Heterogeneous distribution of radionuclides and internal dosimetry

J.M. Gómez-Ros

Internal exposure: whole body absorbed dose

"A **Reference Animal or Plant** is a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism."

ICRP Publication 108. Ann. ICRP 38 (4-6), 2008 (paragraph 23)

"A key quantity for estimating internal dose is the absorbed fraction, ϕ, which is defined as the fraction of energy emitted by a radiation source that is absorbed within the target tissue, organ, or organism. In the simplest case, the organism is assumed to be in an infinite homogeneous medium, with activity uniformly distributed throughout its body (…). Under these conditions, **internal dose conversion factors** ($DCF^{internal}$), defined as absorbed dose rate per activity concentration within the organism for mono-energetic radiation can be expressed as a function of the **absorbed fraction**:

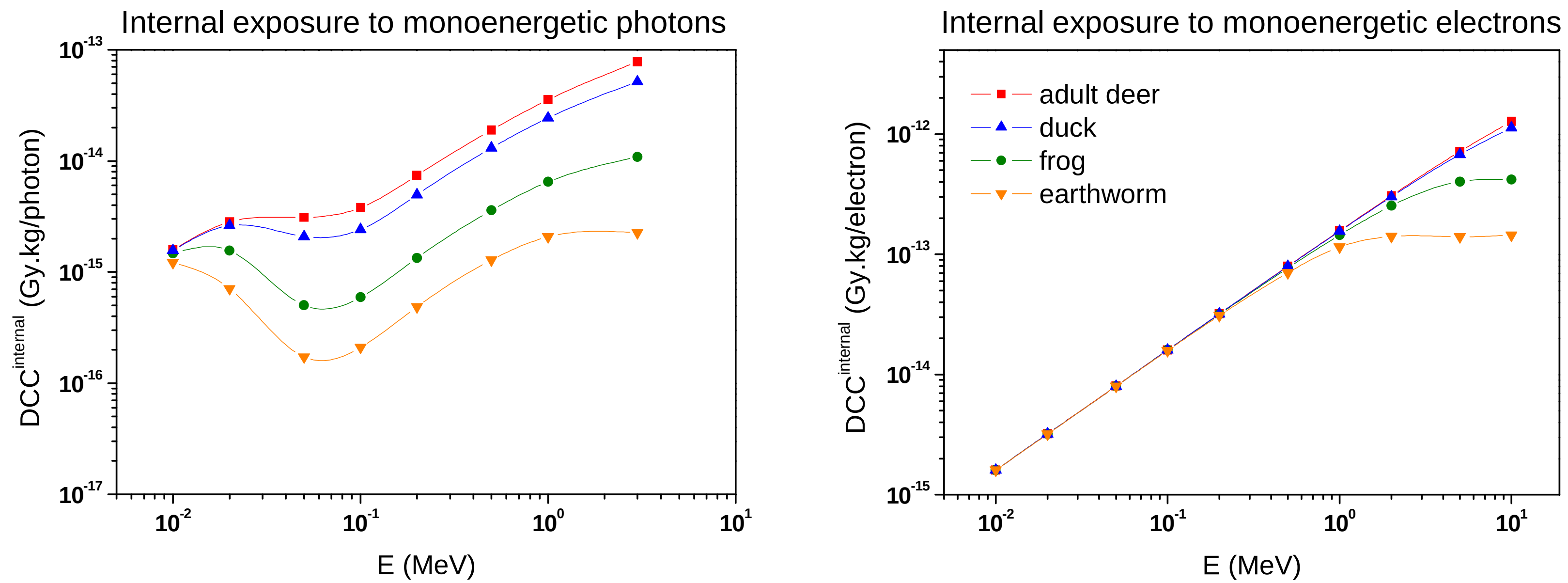
$$DCF^{internal}(E) = \phi(E) \times E"$$

ICRP Publication 108. Ann. ICRP 38 (4-6), 2008 (paragraph 79)

Dose Conversion Coefficients (DCC) for internal dosimetry

to assess absorbed dose rates due to internal contamination in reference animals and plants

$$\dot{D}_{body}^{internal} = DCC^{internal} \times A_{M,body}$$



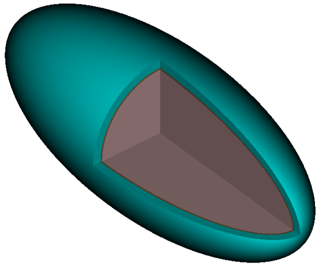
"A **Reference Animal or Plant** is a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism."

ICRP Publication 108. Ann. ICRP 38 (4-6), 2008 (paragraph 23)

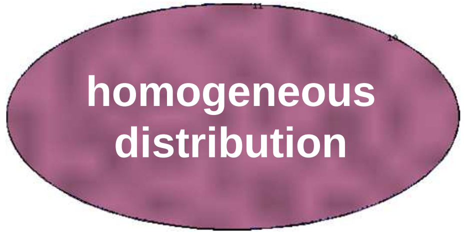
Dose Conversion Coefficients (DCC) for internal dosimetry

to assess absorbed dose rates due to internal contamination in reference animals and plants

(1)



(2)



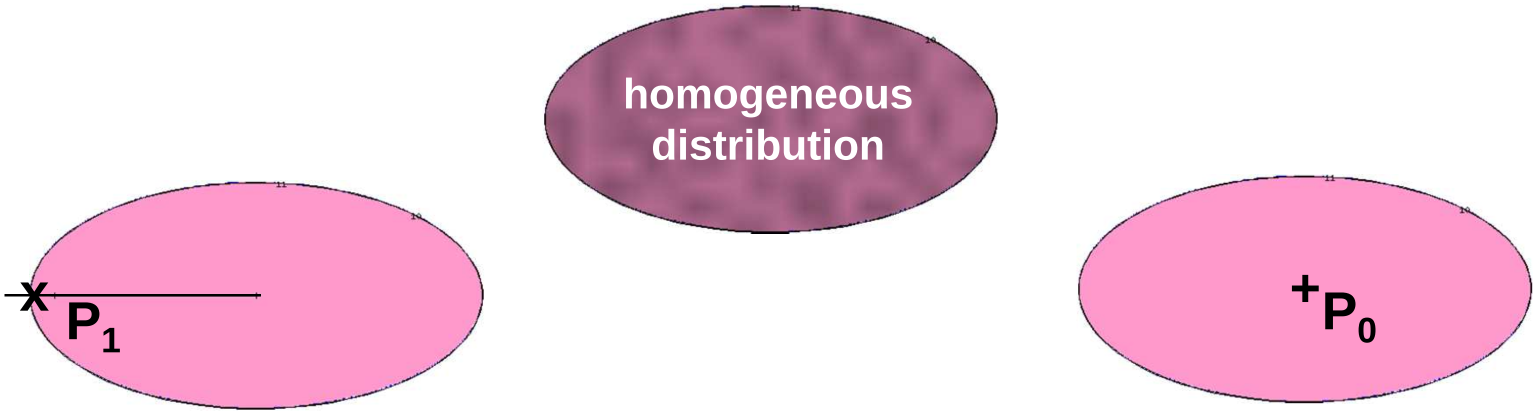
$$DCC^{internal}(E) = \frac{\dot{D}_{body}^{internal}(E)}{A_{M,\,body}(E)} = \frac{whole\ \ body\ \ internal\ absorbed\ \ dose\ \ rate\ \ (Gy\ s^{-1})}{whole\ \ body\ \ activity\ \ concentration\ \ (s^{-1}\ kg^{-1})}$$

$$DCC^{internal}(E) = \phi(E) \times E$$

[A. Ulanovsky et al. J. Environ. Radioact. 99 (2008) 1440-1448]

