Dosimetry for Reference Organisms: Current State and Prospects

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Assessing doses to non-human biota

Major challenge – enormous diversity of biota:
habitats, life-styles, body shapes and masses, feeding, metabolism, exposure conditions etc.

For example, body mass ranges: 1—100 kg (human) vs. 10^{-9}—10^{5} kg (biota)

How to deal with the diversity?

- ⇨ use similarities
- ⇨ apply simple models
- ⇨ represent real exposures as a composition of simple ones

Current approach …

ELSEVIER

ICRP Publication 108

Annals of the ICRP

Environmental Protection: the Concept and Use of Reference Animals and Plants

ICRP Publication 108

Approved by the Commission in October 2008

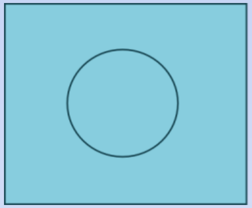
Abstract–In its latest recommendations for a system of radiological protection, the Commission considered it necessary and appropriate to broaden its scope in order to address, directly, the subject of protection of the environment, although it acknowledged that there is no simple or single universal definition of 'environmental protection', and that the concept differs between countries and from one circumstance to another. It is a very large and complicated subject. Nevertheless, the

Basic assumptions

- ✓ Conventional dosimetry, i.e. inapplicable at cellular level
- ✓ DCCs are given in terms of absorbed dose. Radiation weighting factors for biota are not yet adopted, although they may be easily applied
- ✓ Simplified shapes of organisms are used
- ✓ No metabolism is considered, i.e. DCCs are defined per unit radionuclide concentrations in the body (internal exposure) or in the environment (external exposure)
- ✓ Uniform distributions of radioactivity in organisms and in the environment are assumed

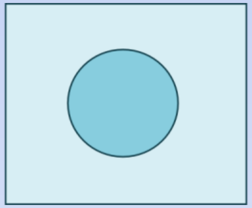
Current approach – basics

- Animals and plants are characterized by:
  - Body mass
  - Shape (proportions)
  - Ecosystems and habitats
- Organism's body is approximated by simple geometric shapes: spheres, prolate and oblate ovoids, and arbitrary ellipsoids
- "Uniform isotropic model" is used:



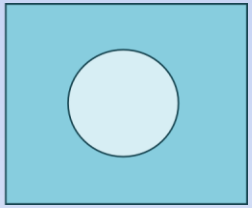
Full-absorption limit

$$D_\infty$$



Internal exposure (aquatic and terrestrial)

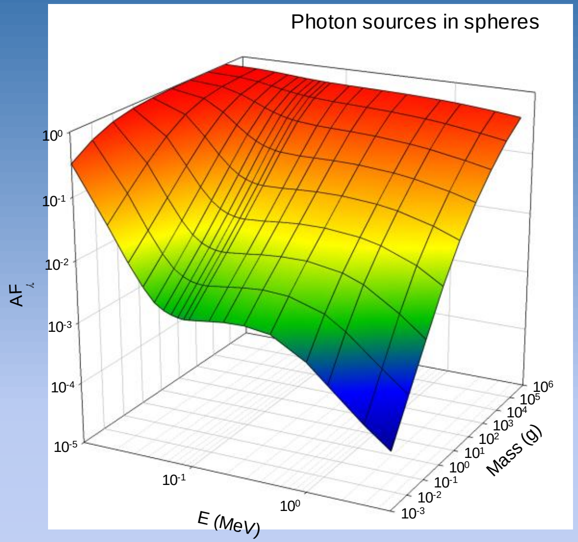
$$D^{\text{int}} = D_\infty \times \phi$$

