Dose Coefficients of the ICRP

Their Computational Development and Current Status

3rd International Symposium on the System of Radiological Protection

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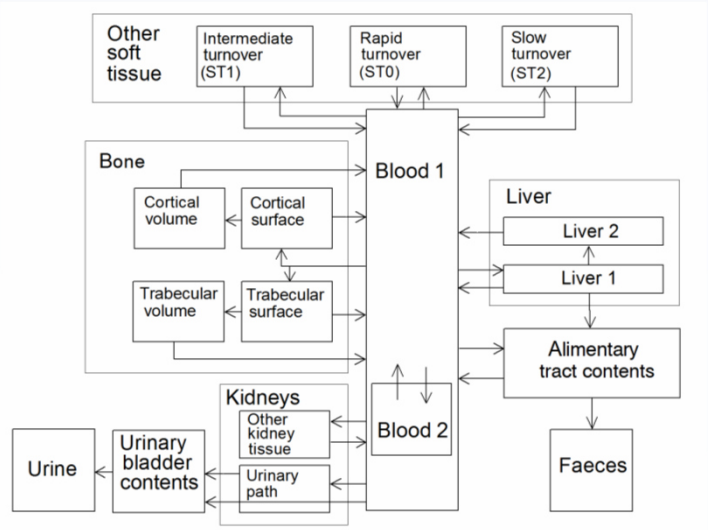
Presentation Outline

- What are reference dose coefficients from the ICRP?
- Review of ICRP dose coefficients for internal exposures
- Review of ICRP dose coefficients for external exposures
- Future developments

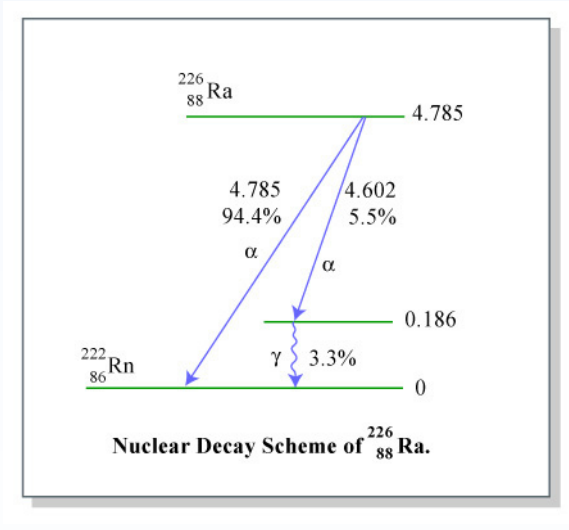
ICRP Dose Coefficients – Internal Exposures

Dose coefficient – Internal Exposures

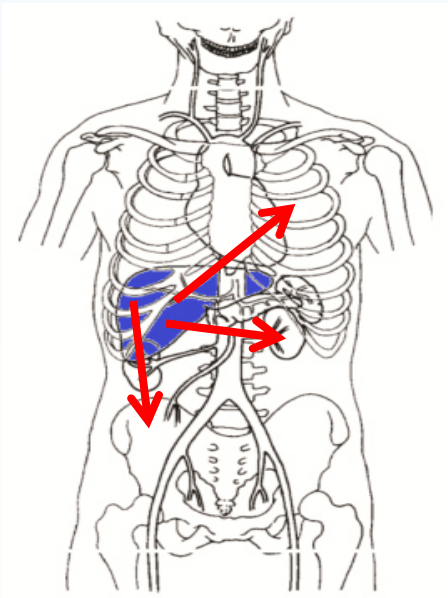
For adult workers, a dose coefficient is defined as either the committed equivalent dose in organ or tissue T per activity intake, $h_T(50)$, or the committed effective dose per intake, $e(50)$, where 50 is the dose-commitment period in years over which the dose is calculated. Note that elsewhere the term 'dose per intake coefficient' is sometimes used.



Intake and Systemic Biokinetic Models



Radionuclide Decay Scheme

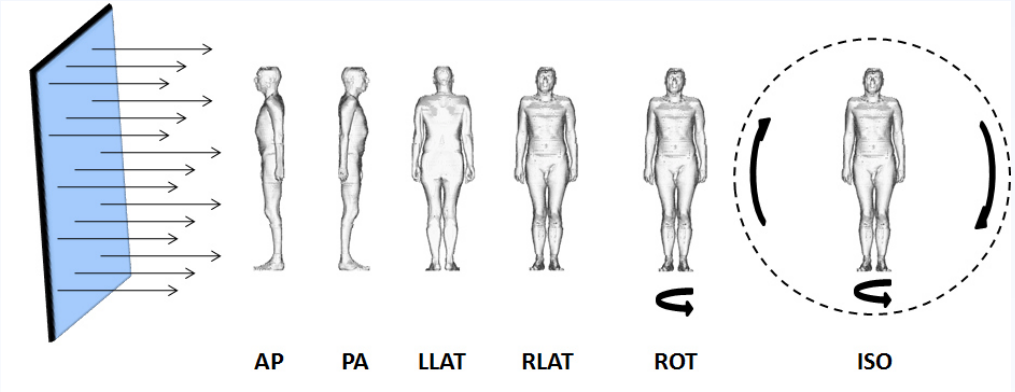


Anatomic Phantom and Radiation Transport Simulation

ICRP Dose Coefficients – Internal Exposures

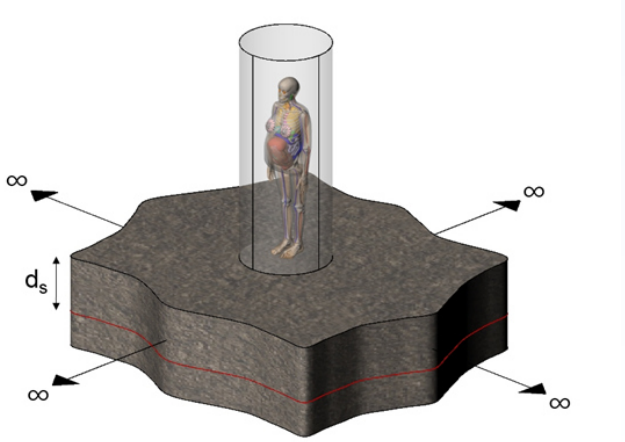
Dose Coefficient – External Exposures

A coefficient relating a dose quantity to a physical quantity. For external exposure, the physical quantity 'fluence' or 'air kerma' is chosen.