Standard uncertainty of $DCC^{internal}(E)$

Due to inhomogeneous distribution of radionuclides



eccentric point source P_1
(maximum axial distance)
minimum absorbed fraction

central point source P_0

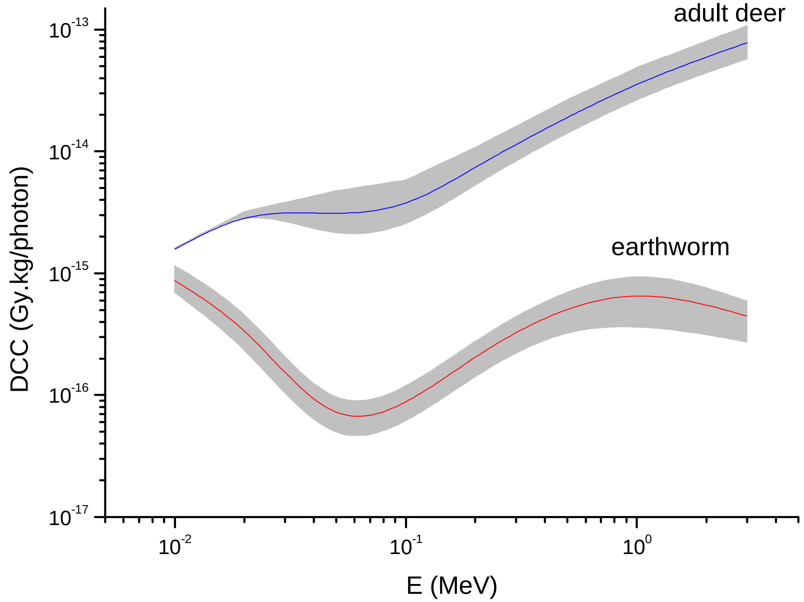
maximum absorbed fraction

Assuming a rectangular probability distribution funciont (pdf) of DCCs values between minimum and maximum values, the standard uncertainty is:

$$u(DCC^{internal}_{homogeneous}) = \frac{\left(DCC^{internal}_{central\ point} - DCC^{internal}_{eccentric\ point}\right)}{2\sqrt{3}}$$

[J.M. Gómez-Ros et al. J. Environ. Radioact. 99 (2008) 1449-1455]

Standard uncertainty of *DCF*^{internal}(*E*) for photons



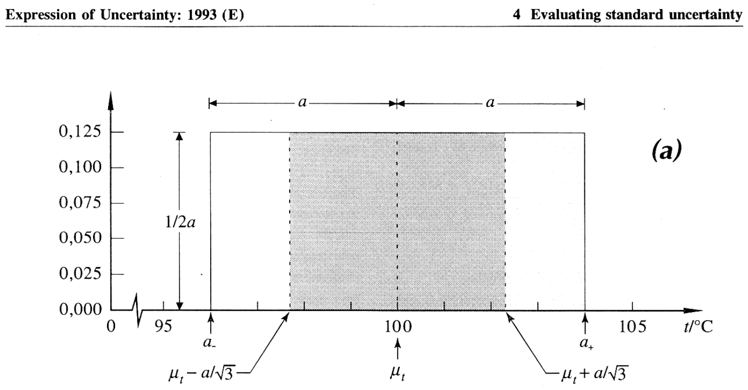


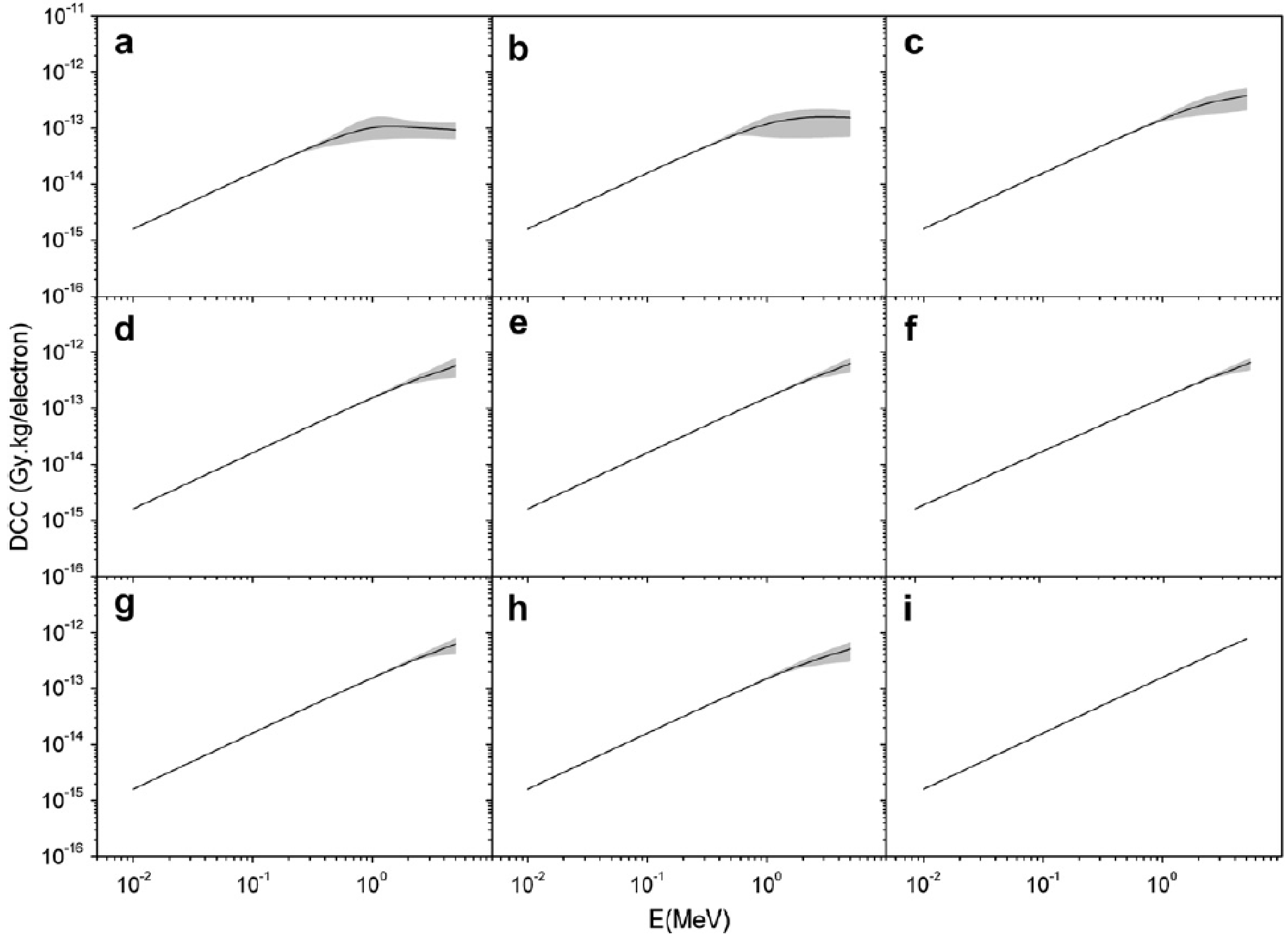
Figure 2. Graphical illustration of evaluating the standard uncertainty of an input quantity from an a priori distribution