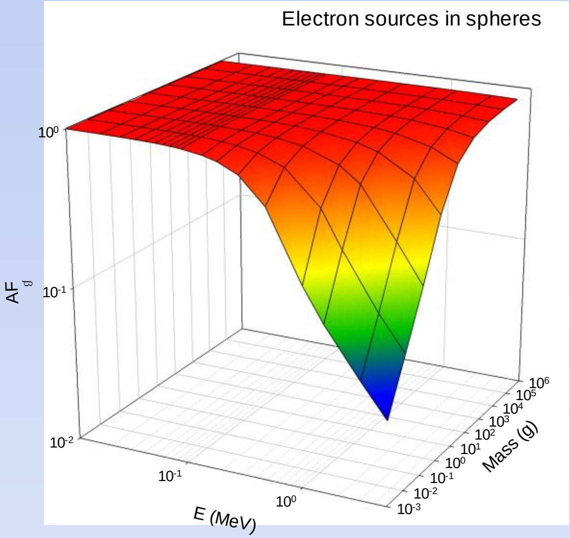


External exposure (aquatic, only)

$$D^{\text{ext}} = D_\infty \times (1-\phi)$$

Current approach – absorbed fractions



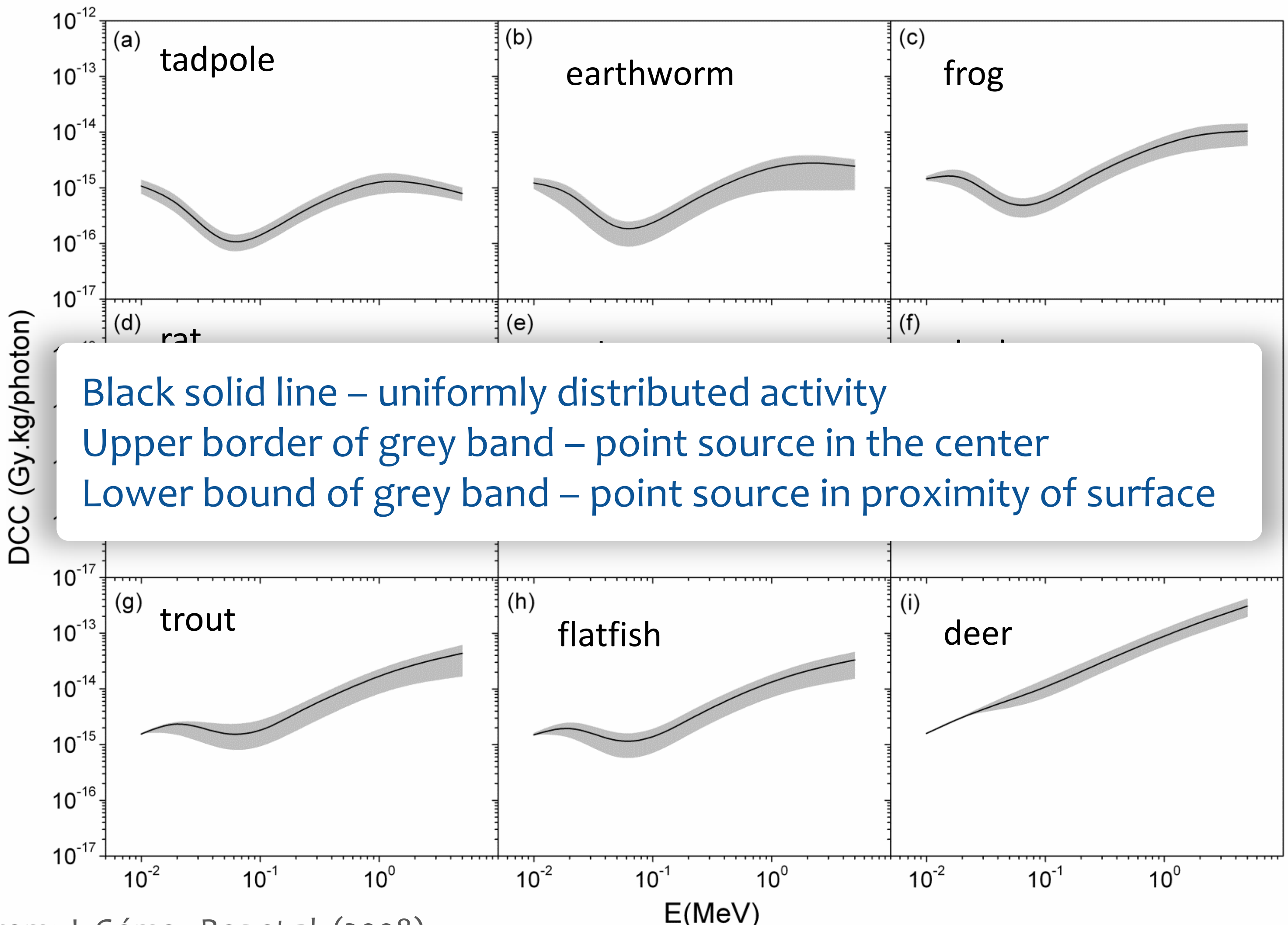


- <u>Absorbed fractions</u> (AF) have been systematically calculated for bodies…
  - ✓ with masses from 1 mg to 1 ton
  - ✓ shapes from spheres to ellipsoidal shapes with non-sphericity parameter equal to 0.15
  - ✓ the responses are smooth (see left) and can be easily interpolated on mass and energy
- An analytical approximation (body mass and non-sphericity parameter) has been found
  - ✓ to allow computation of AF for arbitrary ellipsoidal body
  - ✓ errors are within 10% for electrons and 15% for photons

Current approach – some details

- Alpha-particles and fission fragments are considered as non-penetrating radiation, i.e. absorbed fractions for these particles are assumed equal to 1
- An alternative to the uniform isotropic model – models with realistic elemental composition and density distributions – provide only minor improvements given other uncertainties implicit in environmental dose assessments (e.g. secondary radiation from surrounding water contributes only a few percent to internal dose)
- Still, there can be situations that might require more realistic models (e.g. internal or external exposure of skeletal tissue)

