ICRP Transfer Group Report

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IAEA EMRAS II, WG-5, 8th Sep. 2010

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Background

- **TG 73 Transfer Factor Values for estimating exposures of RAPs in environmental modelling contexts**
  - Annals of the ICRP “Environmental Protection: Transfer parameters for Reference Animals and Plants”
- Per Strand – TG leader; Beresford, Copplestone, Yankovich, Godoy, Jianguo, Brown
- Several years work, builds on :
  - ICRP, 2008. Environmental Protection: the Concept and Use of Reference Animals and Plants. ICRP Publication 108. Ann. ICRP 38 (4-6).
  - ERICA
  - IAEA EMRAS

Report Outline

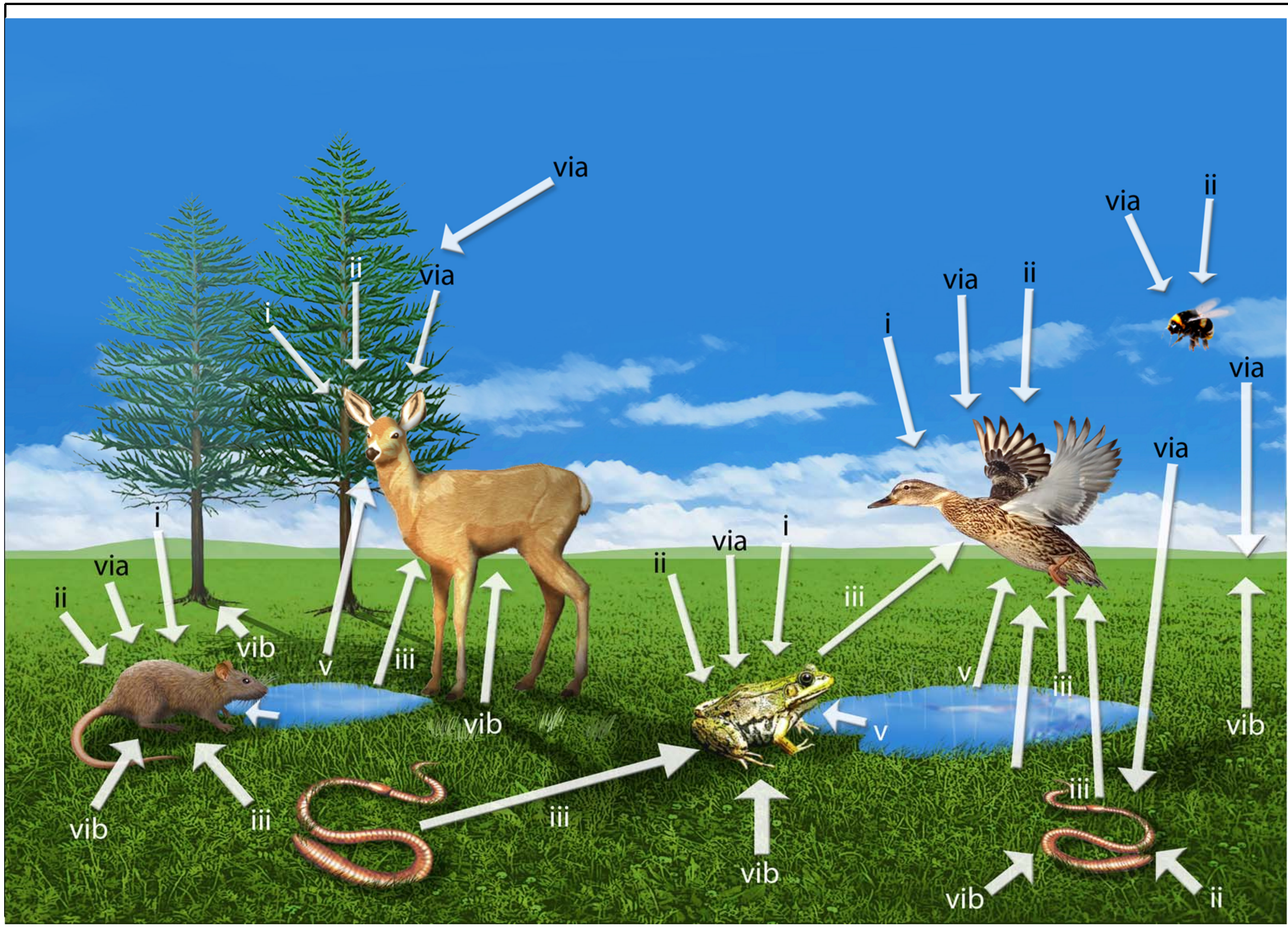
Aims

- The Commission's radiation protection framework has recently been expanded to encompass the objective of protecting the environment
  - aims of preventing or reducing the frequency of deleterious radiation effects 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 (ICRP, 2007).
- In many cases the extent to which animals and plants are exposed to radiation can be determined directly; but for planning and other theoretical exercises it can not, and such exposures therefore need to be estimated. And central to the derivation of such estimates of exposure is the need to model the transfer of radionuclides in a robust manner.
- What is missing, therefore, is a set of reference data values that could be used to estimate the extent to which such types of organisms would be exposed to external and internal exposure in relation to different release rate scenarios in the aquatic and terrestrial environments.
- The report is intended to fill this gap.

Background

- **Physical and chemical processes**
  - Initial release – advection and dispersion
  - Physical interaction with matter (gravitational settling of suspended particulate material; precipitation scavenging, impaction, chemical sorption and exchange)
