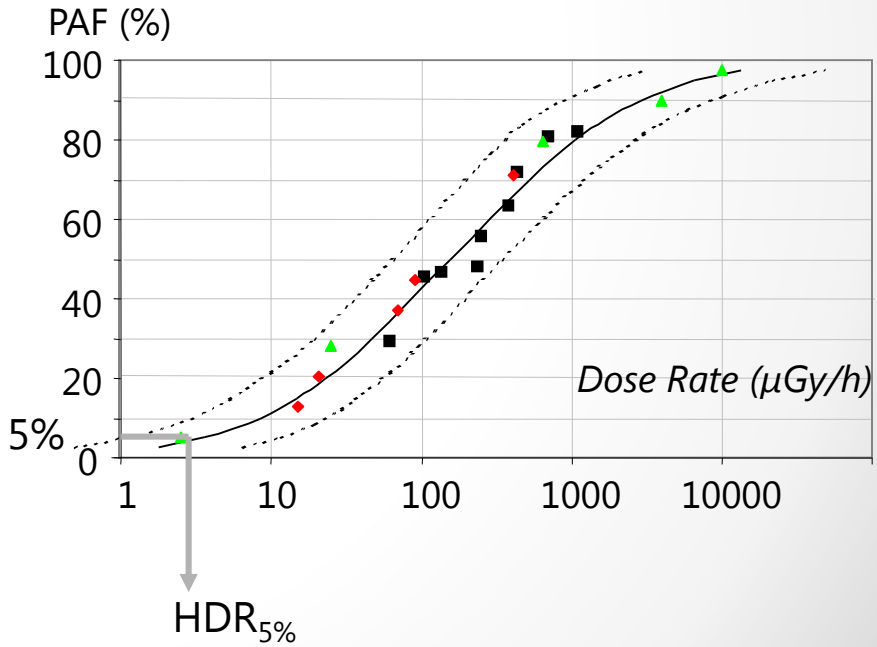
Available ecotoxicity data	SF to obtain chronic PNEDR	SF to obtain acute PNED
At least one short-term ED_{50} from each of three trophic levels (plant, invertebrate, vertebrate)	1000	100
One long-term EDR_{10} (either vertebrate or invertebrate)	100	_
Two long-term EDR_{10}s from species representing two trophic levels among (palnt, invertebrate, vertebrate)	50	_
Long-term EDR_{10}s from at least three species (Plant, invertebrate, vertebrate) representing three trophic levels	10	_

ASPECTS TO CONSIDER TO DERIVE A BENCHMARK VALUE

- **Probabilistic method**: For radioactive compounds/ionising radiation, the PNEDR is calculated from the HDR_5 (dose rate at which 95% of species will be affected below a 10% level), obtained from the EDR_{10} values for the different species and endpoints.

✓ Two main assumptions:

- The species for which results are known are representative, in terms of sensitivity, of the totality of the species in the ecosystem.
- The endpoints measured in laboratory tests are indicative of effects on populations in the field.



APPROACHES USED TO DERIVE BENCHMARK VALUES

- Benchmark values have been derived by:
  - ✓ UNSCEAR
  - ✓ ICRP
  - ✓ IAEA
  - ✓ ERICA, PROTECT
  - ✓ Environmental Agency (England & Wales)
  - ✓ NCRP, DOE (USA)
  - ✓ Environmental Canada
- Approach:
  - ✓ Protection goal (problem formulation)
  - ✓ Data selection (exposure, biological endpoints, weighting factors, etc.)
  - ✓ Method used to derive the benchmark value

APPROACHES USED TO DERIVE BENCHMARK VALUES

	Protection goal
UNSCEAR (1996, 2008)	Populations
IAEA (1992)	Populations
ICRP (2008, 2009, 2014)	Prevent or reduce the frequency of deleterious effects in the environment to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities, and ecosystems.
ERICA (2006) PROTECT (2008)	Sustainability of populations of the vast majority of all species and thus ensure ecosystem function now and in the future. Special attention should be given to keystone, foundation, rare, protected or culturally significant species
Environmental Agency (2003)	The focus of the assessment approach are the species listed in EA Habitats Handbook (2002). In addition, a number of habitats have been identified within EA (2002).
NCRP (1991) DOE (2002)	Populations (Aquatic organisms)
Env. Canada (2003)	Effects on the environment or its biological diversity.