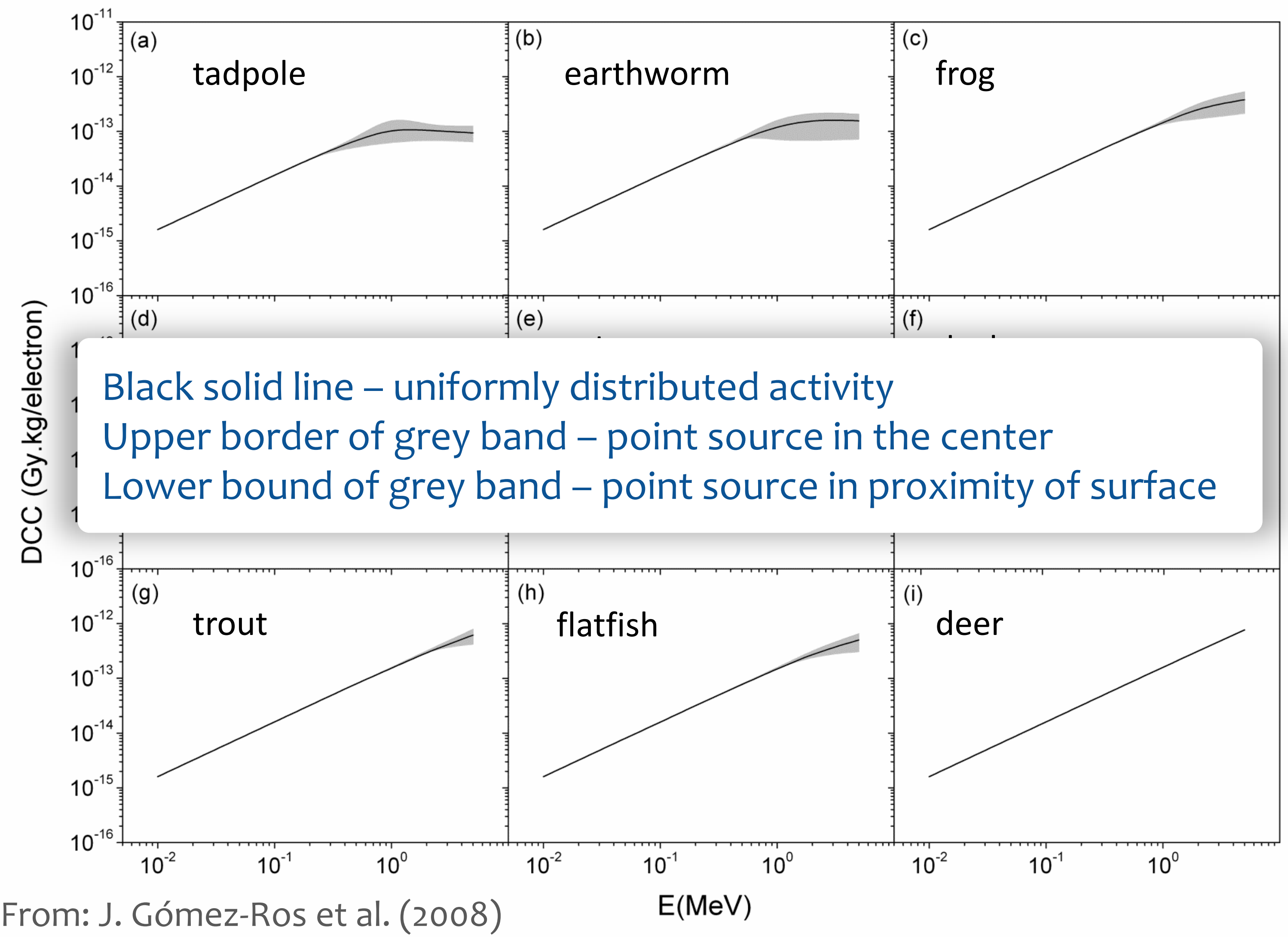
Non-uniform distributions – photons



Black solid line – uniformly distributed activity
Upper border of grey band – point source in the center
Lower bound of grey band – point source in proximity of surface

From: J. Gómez-Ros et al. (2008)

Non-uniform distributions – electrons



Black solid line – uniformly distributed activity
Upper border of grey band – point source in the center
Lower bound of grey band – point source in proximity of surface

From: J. Gómez-Ros et al. (2008)