  - Wet and dry deposition; washoff (terrestrial)
  - Migration in the environment through leaching (in e.g. soils), bioturbation and sediment redistribution (lakes rivers)
  - Influence of geochemical phase associations and chemical environment (e.g. redox)
- **Biological accumulation and food chain transfer**
  - Initial uptake and transfer to plants (root, foliar, plant surfaces)
  - Transfer through trophic levels; primary producers➔ herbivores➔ carnivores.
  - Transfer via gills and GIT, dependence of uptake on physicochemical form

Exposure Pathways



(i) Inhalation of (re)suspended contaminated particles or gaseous radionuclides.

(ii) Contamination of fur, feathers, skin and vegetation surfaces.

(iii) Ingestion of lower trophic level plants and animals.

(iv) Direct uptake from the water column, in the case of truly aquatic organisms (e.g. fish, molluscs, crustaceans, macrolagae and aquatic macrophytes),

(v) Ingestion of contaminated water; For plants - root uptake of water.

(vi) External exposure.

Which radioisotopes ?

Ag	Silver	Ag-110	Nb	Niobium	Nb-94, Nb-95
Am	Americium	Am-241	Ni	Nickel	Ni-59, Ni-65
Ba	Barium	Ba-140	Np	Neptunium	Np-237
C	Carbon	C-14	P	Phosphorus	P-32, P-33
Ca	Calcium	Ca-45	Pa	Protactinium	Pa-231
Cd	Cadmium	Cd-109	Pb	Lead	Pb-210
Ce	Cerium	Ce-141, Ce-144	Po	Polonium	Po-210
Cf	Californium	Cf-252	Pu	Plutonium	Pu-238, Pu-239, Pu-240, Pu-241
Cl	Chlorine	Cl-36	Ra	Radium	Ra-226, Ra-228
Cm	Curium	Cm-242, Cm-243, Cm-244	Ru	Ruthenium	Ru-103, Ru-106
Co	Cobalt	Co-57, Co-58, Co-60	S	Sulphur	S-35
Cr	Chromium	Cr-51	Sb	Antimony	Sb-124, Sb-125
Cs	Caesium	Cs-134, Cs-135, Cs-136, C 137	Se	Selenium	Se-75, Se-79
Eu	Europium	Eu-152, Eu-154	Sr	Strontium	Sr-89, Sr-90
H	Tritium	H-3	Tc	Technetium	Tc-99
I	Iodine	I-125, I-129, I-131, I-132, I-133	Te	Tellurium	Te-129m, Te-132
Ir	Iridium	Ir-192	Th	Thorium	Th-227, Th-228, Th-230, Th-231, Th-232, Th-234
K	Potassium	K-40	U	Uranium	U-234, U-235, U-238
La	Lanthanum	La-140	Zn	Zinc	Zn-65
Mn	Mangenese	Mn-54	Zr	Zirconium	Zr-95