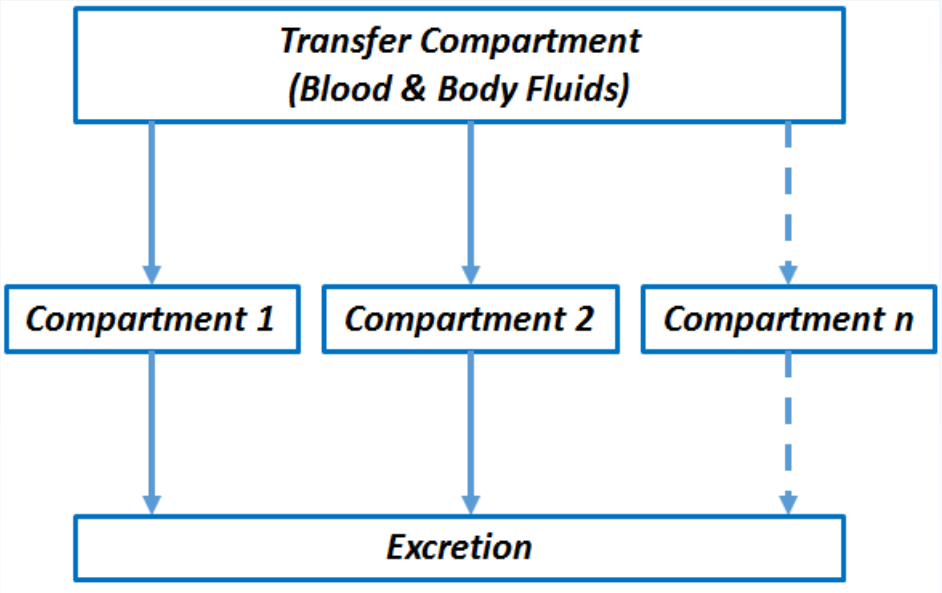


Idealized occupational radiation fields

Idealized environments of radionuclide contaminated air, water, or soils



Biokinetic Models - Publication 30



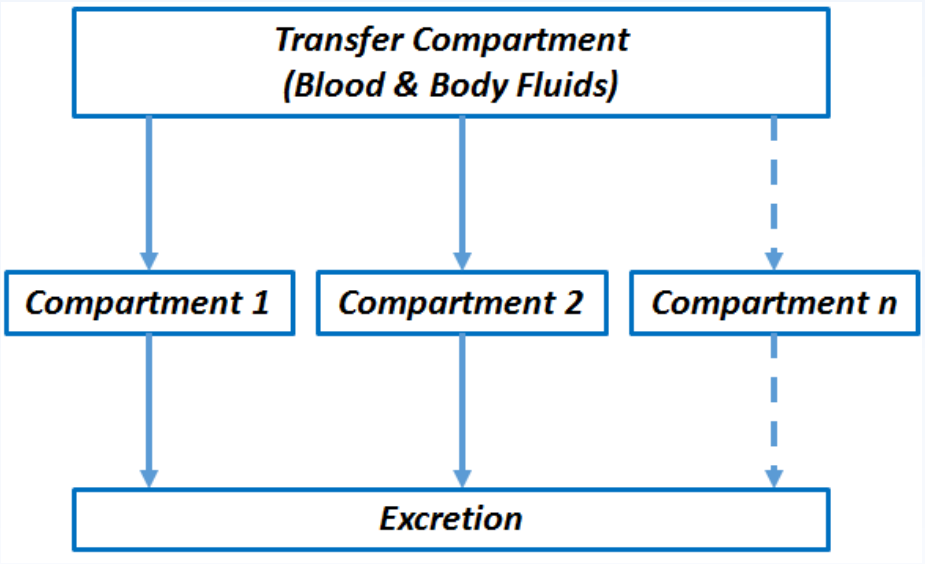
For ^{137}Cs, Publication 30 assumes total body uniform distribution modeled as two compartments:

$$f_1 = 0.10 \quad and \quad f_2 = 0.9$$

$$\lambda_{eff_1} = \lambda_{b_1} + \lambda_R = \frac{ln2}{2\ d} + \frac{ln2}{30\ y}\left(\frac{y}{365\ d}\right)$$

$$\lambda_{eff_2} = \lambda_{b_2} + \lambda_R = \frac{ln2}{110\ d} + \frac{ln2}{30\ y}\left(\frac{y}{365\ d}\right)$$