Current approach – external exposure of terrestrial animals

External exposure of terrestrial organisms is modeled differently than that for aquatic organisms:

$$D^{\text{ext}} \sim K_{\text{air}}\, R$$

where R is a ratio of mean absorbed dose in the organism's body and mean air kerma in air, K_{air}.

The methodology is similar to that used for human external dosimetry.

Predefined set of organisms, interpolation on body mass.

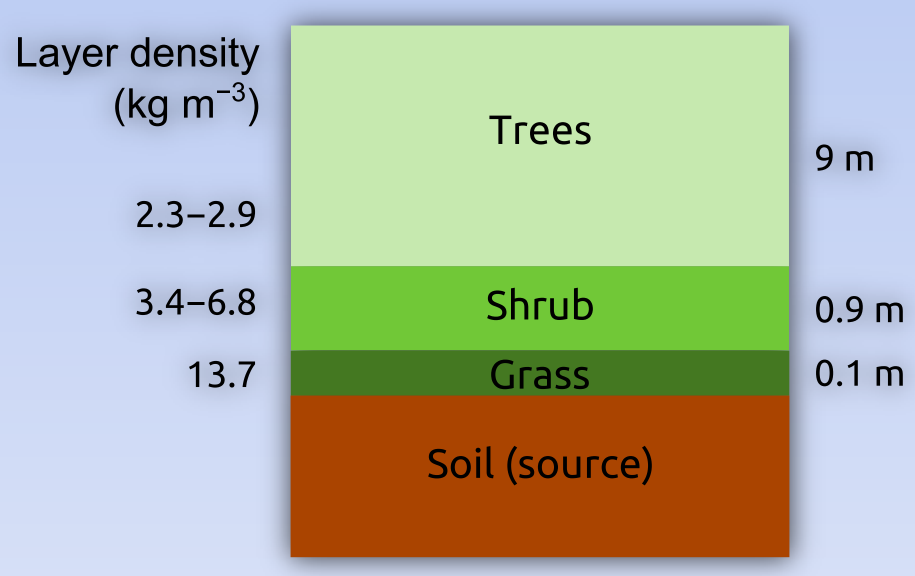
Four radiation sources considered:

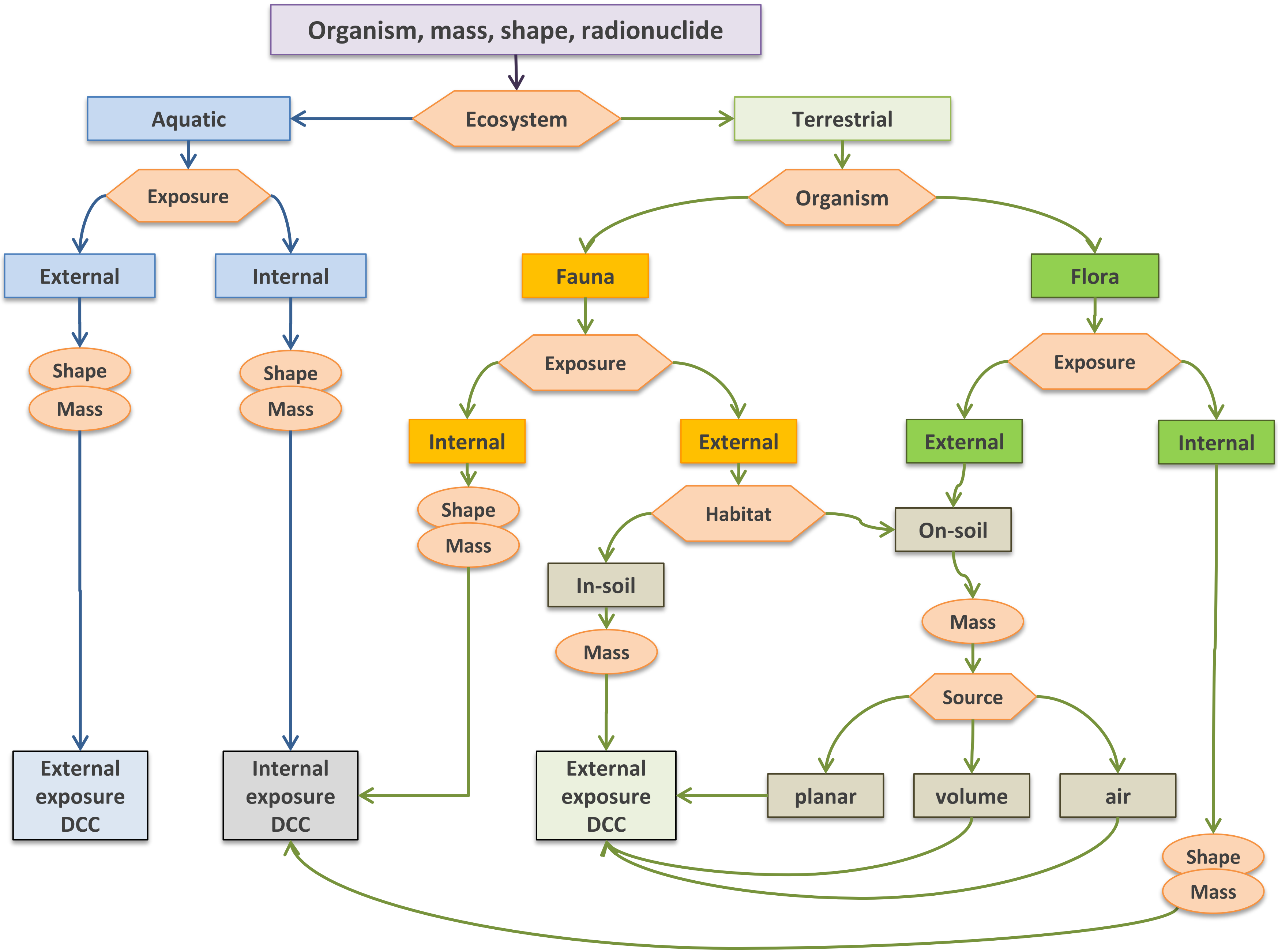
- 'fresh deposit' – effective planar source in soil at depth 0.5 g cm^{-2}
- 'aged deposit' – 10-cm-depth uniform volume sources in soil
- 50-cm-depth uniform volume source in soil (for "in-soil" exposure, only)
- submersion in contaminated air