Assuming a **rectangular probability distribution function (pdf)** of DCCs values between minimum and maximum values (eccentric and central point, respectively), it is possible to calculate the associated **standard uncertainty** for the homogeneous distribution values of DCC:

photons	stand. uncert.	
E (MeV)	adult deer	earthworm
0,01	0%	13%
0,02	1%	24%
0,05	15%	25%
0,1	21%	24%
0,2	21%	24%
0,5	20%	25%
1	20%	29%
2	20%	30%
5	21%	27%

[J.M. Gómez-Ros et al. J. Environ. Radioact. 99 (2008) 1449-1455]

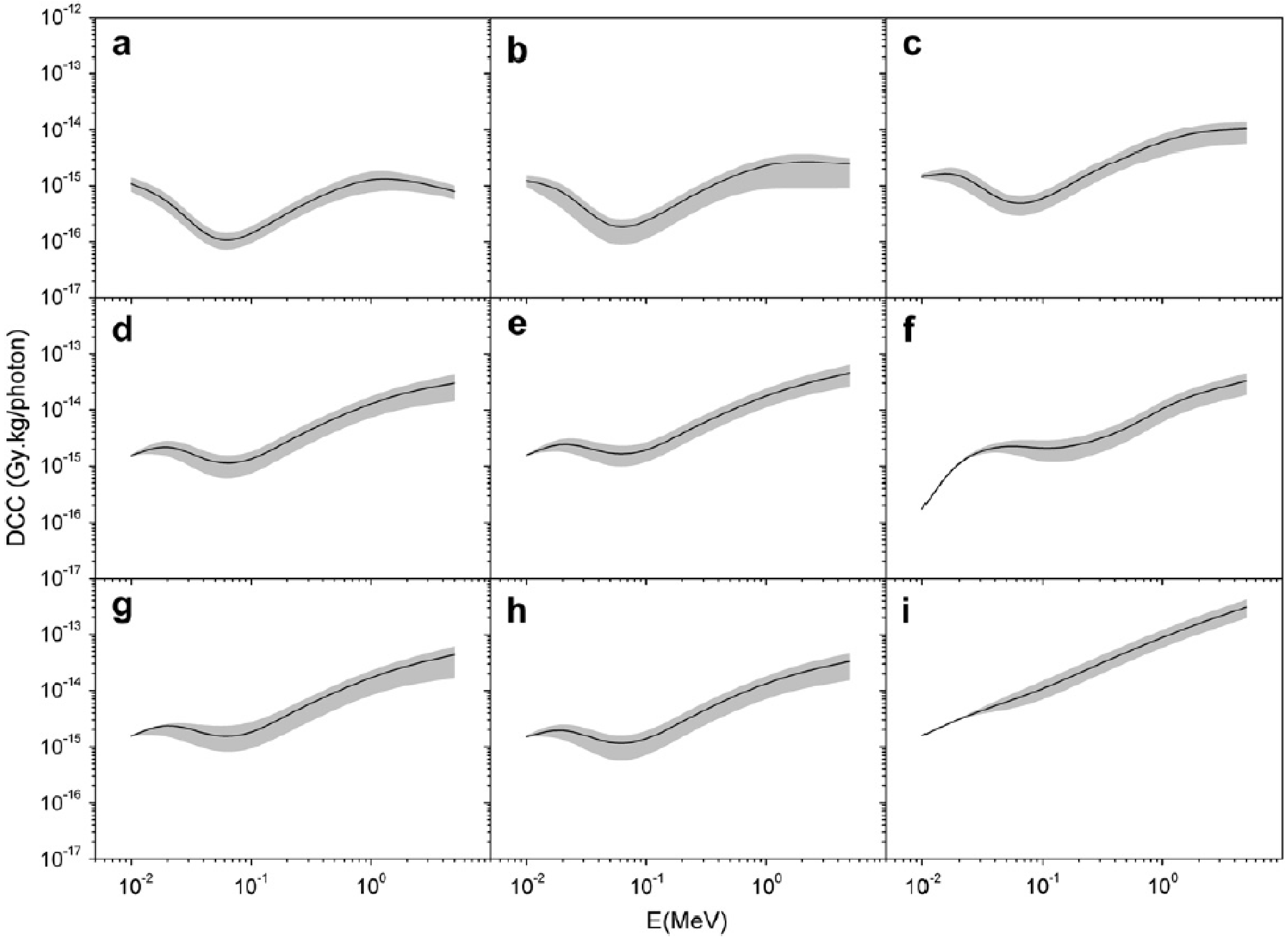
DCC^{internal}(*E*) for electron emitters



Energy dependence of electron *DCC*^{internal}(*E*) for the reference animals:(a) tadpole, (b) earthworm, (c) frog, (d) rat, (e) crab, (f) duck, (g) trout, (h) flatfish and (i) adult deer

[J.M. Gómez-Ros et al. J. Environ. Radioact. 99 (2008) 1449-1455]

$DCC^{internal}(E)$ for photon emitters



Energy dependence of photon $DCC^{internal}(E)$ for the reference animals:(a) tadpole, (b) earthworm, (c) frog, (d) rat, (e) crab, (f) duck, (g) trout, (h) flatfish and (i) adult deer

[J.M. Gómez-Ros et al. J. Environ. Radioact. 99 (2008) 1449-1455]

Standard uncertainty of $DCC^{internal}(E)$ for photon emitters

E_{photon} (MeV)	earthworm	frog	rat	duck	adult deer
0.01	13%	5%	1%	≈ 0	≈ 0
0.02	24%	21%	17%	13%	1%
0.05	25%	21%	24%	24%	15%
0.1	24%	21%	23%	23%	21%
0.2	24%	21%	22%	23%	21%
0.5	25%	21%	22%	22%	20%
1	29%	22%	22%	22%	20%
2	30%	25%	24%	23%	20%
5	27%	23%	27%	26%	21%

Standard uncertainty of $DCC^{internal}(E)$ for electron emitters

$E_{electron}$ (MeV)	earthworm	frog	rat	duck	adult deer
0.01	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
0.02	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
0.05	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
0.1	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
0.2	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
0.5	1%	≈ 0	≈ 0	≈ 0	≈ 0
1	22%	5%	≈ 0	≈ 0	≈ 0
2	27%	17%	6%	1%	0.1%
5	26%	24%	22%	13%	0.2%

[J.M. Gómez-Ros et al. J. Environ. Radioact. 99 (2008) 1449-1455]

Internal exposure: organ absorbed dose

"Two cases can therefore be considered. In the first case, a radionuclide with activity, A (Bq) is distributed homogeneously throughout the entire body of the organism of mass, m_{wb}. In the second case, the same activity is concentrated in an organ of mass, m_{org}. Under these conditions, and ***when the absorbed fractions for emitted energies are equal to unity***, it can be shown that:

$$\frac{D_{org}}{D_{wb}} = \frac{m_{wb}}{m_{org}}$$

where D is the absorbed dose and m is the mass of the whole body and the organs considered. This relationship is valid for organisms and organs which are large enough to justify the assumption of an absorbed fraction for both alpha and beta radiation."