APPROACHES USED TO DERIVE BENCHMARK VALUES

	Data (exposure, endpoints)
UNSCEAR (1996, 2008)	Mortality, fertility, fecundity, induction of mutations. Chronic irradiation to the most highly exposed individuals.
IAEA (1992)	Mortality, fertility, fecundity, growth rate, vigour and mutation rate
ICRP (2008, 2009, 2014)	Early mortality; morbidity; reproduction; induction of chromosomal damage. FREDERICA, UNSCEAR Reports. Chronic
ERICA (2006)	Mortality, morbidity and reproduction. FRED (papers with >35 score). Acute and chronic external exposure. Well defined criteria for data inclusion in SSD
PROTECT (2008)	Mortality, morbidity and reproductive capacity. Hormetic response considered; FREDERICA (papers with >35 score). Chronic external exposure. Well defined criteria for data inclusion in SSD
Environmental Agency (2003)	Effects: Based in IAEA 1992 report
NCRP (1991); DOE (2002)	Reproduction (only aquatic organisms)
Env. Canada (2003)	Mortality, growth, reproduction (considered the most likely limiting endpoint)

APPROACHES USED TO DERIVE BENCHMARK VALUES

	Method
UNSCEAR (1996, 2008)	Expert judgement
IAEA (1992)	Expert judgement
ICRP (2008, 2009, 2014)	A clear framework for the expert judgement has been described. Data used to derive the DCRLs and summary tables for each RAP are described (ICRP-108). How to apply the DCRLs (ICRP-124)
ERICA (2006)	Probabilistic method (SSD). When expert judgement needed, decisions are documented
PROTECT (2008)	Deterministic (Safety Factor) and Probabilistic (SSD) methods (EU, TGD 2003) Generic screening value: lowest EDR10 and EDR10 with the lower uncertainty. Comparing results of unweighted and weighted SSDs (weighting based on taxonomic group)
Environmental Agency (2003)	Expert judgement
NCRP (1991); DOE (2002)	Expert judgment: considering the UNSCEAR, NCRP and IAEA outputs
Env. Canada (2003)	Deterministic (Safety factor)

APPROACHES USED TO DERIVE BENCHMARK VALUES

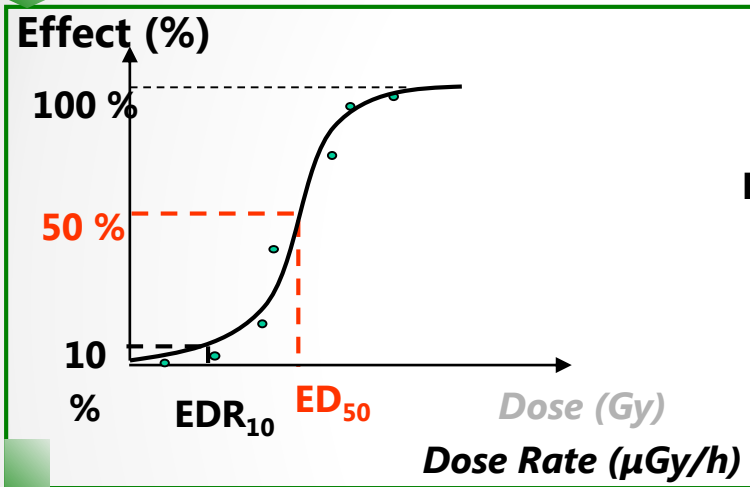
ICRP: Derived Consideration Reference Levels (DCRLs)

mGy d^{-1}	Pine	Grass	Seaweed
100-1000	→Mortality of some trees after prolonged exposure. [46 Gy LD_{50} at 130 mGy d^{-1}]	→Reduced reproductive capacity	→No information*
10-100	→ Mortality of some trees after very long exposure [76 Gy LD_{50} at ~30 mGy d^{-1} for ten years] • Growth defects. • Reduced reproductive success.	→Reduced reproductive capacity	→No information
1-10	→Morbidity as expressed through anatomical and morphological damage. Prolonged exposure leads to reduced reproductive success.	→No information	→No information
0.1-1	→No information	→No information	→No information
0.01 – 0.1	→No information	→No information	→No information

Approach of ERICA and PROTECT European projects

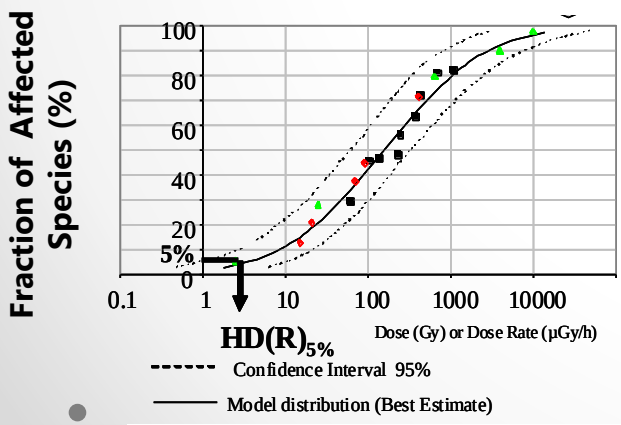
STEP 1 – Extracting appropriate data sets

- Data from FRED or FREDERICA sorted per ecosystem, per exposure condition, per bibliographic reference and per test . Quality of data describing each test is assessed.