Biokinetic Models - Publication 30

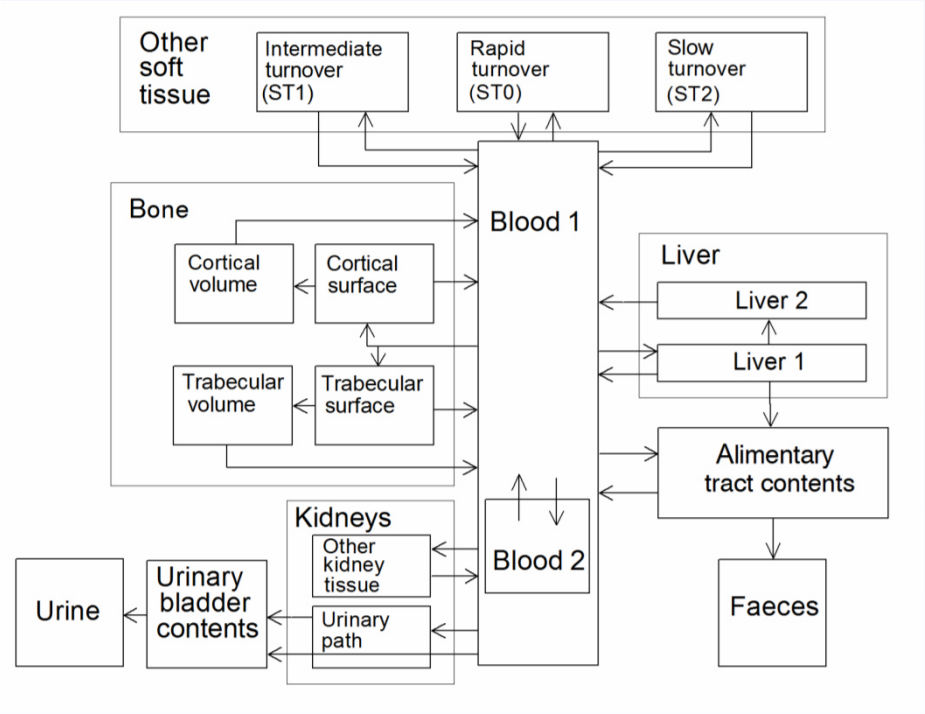


$$A_{TB}(t) = f_1 A_{blood}(0)\, exp\left(-\lambda_{eff_1} t\right) + f_2\, A_{blood}(0) exp\left(-\lambda_{eff_2} t\right)$$

$$\tilde{A}_{TB} = \int_0^{T=50y} A_{TB}(t)\, dt$$

$$\tilde{A}_{TB} = \frac{f_1\, A_{blood}(0)}{\lambda_{eff_1}} \left[1 - exp\left(-\lambda_{eff_1} T\right)\right] + \frac{f_2\, A_{blood}(0)}{\lambda_{eff_2}} \left[1 - exp\left(-\lambda_{eff_2} T\right)\right]$$

Biokinetic Models – Current Generation



Transfer coefficients (d^{-1}) for systemic cobalt

Compartments	Transfer Coefficient (d^{-1})
Blood 1 to Liver 1	70
Blood 1 to Urinary bladder contents	60
Blood 1 to Right colon contents	4.0
Blood 1 to ST0	18
Blood 1 to ST1	10
Blood 1 to ST2	4.0
Blood 1 to Cortical bone surf	6.0
Blood 1 to Trabecular bone surf	6.0
Blood 1 to Kidneys 1	9.0
Blood 1 to Kidneys 2	1.0
Blood 1 to Blood 2	12
Blood 2 to Blood 1	0.693
Liver 1 to SI cont	0.0924
Liver 1 to Blood 1	0.347
Liver 1 to Liver 2	0.0231
Liver 2 to Blood 1	0.0019
ST0 to Blood 1	0.099
ST1 to Blood 1	0.0139
ST2 to Blood 1	0.00095
Cortical bone surf to Blood 1	0.0842
Cortical bone surf to Cortical bone vol	0.0149
Trabecular bone surf to Blood 1	0.0842
Trabecular bone surf to Trabecular bone vol	0.0149
Cortical bone vol to Blood 1	0.0000821
Trabecular bone vol to Blood 1	0.000493
Kidneys 1 to Urinary bladder contents	0.462
Kidneys 2 to Blood 1	0.0019

surf = surface, vol = volume, SI = small intestine

Biokinetic Models - Numerical Solution

$$\frac{dA_{i,j}(t)}{dt} = \sum_{\substack{k=1 \\ k \neq j}}^{M} A_{i,k}\,\lambda_{i,k,j} - A_{i,j}\left[\sum_{\substack{k=1 \\ k \neq j}}^{M} \lambda_{i,j,k} + \lambda_i^P\right] + \sum_{k=1}^{i-1} A_{k,j}\,\beta_{k,i}\,\lambda_i^P$$

M is the number of compartments describing the kinetics;

$\lambda_{i,j,k}$ is the fractional transfer rate of chain member i from compartment j (donor compartment) to compartment k (receiving compartment) in the biokinetic model;

λ_i^P is the physical decay constant of chain member i; and

$\beta_{k,i}$ is the fraction of the decays of chain member k forming member i.

Time Integration of Organ Activity

Integration of organ activity over the dose commitment period τ and summation over all biokinetic compartments j yields the time-integrated activity $\tilde{\mathbf{A}}$

$$\tilde{A}_i(r_S, \tau) = \sum_j \int_0^\tau A_{i,j}(t)\, dt$$

Normalizing by the activity intake at t = 0, yields the time-integrated activity coefficient $\tilde{\mathbf{a}}$

$$\tilde{a}_i(r_S, \tau) = \frac{\tilde{A}_i(r_S, \tau)}{\sum_j A_{1,j}(0)}$$

The parameter $\tilde{a}$ is equivalent to the older term "residence time" in the MIRD schema

ICRP Dose Coefficients for Equivalent dose

The committed equivalent dose coefficient in target region r_T of the Reference Adult Male, $h^M(r_T, \tau)$, and Reference Adult Female, $h^F(r_T, \tau)$, for integration time τ is given by

$$h^F(r_T, \tau) = \sum_i \sum_{r_S} \tilde{a}_i(r_S, \tau)\ S_w^F\ (r_T \leftarrow r_S)_i$$

$$h^M(r_T, \tau) = \sum_i \sum_{r_S} \tilde{a}_i(r_S, \tau)\ S_w^M\ (r_T \leftarrow r_S)_i$$

S coefficients, $S_w^M(r_T \leftarrow r_S)_i$ and $S_w^F(r_T \leftarrow r_S)_i$, are the radiation-weighted equivalent doses in target region r_T per nuclear transformation of chain member *i* in source region r_S [Sv (Bq s)$^{-1}$] for the male and female worker, respectively.

ICRP Dose Coefficients for Equivalent Dose

The committed equivalent dose coefficients for tissue T in the Reference Adult Male, $h_T^M(\tau)$, and Reference Adult Female, $h_T^F(\tau)$, are thus given as:

$$h_T^F(\tau) = \sum_{r_T} f(r_T, T)\ h^F(r_T, \tau) \qquad h_T^F(\tau) = \sum_{r_T} f(r_T, T)\ h^F(r_T, \tau)$$

where the target region fractional weights $f(r_T, T)$ are the proportions of the equivalent dose in tissue T associated with target region r_T.