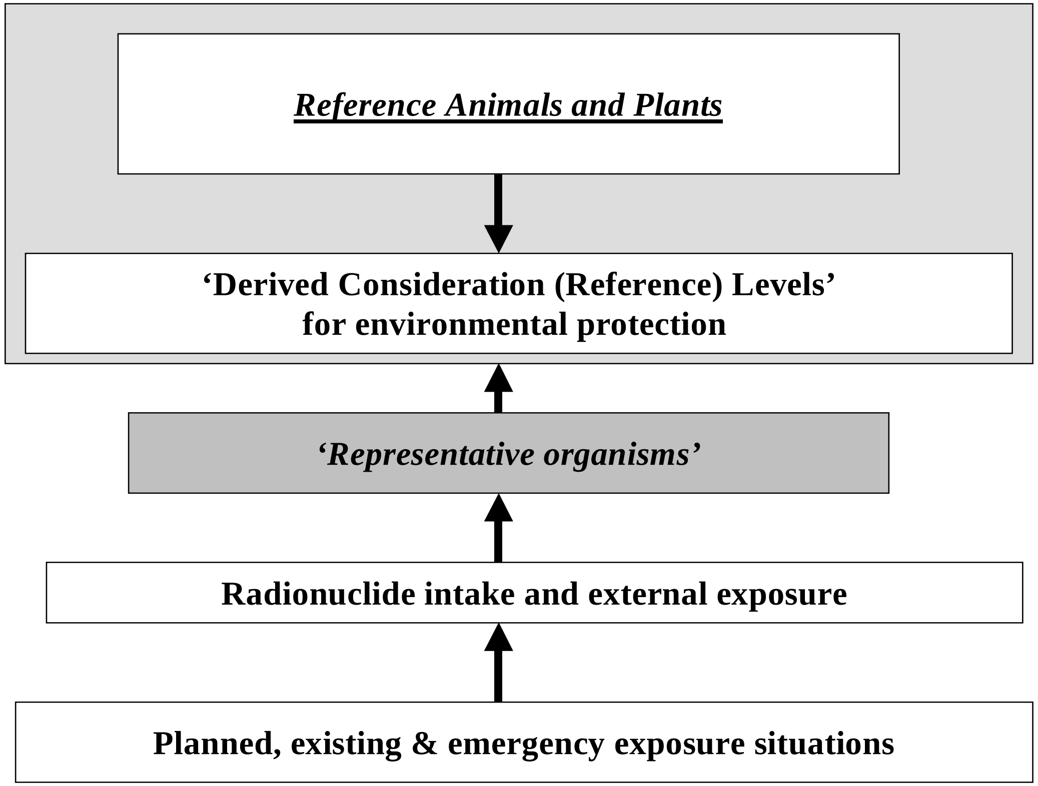
Reference animals and plants - definition

A Reference Animal and Plant is defined as:

- *'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.'*

Relationships of various points of reference for protection of the environment (from ICRP, 108)

- Any specific evaluation of the radiation exposure of animals and plants will normally be carried out for specific reasons, in order to ‘comply’ or otherwise satisfy specific national or international environmental protection requirements.
- In many cases the representative organisms chosen for this purpose may be the same as, or very similar to, the Reference Animals and Plants; but in some cases they may be very different



Consideration of various methods to 'model' transfer

- CRs $$CR = \frac{Activity\ concentration\ in\ biota\ whole\ body\ (Bq\ kg^{-1}\ fresh\ weight)}{Activity\ concentration\ in\ soil\ (Bq\ kg^{-1}\ dry\ weight\ (dw))}$$
- Allometry – biological scaling $$Y = aM^b$$
- Dynamic transfer – biokinetic approaches $$\frac{\partial C_{r,m}}{\partial t} = \sum_{i=1}^{i=n} \left(x_i . AE_{r,i} . IR . C_{r,i}\right) - C_{r,m} . k_{r,em}$$
- Data gap filling approaches –
  - taxonomic analogues (sub-set of CRs)
  - Biogeochemical analogues,

Concentration ratios

- For pragmatic reasons transfer collation based around CRs
- ‘Wildlife transfer database’

  web address: [http://www.wildlifetransferdatabase.org])
- ERICA databases + IAEA EMRAS WG
  - e.g. Canadian assessments (CanNorth, 2005), Japan NIRS, Fesenko-Russian data etc.)