STEP 2 – Building dose(rate)-effect relationships

- Dose-effect relationship was built for each accepted test. Estimated toxicity values are ED_{50} for acute exposure or EDR_{10} for chronic exposure
- The quality of the fitted model was judged.



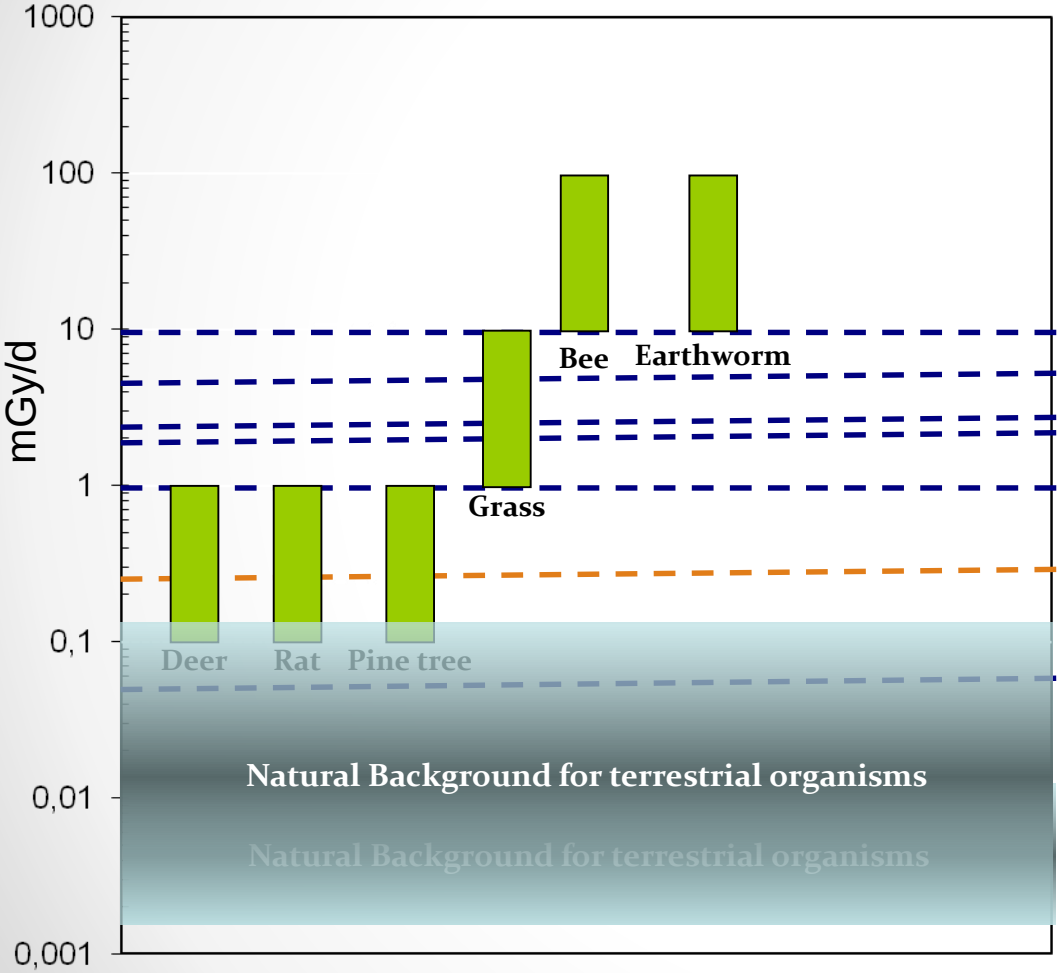
STEP 3 – Deriving PNED(R) values

- The two methods recommended by the EC were applied on the basis of the estimated toxicity values accepted after step 2.
- Comparison of the obtained PNED(R) values

BENCHMARK VALUES PROPOSED BY DIFFERENT GROUPS

- Benchmark values have been derived by:
  - ✓ UNSCEAR
  - ✓ ICRP
  - ✓ IAEA
  - ✓ ERICA, PROTECT
  - ✓ Environmental Agency (England & Wales)
  - ✓ NCRP, DOE (USA)
  - ✓ Environmental Canada