ICRP Publication 108. Ann. ICRP 38 (4-6), 2008 (paragraph 116)

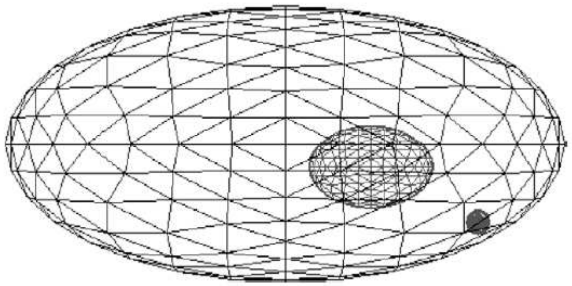
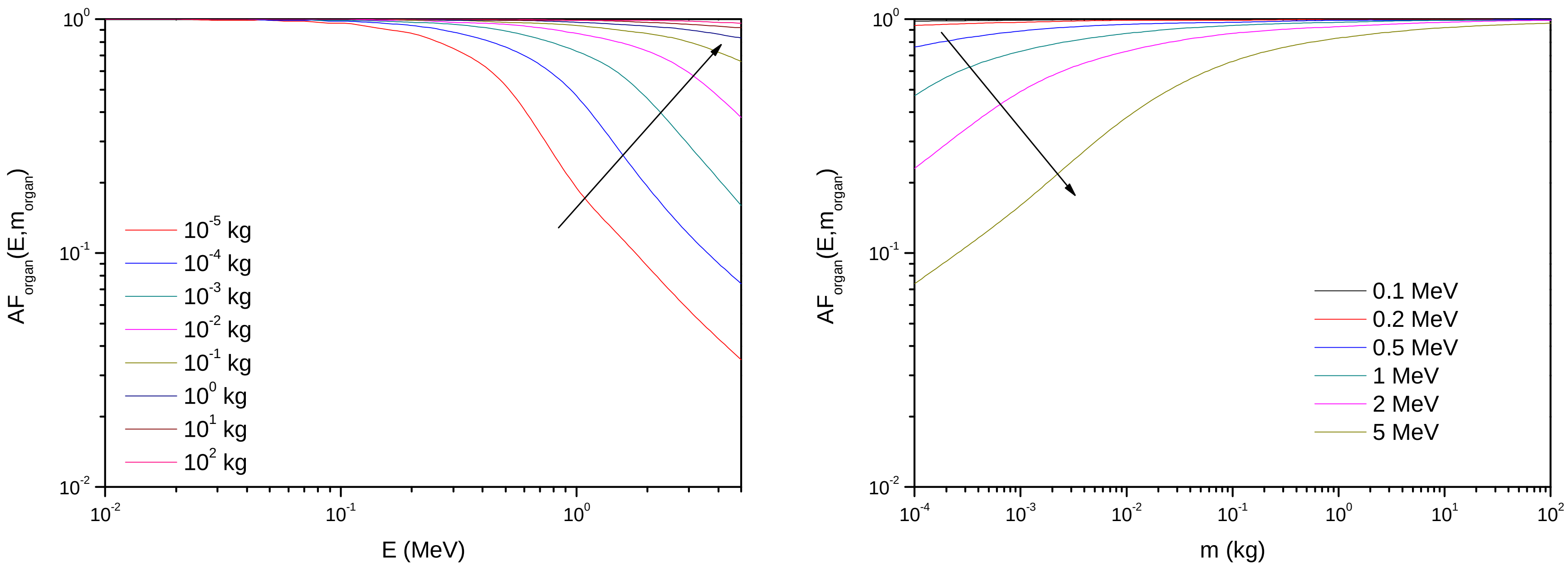


Fig. 4.4. Geometrical model of deer body with liver (large inner ellipsoid) and testes (small inner ellipsoid).

Organ absorbed dose (electrons)

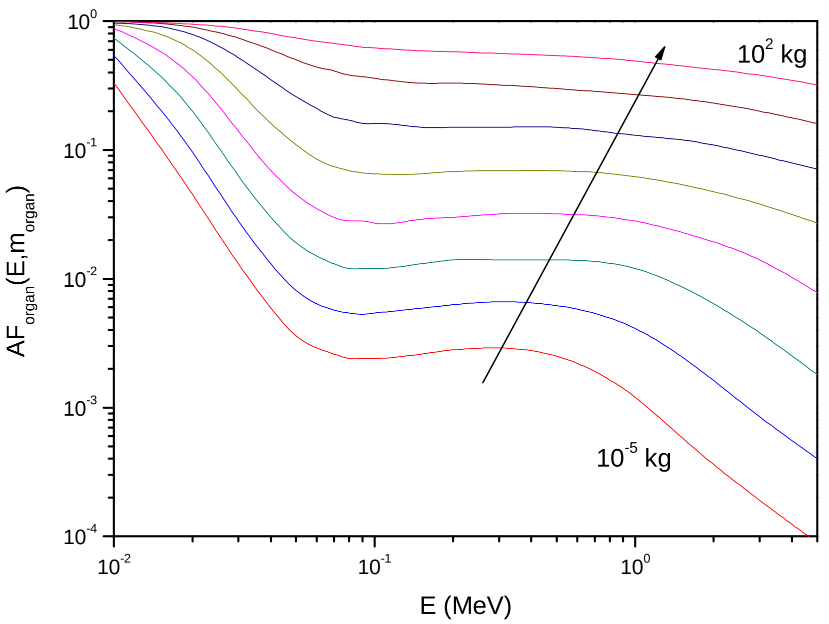


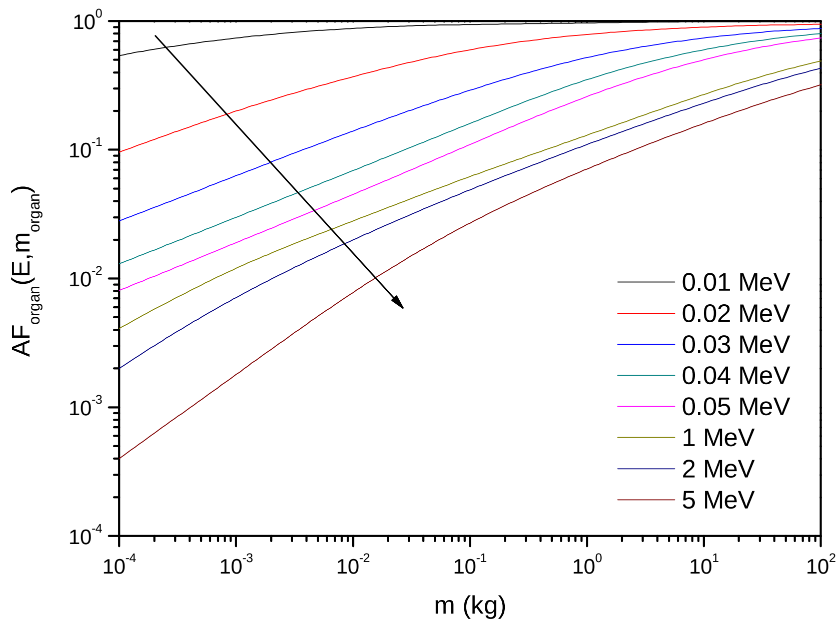
Spherical organ in effectively infinite infinite media

$$\dot{D}_{organ} = E \times AF_{organ}(E, m_{organ}) \times A_{M,organ}$$

If $AF_{organ} \approx 1$ $$\dot{D}_{organ} \approx \dot{D}_{body} \times \frac{m_{body}}{m_{organ}}$$

Organ absorbed dose (photons)