For example, the colon (target tissue T) is composed of three target regions (r_T) – right colon, left colon, and rectosigmoid colon. However, the liver is composed of only one target region (f = 1).

ICRP Dose Coefficients for Equivalent Dose

With the exception of the tissues addressed below, the tissues of the effective dose are represented by a single target region and thus for these tissues $f(r_T, T) = 1$.

Table 3. Target region fractional weights, $f(r_T, T)$

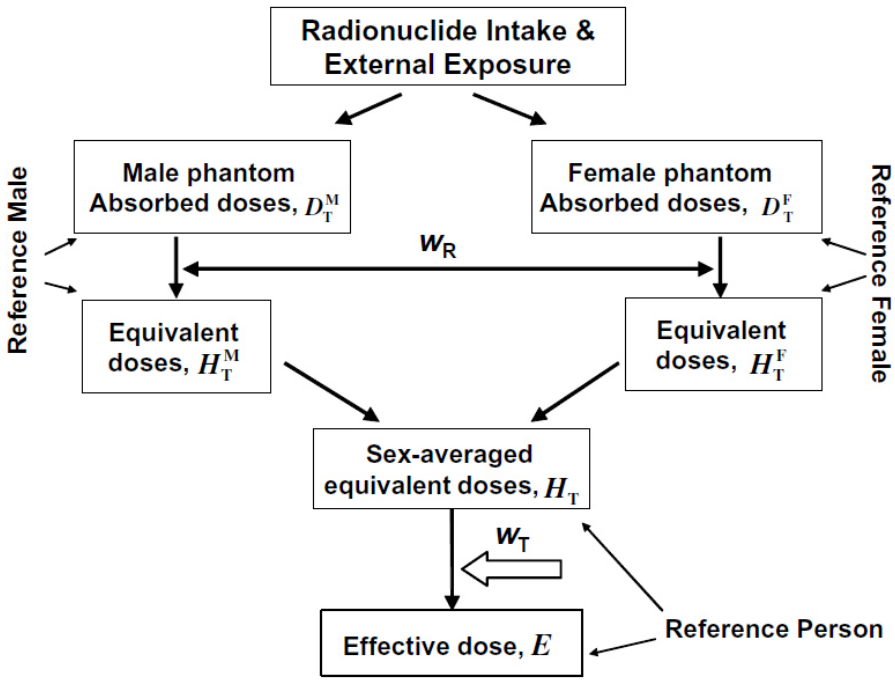
Tissue, T	r_T	$f(r_T, T)$
ET region	ET_1 (anterior nose)	0.001
	ET_2 (posterior nasal passages larynx and pharynx)	0.999
Lung (Thoracic)	BB (bronchial)*	1/3
	bb (bronchiolar)	1/3
	AI (alveolar-interstitial)	1/3
Colon	Right colon	0.4
	Left colon	0.4
	Rectosigmoid	0.2
Lymphatic nodes	LN_{ET}	0.08
	LN_{TH}	0.08
	Lymph (systemic)	0.84

* The basal and secretory cells are the two target regions weighted equally.

ICRP Dose Coefficients for Effective Dose

As defined in *Publication 103*, the committed effective dose coefficient, $e(\tau)$, is then :

$$e(\tau) = \sum_T w_T \left[\frac{h_T^M(\tau) + h_T^F(\tau)}{2}\right]$$



Specific Absorbed Fractions with the ICRP System

The radiation-weighted S coefficient [Sv (Bq-s)$^{-1}$] for a radionuclide is calculated as:

$$S_w(r_T \leftarrow r_S) = \sum_R w_R \sum_i E_{R,i}\, Y_{R,i}\ \Phi\left(r_T \leftarrow r_S, E_{R,i}\right)$$

$E_{R,i}$ is the energy of the i^{th} radiation of type R emitted in nuclear transformations of the radionuclide;

$Y_{R,i}$ is the yield of the i^{th} radiation of type R per nuclear transformation, [(Bq s)$^{-1}$];

w_R is the radiation weighting factor for radiation type R; and

$\Phi\left(r_T \leftarrow r_S, E_{R,i}\right)$ is the SAF, defined as the fraction of energy $E_{R,i}$ of radiation type R emitted within the source tissue r_S that is absorbed per mass in the target tissue r_T (kg^{-1}).

Specific Absorbed Fractions – Distributed Sources

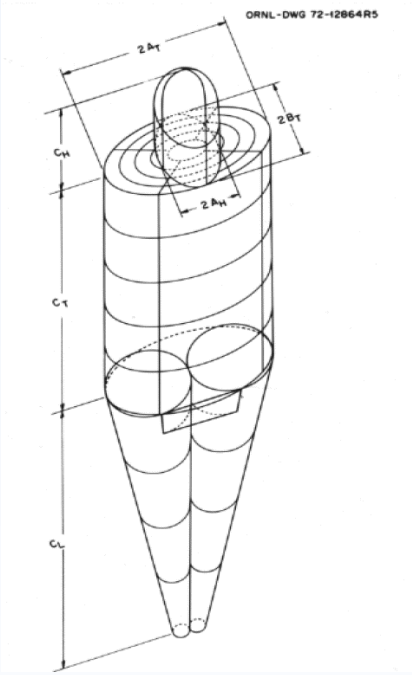
Systemic biokinetic models indicate radionuclide deposition from blood to various identified source regions r_S, each with its own compartmental representation in the biokinetic model. In many instances, the balance of radionuclide deposition from blood will be assigned to "other tissues" of the body, which implies all other soft tissues not previously identified as source organs.