Current approach – external exposure of terrestrial vegetation

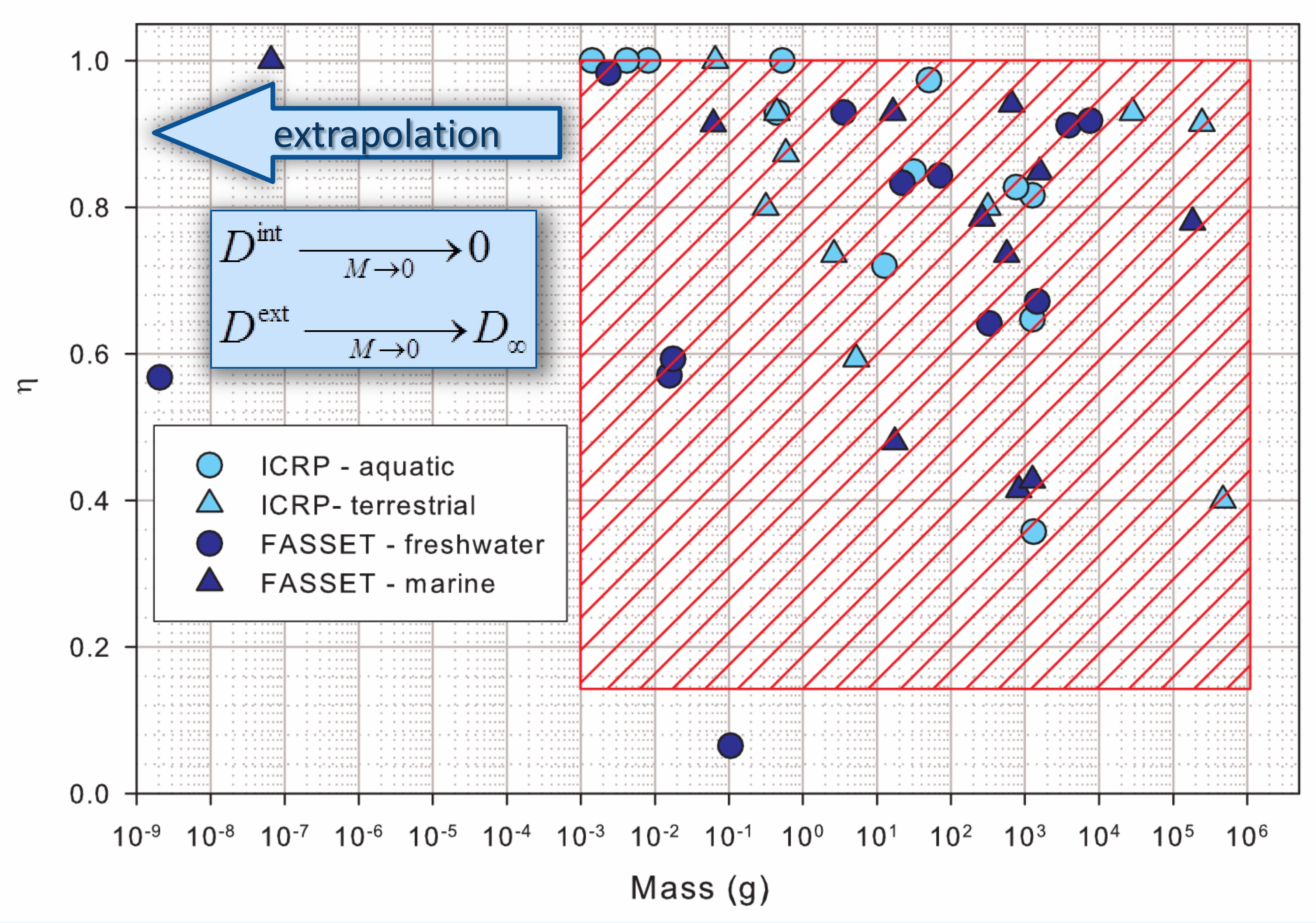
- External exposure of the terrestrial vegetation is assumed in very simplistic way; namely, for the three infinite homogeneous (**biomass**+**air**) layers, representing grasses, shrub, and trees