Spherical organ in effectively infinite infinite media

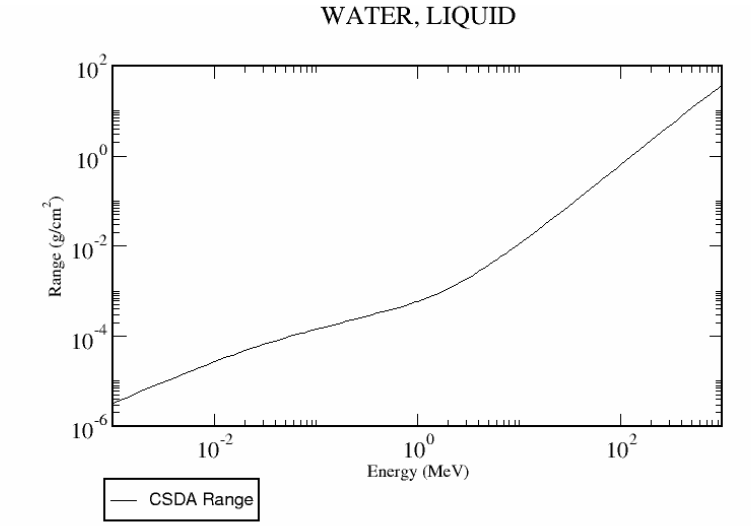
$$\dot{D}_{organ} = E \times AF_{organ}(E, m_{organ}) \times A_{M,organ}$$

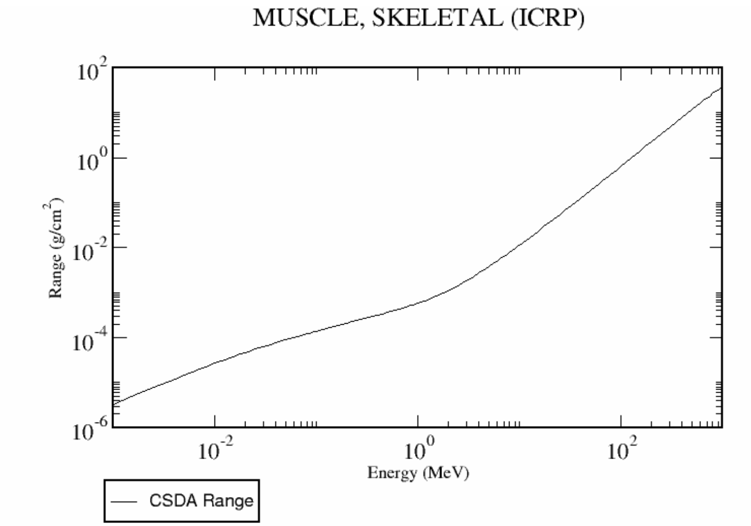
Organ absorbed dose (alpha)

Due to the very short range of alpha radiation in water and soft tissue, it can be assumed that *AF* ≈ 1. Then, for a given alpha emitter:

$$\dot{D} = A_M \sum_{\alpha} E_\alpha y_\alpha$$

A_M is the activity density (in Bq/kg)
E_α is the emission energy
y_α is the emission yield

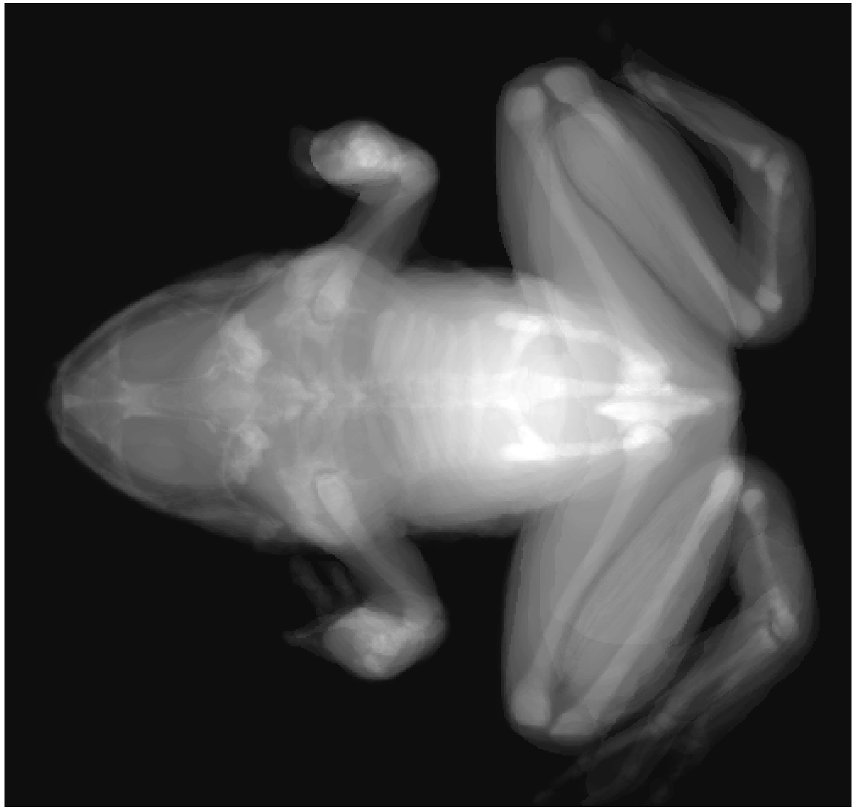


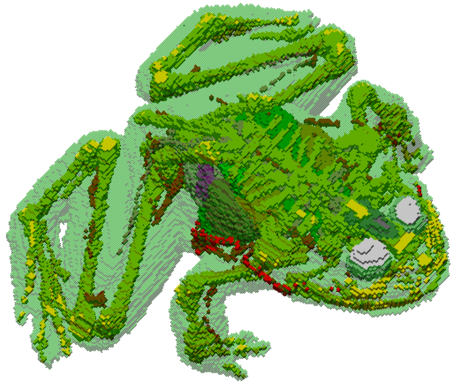


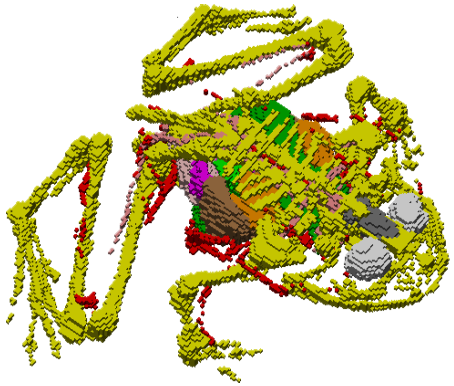
FROG voxel phantom

	original frog phantom[1]	scaling factor	FROG voxel phantom	ICRP ref. animal ‘FROG’
major axis (mm)	~ 86 – 103*	0.7	~ 60 – 72*	80
1st minor axis (mm)	~ 43	0.6	~ 26	30
2nd minor axis (mm)	~ 29	0.74	~ 21	25
body mass (g)	101.14	0.31	31.06	31.4