Categorisation of Reference Animal and Plants

Table 3.1 The ICRP Reference Animal and Plants and their life-stages and specified taxonomic Family as identified by ICRP (2008). The table also list species for which data are available within the Family groups.

Reference Animal and Plant	*Ecosystem*	*Family*	*Species for which data are available*
Deer	Terrestrial	Cervidae	*Alces alces; Capreolus capreolus; Cervus elaphus; Odocoileus hemionus; O. virginiannus*
Calf	Terrestrial		
Adult Deer	Terrestrial		
Rat	Terrestrial	Muridae	*Apodemus flavicollis; A. sylvaticus; Hydromys chrysogaster; Peromyscus leucopus; P. maniculatus; Rattus rattus*
Duck	Terrestrial, Freshwater	Anatidae	*Anas crecca; A. penelope; A. Platyrhynchos; Anseres spp.; Cygnus olor; Mergus merganser; Somateria mollissima*
Duck egg	Terrestrial		
Adult duck	Terrestrial, Freshwater		
Frog	Terrestrial, Freshwater	Ranidae	*Rana arvalis; R. catesbeiana; R. clamitans; R. esculenta; R. palustris; R. pipiens; R. temporia; R. terrestris*
Frog egg	Freshwater		
Frog mass of spawn	Freshwater		
Tadpole	Freshwater		
Adult frog	Terrestrial, Freshwater		

Structure under the online wildlifedatabase

Freshwater	Marine	Terrestrial
Amphibian (*Frog*)	Fish *Fish – Benthic Feeding (*Flat fish*)	Amphibian (*Frog*)
		Bird (*Duck*)
Bird (*Duck*)	Crustacean *Crustacean – Large (*Crab*)	Bird egg (*Duck egg*)
		Flying insect (*Bee*)
Fish *Fish – piscivorous (*Salmonid*)	Macroalgae (*Brown seaweed*)	Grasses and herbs (*Wild grass*)
		Mammal (*Rat, Deer*)
Vascular Plant (*Wild Grass*)	Fish (*Salmonid*) *Fish – piscivorous (*Salmonid*)	Earthworm (*Earthworm*)
		Tree (*Pine tree*)

* Wildlife group "Subcategory"

Data manipulations

- The principal objectives of this exercise :
  - to derive **baseline CR values** that were based, as far as possible, upon summarised statistical information for Reference Animals and Plants derived from empirical datasets.
  - In cases where this was not possible, to provide surrogate values, the selection of which could be reasonably justified from an understanding of the transfer processes involved, and in all cases to document clearly the provenance of the values describing any derivations performed.
- The report provides details on how data manipulations were applied to some data entries (primarily those from the ERICA transfer databases), e.g.
  - In converting from d.w. to f.w.; Bq m^{-2} to Bq kg^{-1} (soil); tissue to whole-body.
- Details also provided on how values are summarised to derived comibined means, geometric means etc. (and as coded in the online wildlifedatabase)

$$V_{combined} = \frac{V_w + V_B}{N-1} = \frac{\left(\sum_i (n_i - 1)E_i\right) + \left(\sum_i n_i CR_i^2 - NM^2\right)}{N-1} \quad (1)$$

$$N = \sum_i n_i \qquad \text{and} \qquad M = \frac{\sum_i n_i CR_i}{N}$$

where:
n_i is the number of observations in study i and CR_i is the mean CR value associated with that study. E_i stands for the reported measure of error in study i, this can be variance ($E_i = V_i$), standard deviation ($E_i = (Sd)_i^2$) or standard error ($E_i = n_i(Se)_i^2$). N is the total number of observations in all studies and M defines the weighted mean composed of means associated with all the considered studies.

Deriving surrogate RAPs data

- Use an available CR value for the generic wildlife group ‘Subcategory” within which the Reference Animal and Plant fits for the radionuclide under assessment;
- Use an available CR value for the generic wildlife group ‘Broad group” within which the Reference Animal and Plant fits for the radionuclide under assessment
- In the case of the marine ecosystem use CR data from the estuarine ecosystem;
- Use an available CR value for the given Reference Animal and Plant for an element of similar biogeochemistry;
- Use an available CR value for biogeochemically similar elements for the generic wildlife group within which the Reference Animal and Plant fits;
- Use allometric relationships, or other modelling approaches, to derive appropriate CRs;
- Expert judgement of CR data within that ecosystem for the radionuclide under assessment which might include, for example, the use of data from general reviews on this subject. In all cases the reasoning underpinning the selection of values is transparently recorded.