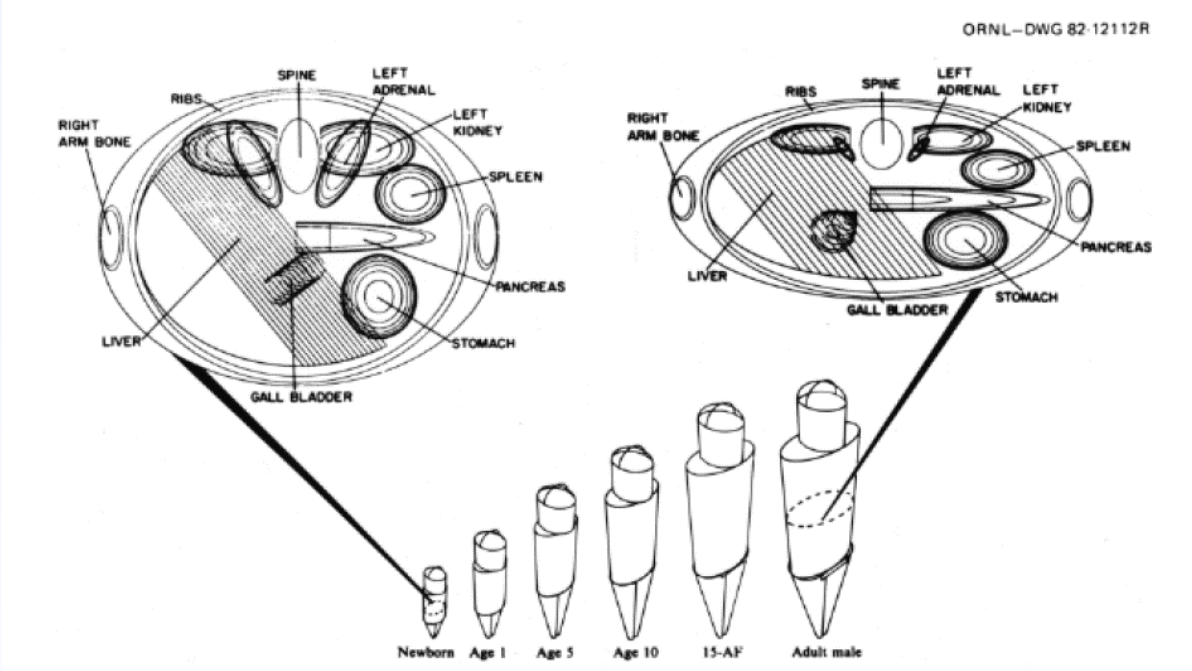
To address this source region, which is generally unique to a given radionuclide biokinetic model, one must derive the SAF for the relevant target tissues r_T. This SAF may be calculated using the so-called additive approach as:

$$SAF(r_T \leftarrow Other) = \frac{1}{M_{Other}} \sum_{r_S} M_{r_S} \, SAF(r_T \leftarrow r_S)$$

where the summation is over source regions not explicitly included in the systemic biokinetic model. Unless specifically noted in the biokinetic model, deposition to other tissues is not assigned to mineral bone in either its cortical or trabecular form.