* depending on whether or not the legs are included



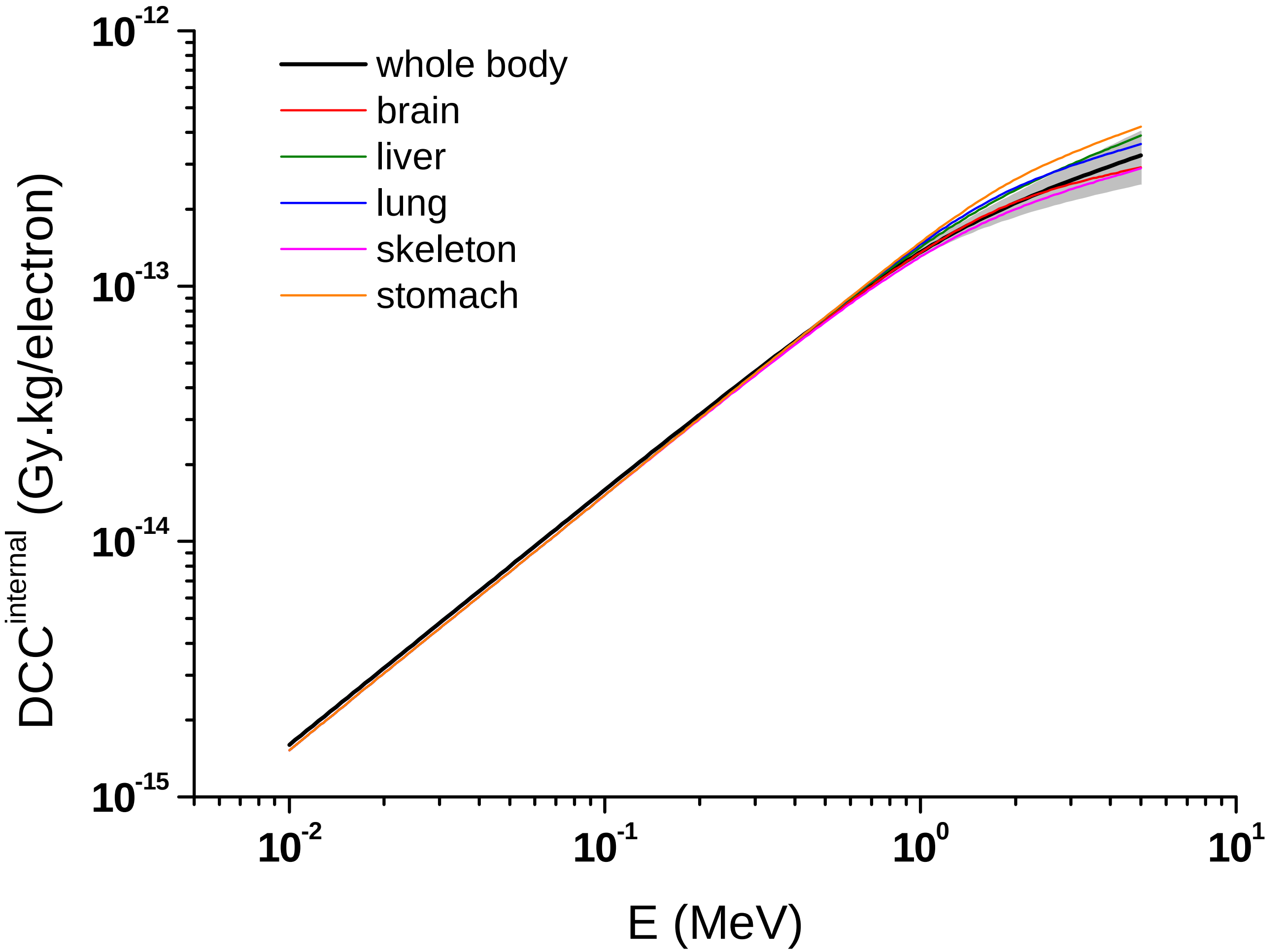




[1]**S. Kinase. Frog phantom for internal dose evaluation. J. Nucl. Sci. Technol. 45(10), 1049-1052 (2007).**

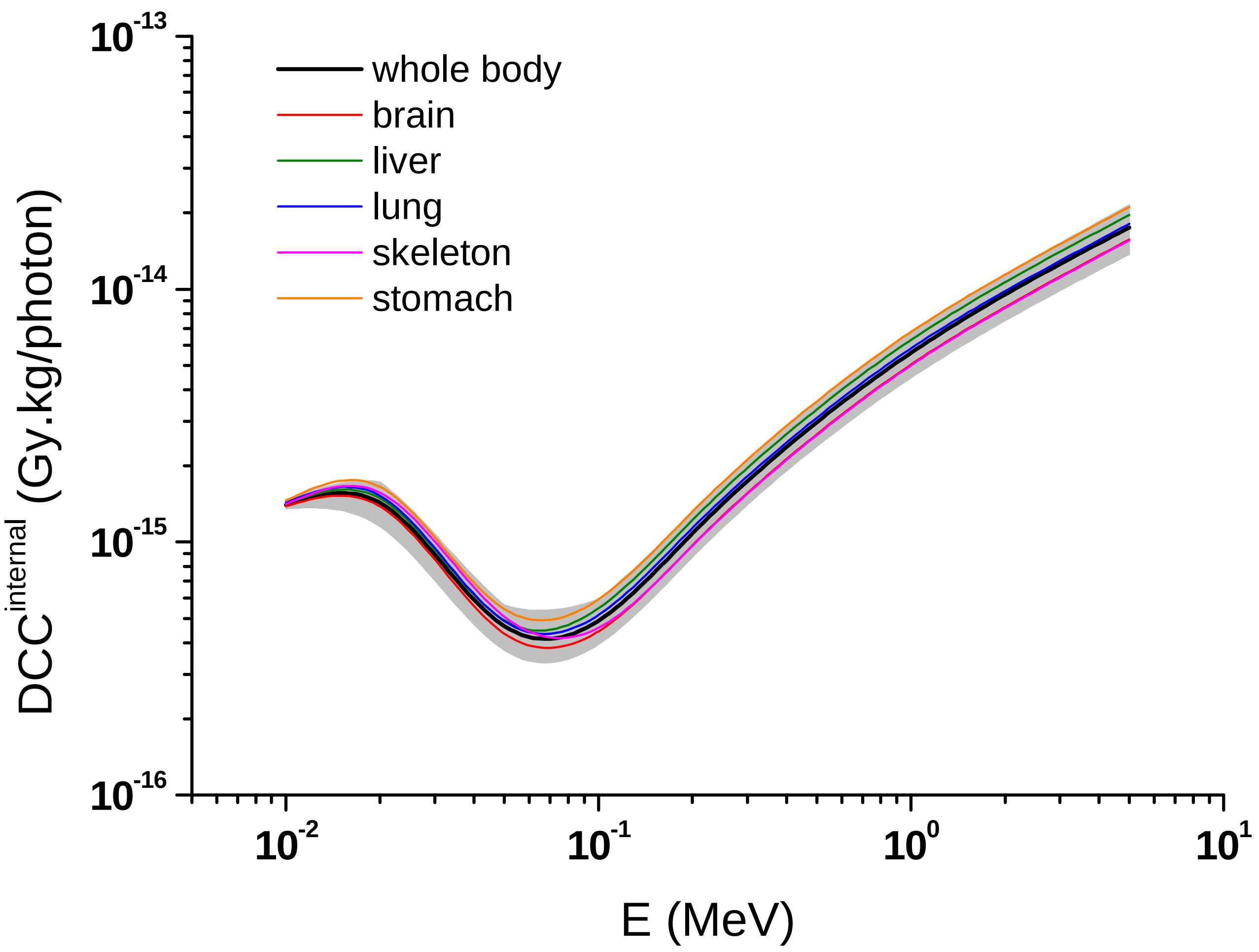
FROG voxel phantom

Whole body *DCC^{internal}*, target: whole body, electron source in a given organ