ANNEX A : Detailed statistical information on Concentration ratios for Reference Animals and Plants

Table A.1.2 Pine tree (Pinaceae) - CR values (units of Bq kg^{-1} f.w. per Bq kg^{-1});.

Element	Arithmetic Mean	Arithmetic Standard Deviaton	Geometric Mean	Geometric Standard Deviation	Minimum	Maximum	N	RefID
Cl	1,5E+0	1,4E+0	1,1E+0	2,2E+0	2,6E-1	3,9E+0	5	251
Cs	9,6E-2	1,1E-1	6,2E-2	2,6E+0	1,3E-2	1,8E-1	90	183
Pb	6,1E-2	3,4E-2	5,3E-2	1,7E+0	2,2E-2	7,1E-2	10	220
Po	4,7E-2	2,8E-2	4,0E-2	1,7E+0	1,3E-2	5,5E-2	10	220
Ra	9,2E-4	9,9E-4	6,3E-4	2,4E+0	5,6E-4	2,4E-3	10	220
Th	1,0E-5	0,0E+0	1,0E-5	1,6E+0	1,0E-5	1,0E-5	3	200
U	1,3E-3	1,0E-3	9,9E-4	2,0E+0	2,0E-4	1,8E-3	13	200,220

ANNEX B: Derived Concentration ratios

Element	Best estimate	Derivation method
Ba	4×10^{0}	Assume CR value for Ca – Macroalgae (This table)
C	8×10^{3}	Assume same as Macroalgae; Ref IDs : 21
Ca	4×10^{0}	Assume same as Estuarine Macroalgae; Ref IDs : 101
Cf	1×10^{2}	Assume CR value for Am – Brown Seaweed (Table A.3.1)
Cl	7×10^{-1}	Assume as Macroalgae, Ref ID 21, 65
Cr	6×10^{3}	Recommended value for Macroalgae from IAEA (2004)
Eu	1×10^{3}	Assume as Macroalgae, Ref ID 141
I	1×10^{3}	Assume as Macroalgae, Ref ID 10,120,21,62, 65
Ir	1×10^{3}	Recommended value for Macroalgae from IAEA (2004)

CR values (Geometric mean, arithmetic mean (n<2) OR best estimate-derived value in units of Bq kg^{-1} f.w. per Bq kg^{-1}) for Adult marine Reference Animal and Plants; values in grey shading are derived

Element	Flatfish	Crab	Brown seaweed
Ag	8×10^{3} (b)	2×10^{5} (g)	2×10^{3}
Am	2×10^{2}	5×10^{2} (b)	8×10^{1}
Ba	4×10^{-1} (d)	7×10^{-1} (g)	4×10^{0} (d)
C	1×10^{4} (b)	1×10^{4} (b)	8×10^{3} (b)
Ca	4×10^{-1}	5×10^{0} (g)	4×10^{0} (c)
Cd	1×10^{4} (b)	8×10^{2} (a)	2×10^{3}
Ce	2×10^{2} (b)	1×10^{2} (b)	1×10^{3}
Cf	2×10^{2} (d)	5×10^{2} (e)	1×10^{2} (d)
Cl	6×10^{-2} (g)	6×10^{-2} (b)	7×10^{-1} (b)
Cm	2×10^{2} (d)	5×10^{2} (e)	8×10^{3}
Co	3×10^{2}	5×10^{3} (a)	7×10^{2}
Cr	2×10^{2} (g)	1×10^{2} (g)	6×10^{-3}(g)
Cs	4×10^{1}	1×10^{1}	1×10^{1}
Eu	7×10^{2} (b)	4×10^{3} (g)	1×10^{3} (b)
H	1×10^{0} (g)	1×10^{0} (g)	1×10^{0}
I	9×10^{0} (g)	3×10^{0} (g)	1×10^{3} (b)
Ir	2×10^{1} (g)	1×10^{2} (g)	1×10^{3} (g)

(a) CR value for a similar generic wildlife group "Subcategory" within that ecosystem for the radionuclide under assessment (b) CR value for a similar generic wildlife group "Broad Group" within that ecosystem for the radionuclide under assessment (c) CR data from estuarine environment (d) CR value for the given Reference Animal and Plant for an element of similar biogeochemistry (e) CR value for biogeochemically similar elements for similar generic wildlife group (f) allometric relationships, or other modelling approach (g) Expert judgement.