Adult Specific Absorbed Fractions - Previous





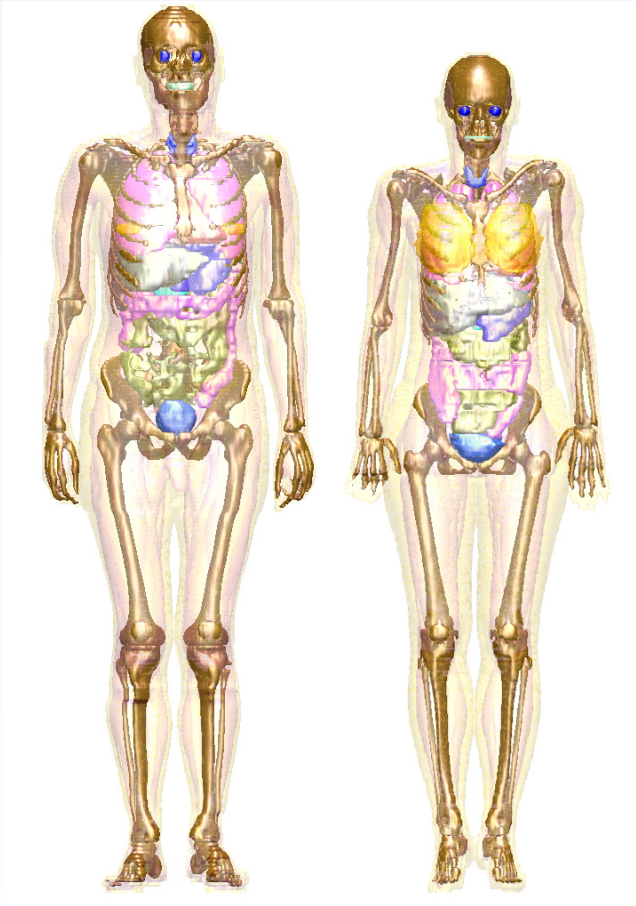
ICRP Publication 30

Appendix I of ICRP Publication 23 – MIRD Phantom

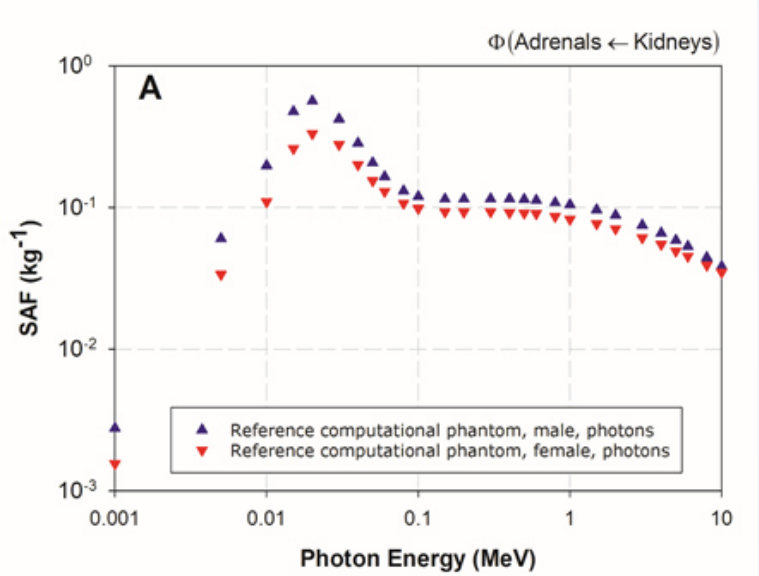
Subsequent ICRP Publications

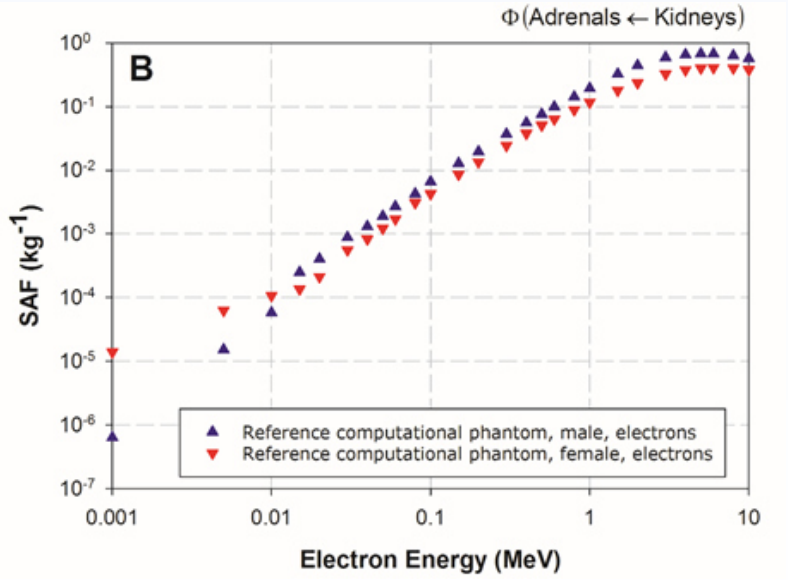
Specific Absorbed Fractions of Energy at Various Ages from Internal Photon Sources (ORNL TM-8381)