- Such simple models might become inadequate in a specific assessment
- Needs in reconsideration and, possibly, in an improvement




Organism, mass, shape, radionuclide
Ecosystem
Aquatic
Terrestrial
Exposure
External
Internal
Shape
Mass
Shape
Mass
External exposure DCC
Internal exposure DCC
Organism
Fauna
Flora
Exposure
Internal
External
Shape
Mass
Habitat
In-soil
Mass
On-soil
Mass
Source
planar
volume
air
External exposure DCC
Exposure
External
Internal
Shape
Mass

Masses and shapes covered



Implementation

- DCCs are calculated using special-purpose program, BiotaDCC
- This program in the form of external library is incorporated in the ERICA Accessment Tool (http://www.erica-tool.com/)
- The program outputs the whole body absorbed dose and fractions of it from different radiation types:

    (a) alpha-particles and fission fragments
    (b) low-energy electrons
    (c) high-energy electrons and photons

Radionuclides considered

- BiotaDCC uses the electronic version of ICRP Publication 38 (Eckerman et al. 1994) with emission data for 838 radionuclides
- Only short-lived ($T_{½}$<10 d) progeny in equilibrium with parent nuclide is considered
- Truncation of decay chain may be inappropriate for certain exposure scenarios.
- For certain radionuclides, the DCCs strongly depend on time (non-equilibrium conditions for parent and daughters)

Dose assessment (1)

External exposure:

- Time shares in various locations = ‘life-style’
- Contamination of these locations:
  - Uncertainty due to spatial variability of contamination
  - Uncertainty due to a scarcity of sampled data (contamination data are available only for certain locations not for the whole areal)
  - Uncertainty due to approximating real exposure conditions by simplified ‘source geometries’
  - Less uncertainty if contamination data are measured, higher uncertainty if they are implied or assessed from radioecological transfer models

Dose assessment (2)

Internal exposure

- Activity concentration in the body
  - Concentration ratios (CRs) are commonly used to derive activity concentration in the (whole) organism from activity concentration in the environment
  - Estimates of CR for many elements are missing or incomplete, while available CRs often have large uncertainties
  - CRs are defined for equilibrium condition

Use of CR is a very approximate way to assess activity concentration in the whole organism, uncertainty of this quantity is high

Dose assessment (3)

Internal exposure

- Use biokinetic modeling to assess activity concentration in the organism
- Even simplest single-compartment modeling will require to define:
  - Intake (depends on many environmental and biological parameters, i.e. additional uncertainty)
  - Uptake and retention (many parameters like biological half-lives are not well known for many animals and plants)

Allometric ‘laws’ can be helpful to approximate biological parameters

Some answers to typical misbeliefs…

- One does not need a special DCC for each and every exposure scenario. Instead, a dose assessment assumes that a specific exposure scenario is modeled as a superposition of simple basic exposure scenarios
- DCCs themselves are only part of a dose assessment. Other data used in the assessment may bring uncertainties, which considerably exceed those due to use of simplified dosimetric models
- Often, basic assumptions are forgotten or ignored. Examples are:
  - A request for bacteria's DCC – the organism is too small to be considered within assumptions of the conventional dosimetry
  - It is commonly forgotten that the DCC in the ICRP tabulations are given for parent nuclides and short-lived ($T_{1/2}$<10 d) daughters

Recent developments/work in progress

Task	Status
External exposures from contaminated air (cloudshine)	implemented
Inhalation of radionuclides by mammals	implemented, to be finalized
Inhomogeneous distributions (accumulation of radioactivity in certain critical organs or tissues of various animals or plants)	partially implemented, in progress
Impact of shapes (comparison of realistic voxel-based models with simple shape-based models)	in progress

Under discussion…

Task	Status
Expansion of ranges of body mass and heights above ground in modeling external exposure of terrestrial animals and plants to match those for aquatic organisms	planned
Transition from ICRP38 to ICRP 107	planned
External beta-exposure for terrestrial and aquatic organisms and protective properties of skin, fur or shell	???
Exposures to radon and thoron for plants and animals	???
Improvement of external exposure assessment for terrestrial plants	???

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Thank you for attention!