Transfer factor data for different life stages of development for Reference Animals and Plants

- Few empirical data ('baseline values' not reported); Therefore guidance given, e.g.
  - The larval stage of ***Crab***, known as the zoea, is a minute transparent organism with a rounded body that swims and feeds as part of the plankton. Data for zooplankton in general have previously been published (IAEA, 2004; Hosseini et al., 2008).

Distributions of radionuclides within the organs/body parts of reference plants and animals

- For the purpose of relating dose received to the biological endpoints of interest, the critical information required for alpha particles and low-energy electrons is the concentration of the relevant radionuclide in the 'tissue or organ of interest' (ICRP, 2008).
  - For animals = the reproductive organs, as reproduction is a primary biological endpoint of interest (especially with respect to the maintenance of populations), and accumulating organs because clearly the highest exposures will be associated with these body compartments.
  - For plants = active growing points of the shoot and root tips, the ring of phloem and xylem underneath the bark (much of the centre of the tree trunk is literally 'dead wood'), the seeds (within cones), and the root mass beneath the soil surface
- The conversion factors used to derive whole body concentration ratios from organs and body parts can be considered as a first step in collating and tabulating baseline values on this subject, but a more comprehensive derivation of values awaits further deliberation and guidance from the Commission. In this respect, the recent work of Yankovich and co-workers (Yankovich et al., submitted) has provided a useful input to the process.

Yankovich, T. L., Beresford, N. A., Wood M.D., et al. (submitted). Whole-body to Tissue-specific Concentration Ratios for Use in Biota Dose Assessments for Animals. Radiation and Environmental Biophysics.

Limitations in CR approach

- Applicability of CRs
  - Tenuous relationship between soil activities and organism activities in some case, e.g. bees (indirect, plants, hive) and ducks : (migratory, water body, food-sources)
- Ad hoc nature
  - Different studies for different reasons (large discrepancies in quality of information and ancillary data)
- Life stages
  - Little studied; can provided guidance but no validation
- Activity concentrations within RAPs
  - Limited data, heterogeneity for some radionuclides might be considered as important
    - Pu – Liver, bone; Sr and Ra – bone etc.

ICRP – Reference Man

- The report of the task group on reference man (ICRP,1975) contains anatomical, physical and elemental content information for humans.
- The elemental composition of organs and tissues is required in

  (1) external dose calculations (derived in conjunction with data on mass and dimensions of organs/tissues) and

  (2) constructing retention models and validating the output from such models.

ICRP, 1975. Reference Man: Anatomical, Physiological and Metabolic Characteristics. ICRP Publication 23. Pergamon Press, Oxford.

Reference sites

- Sites where it is possible to collect samples of each Reference Animal and Plant and their different lifestages.
  - all the samples should come from the same (known and coordinated) location (e.g. the duck, frog and trout should all come from the same lake).
  - collected along with corresponding samples of media (water, soil). The number and specific location of any media samples will need to take into account spatial aspects such as the home range of the Reference Animal and Plant (and its lifestages)
- ‘reference’ values can be compared with the wider CR data that is available
  - to help understand how CR may vary between different geographic areas.
- For each of the adult Reference Animal and Plant, the composition of the 40 elements should be determined for a number of the tissues of interest.
  - gonads muscle and liver etc. depending upon the specific Reference Animal and Plant in question.

Why bother ?

- Internally consistent
  - Previous data from ad hoc studies
- Potential for a more mechanistic understanding of transfer
  - Test various hypotheses under ’controlled’ conditions
- Parallels system for man

Draft document for consultation

- http://www.icrp.org/draft_environ.asp
- Comments before October 1st 2010
- Meeting in November to finalise tables