Adult Specific Absorbed Fractions - Current



Publication 110 Reference Phantoms



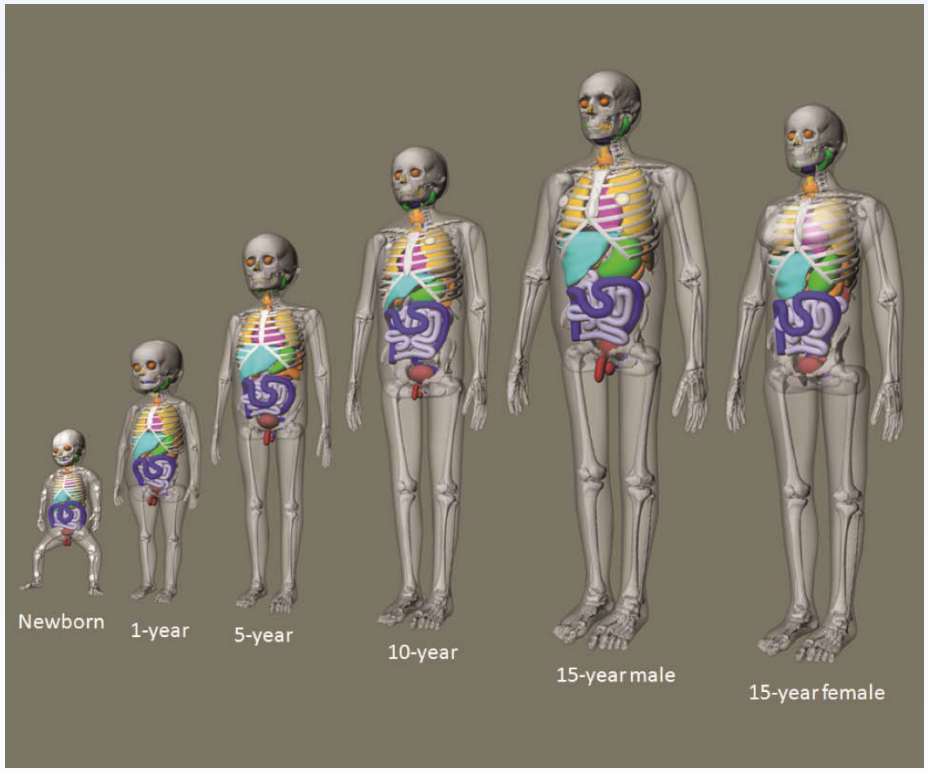


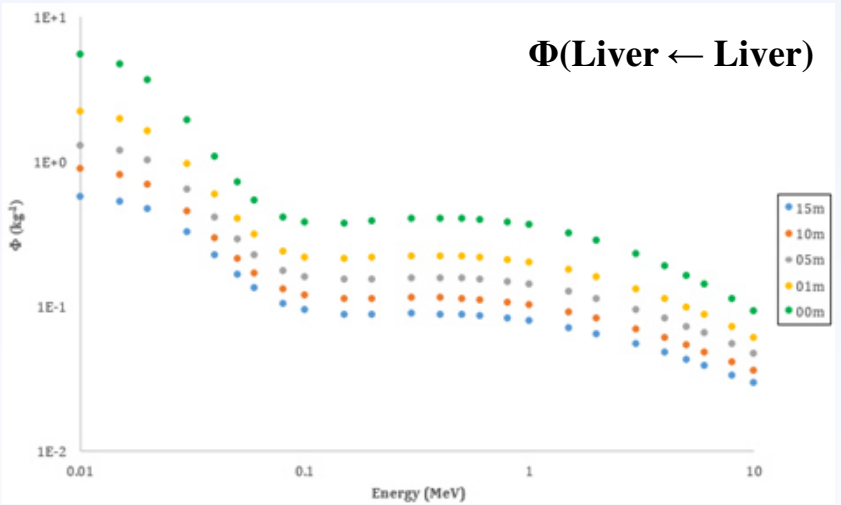
Adult Specific Absorbed Fractions

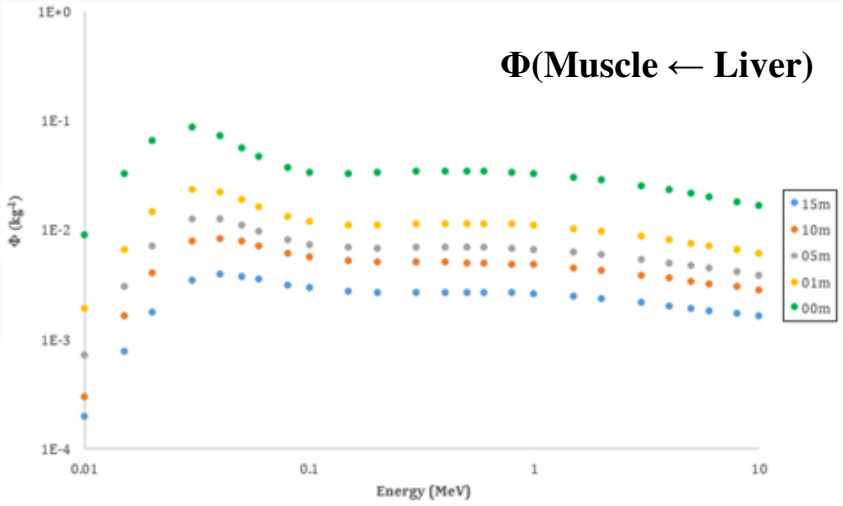
Examples of the many challenges within C2 Task Groups 95 and 96

- First-time use of fractional values of electron absorbed fractions
- Discernment of "wall sources" for the Publication 100 alimentary tract organs
- Integration of phantom-derived SAFs with those derived from stylized models of the alimentary tract and respiratory tract
- Interpretation of ICRP Publication 89 Reference Masses – inclusive or exclusive of blood content?
- Computation of blood sources – example of a distributed organ
- Treatment of progeny in-growth with unique systemic biokinetics
- First-time consideration of coefficients giving effective dose per bioassay content