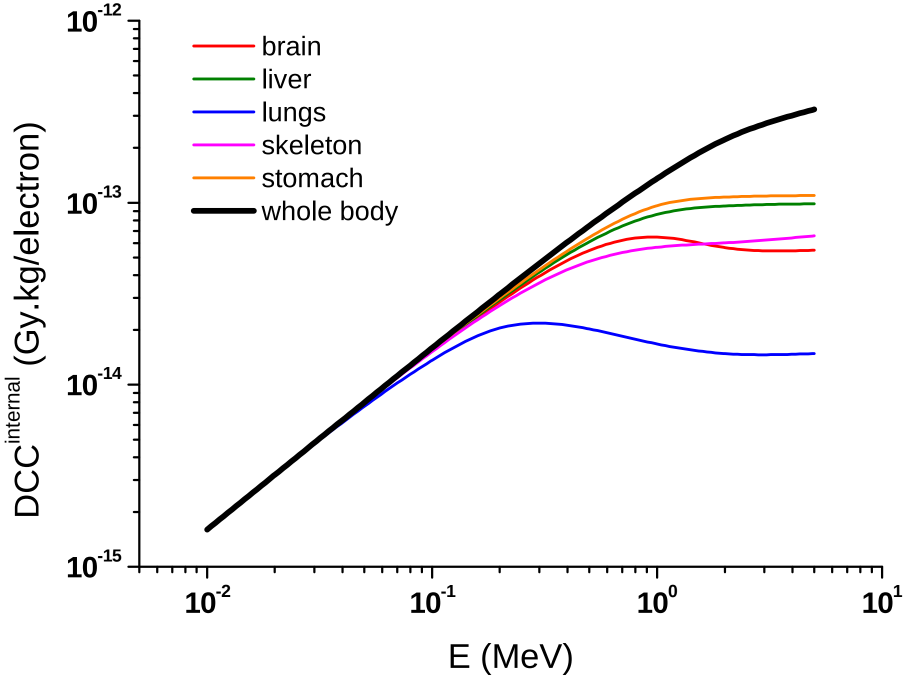
FROG voxel phantom

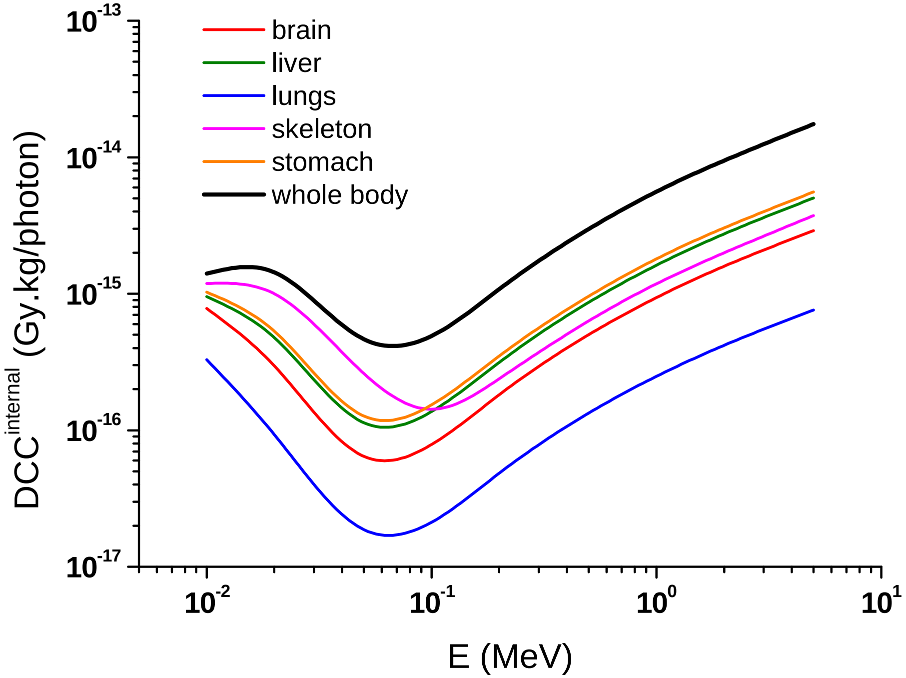
Whole body *DCC^internal*, target: whole body, photon source in a given organ



FROG voxel phantom

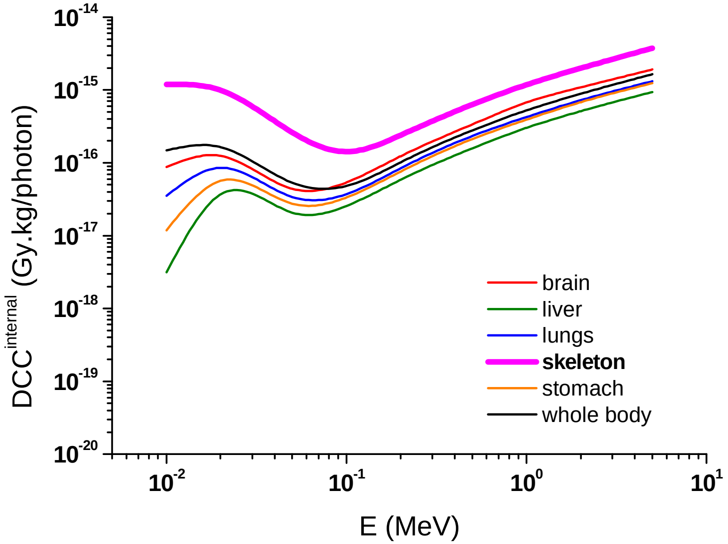
Organ vs. whole body $DCC^{internal}$
target and source organs are the same