BENCHMARK VALUES PROPOSED BY DIFFERENT GROUPS

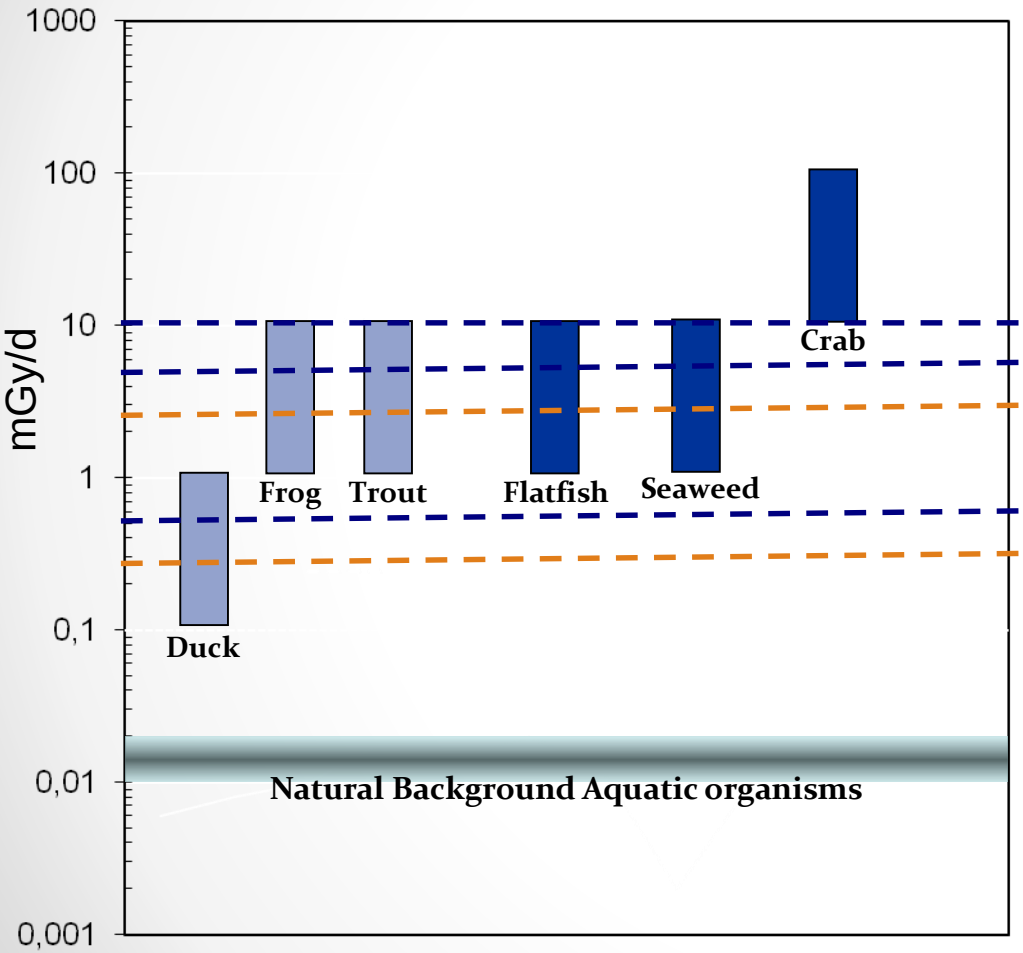


Terrestrial ecosystems

10 Plants (IAEA, UNSCEAR)
5 Invertebrates (PROTECT)
2.5 Plants & Mammals (E. Canada)
2 Plants (PROTECT)
1 Animals (IAEA, UNSCEAR)
0.24 Generic (ERICA, PROTECT)
0.05 Vertebrates (PROTECT)

0.0015–0.015 mGy/d (no Rn) (Beresford et al., 2008)
^{222}-Rn exposure: absorbed dose rates to burrowing mammals likely to be at least an order of magnitude higher (Beresford et al., 2012).

BENCHMARK VALUES PROPOSED BY DIFFERENT GROUPS



Aquatic ecosystem

10 Aquatic organisms (NCRP)
5 Freshwater benthic invertebrates (E. Canada)
2.5 Screening value aquatic organisms (NCRP)
2.5 Freshwater algae and macrophytes (E. Canada)
0.5 Freshwater fish (E. Canada)
0.24 Generic (ERICA, PROTECT)

Natural background aquatic organisms (Hosseini et al., 2010)

- Freshwater = 0.0096-0.012 mGy/d;
- Marine =0.0144 -0.0216 mGy/d

BENCHMARK VALUES PROPOSED BY DIFFERENT GROUPS

- Comparison of the benchmark values with dose rates producing observable biological effects

The values are lower than dose rates triggering effects on individual life traits in radiosensitive species (e.g. reproduction in vertebrates) on contaminated sites according to EPIC data (Sazykina, 2005).

CONCLUSIONS

- Benchmark values have been derived by different organizations, using different approaches: values broadly comparable
- Data from Chernobyl and Fukushima: Effects at dose-rates below the benchmark values.
- Background levels: Radon exposure of burrowing mammals

Thanks for your attention!