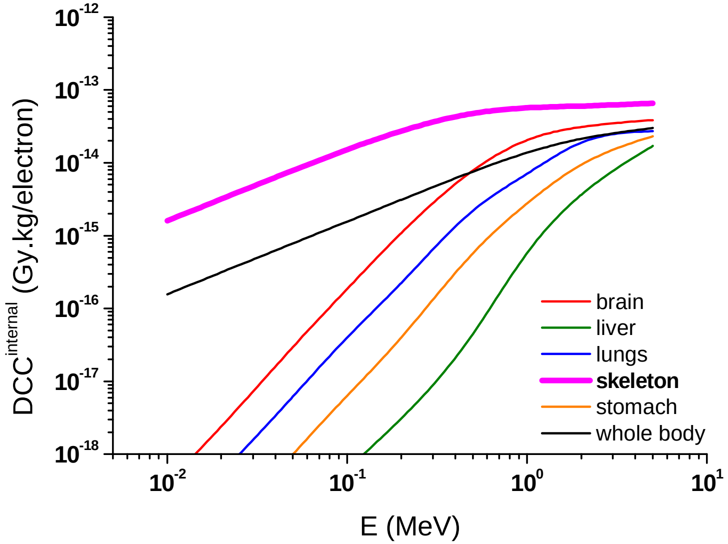




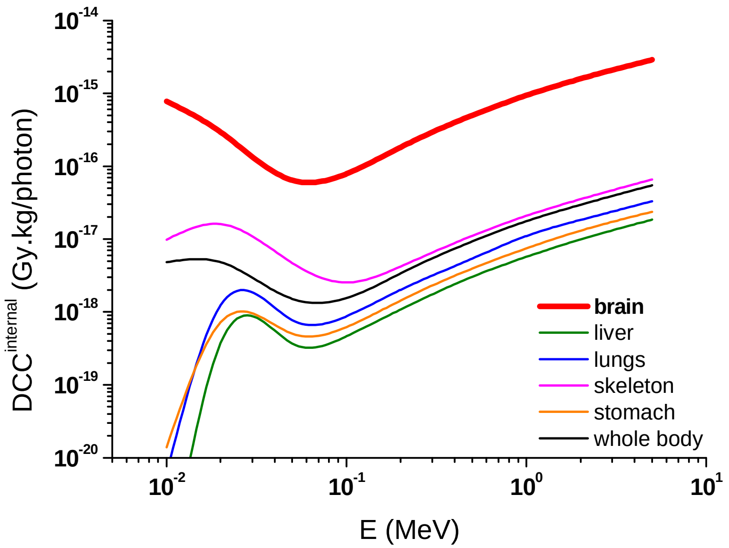
FROG voxel phantom

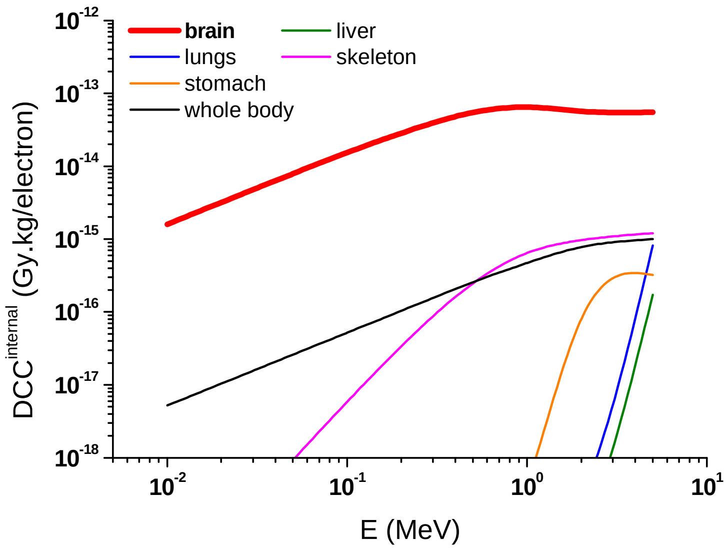
source organ: skeleton





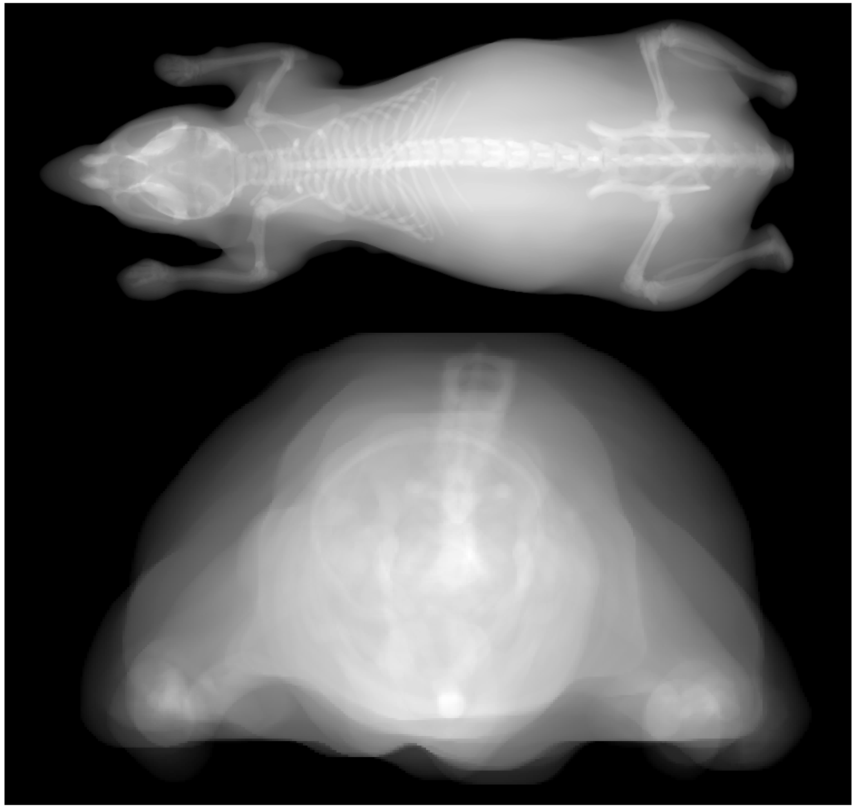
source organ: brain

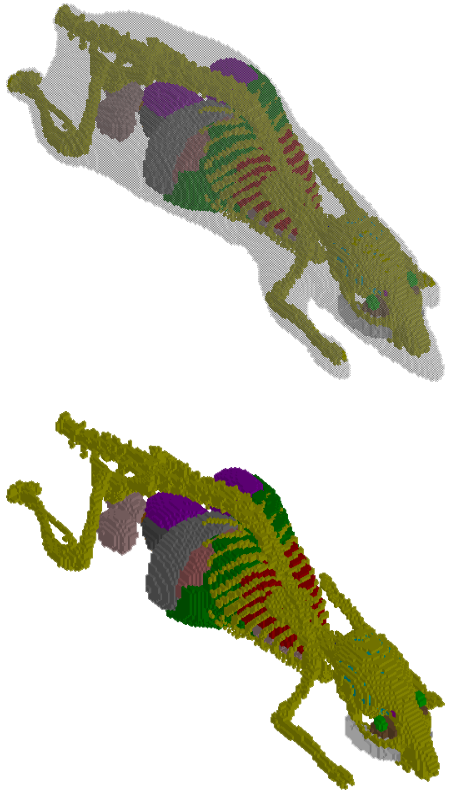




RAT voxel phantom

	original mouse phantom[1,2]	scaling factor	RAT voxel phantom	ICRP ref. animal 'RAT'
major axis (mm)	~ 82	2.4	~ 200	200
1st minor axis (mm)	~ 28	2.1	~ 60	60
2nd minor axis (mm)	~ 18	2.8	~ 50	50
body mass (g)	23.39	14.1	312	314





[1]B. Dogdas et al. Digimouse: a 3D whole body mouse atlas from CT and cryosection data. Phys. Med. Biol. 52, 577-587 (2007).
[2]S. Kinase et al. Evaluation of self-absorbed doses for kidneys of a voxel mouse. J. Nucl. Sci. Technol. Suppl. 5, 268-270 (2008).

Discussion points

- ✓ Homogeneous distribution of radionuclides in reference animals and plantas may not be always a realistic assumption (e.g. ^{131}I in thyroid, ^{222}Rn in lungs, ^{90}Sr and ^{226}Ra in bone).
- ✓ Absorbed fraction $\phi \approx 1$ is only valid when size is bigger than the range of secondary electrons (alpha, low energy electrons and photons).
- ✓ Whole body absorbed dose can be calculated using the average whole body activity concentration and the homogeneous DCC with a certain uncertainty (up to 30% in case of small reference animals), is this acceptable?
- ✓ Specific organ absorbed dose can be higher than whole body absorbed dose (and relationship is dependent on ϕ). How much detail should be considered?
- ✓ Is it worthwhile to consider voxel phantoms for reference animals and plants? Moreover, could there not be a contradiction between the concept of reference animal or plant (hypothetical entity) and a voxel phantom (real individual)?

(23) "A **Reference Animal or Plant** is a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism." [ICRP Publication 108. Ann. ICRP 38 (4-6), 2008]