Pediatric Specific Absorbed Fractions



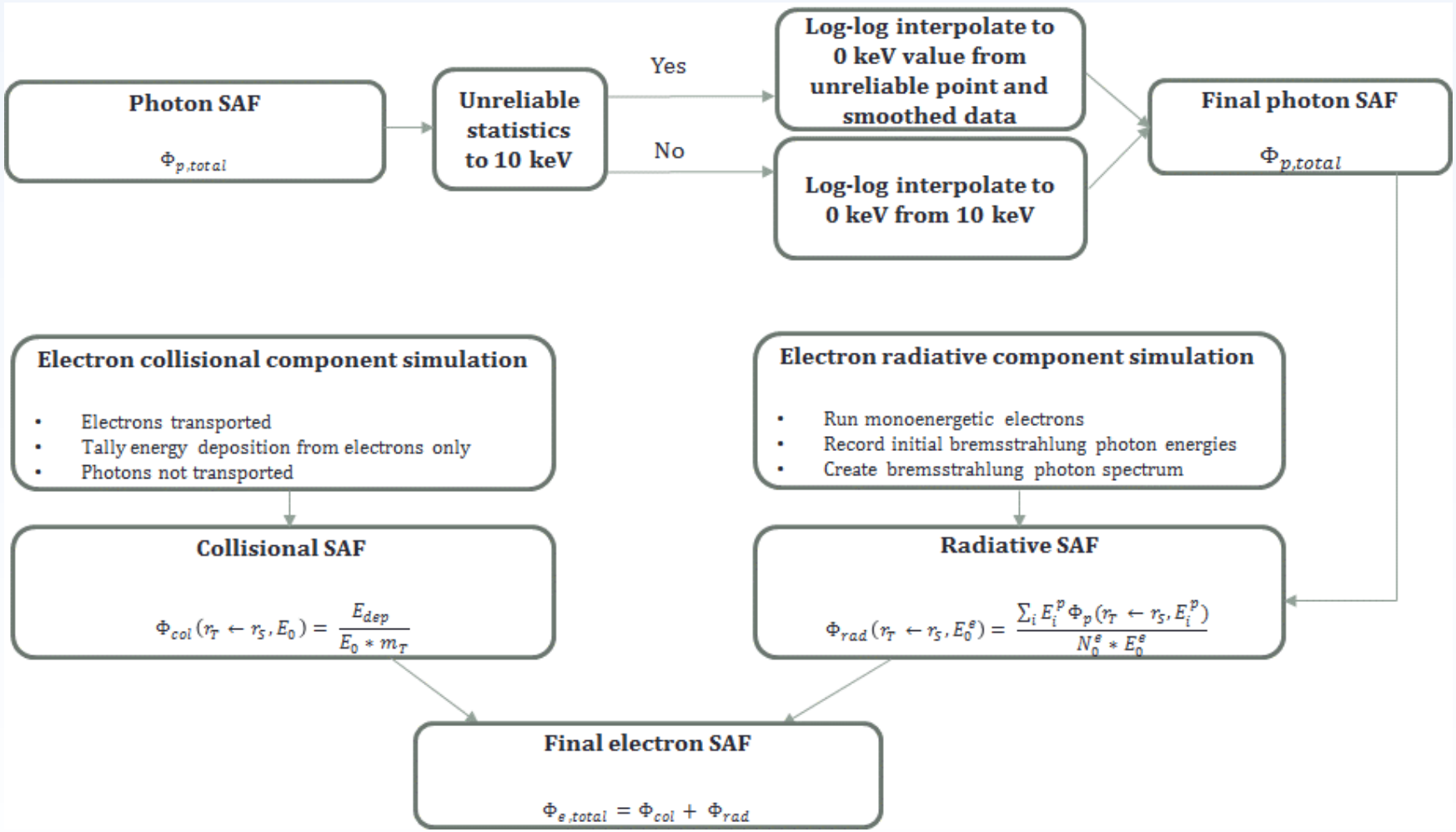




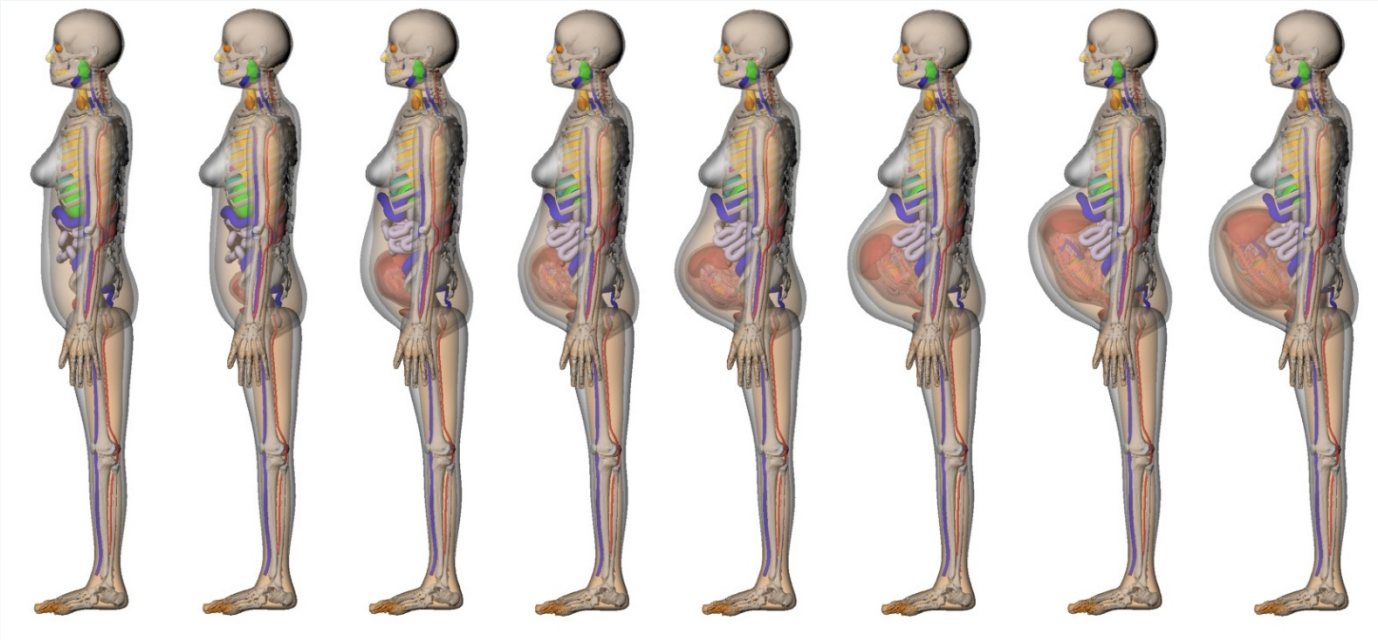
ICRP Series of Pediatric Reference Phantoms

- Derived from UF/NCI hybrid phantom series
- Photon and Electron SAFs currently being completed
- QA to start within ICRP TG 96
- *Support* – U.S. Environmental Protection Agency

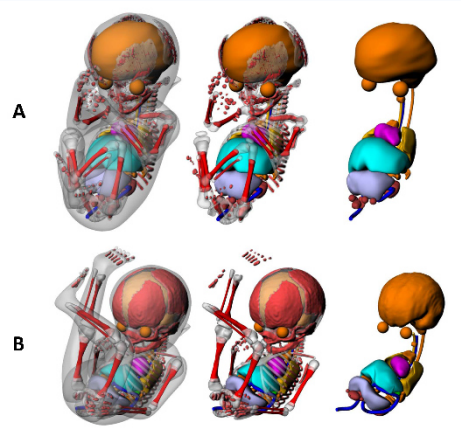
Computation of Electron SAFs



Pregnant Female Specific Absorbed Fractions



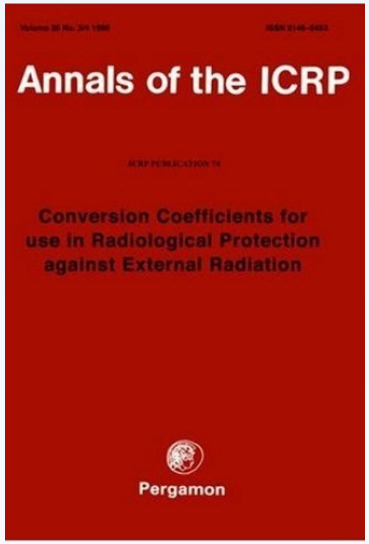
Models at 8 week to 38 weeks post-conception



ICRP Series of Fetal and Pregnant Female Phantoms

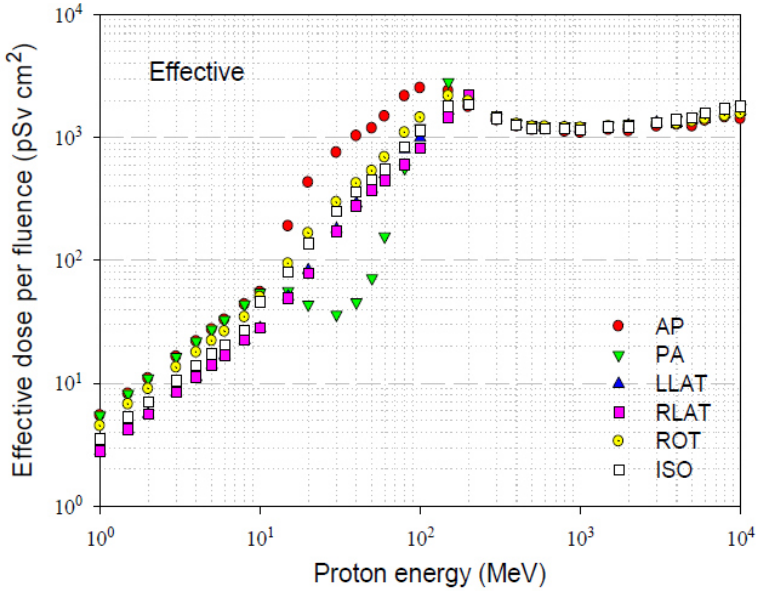
- Derived from UF hybrid phantom series developed for the SOLO Project
- Primary photon and electron SAFs beginning currently
- QA to be completed under TG 96
- *Support* – U.S. Environmental Protection Agency

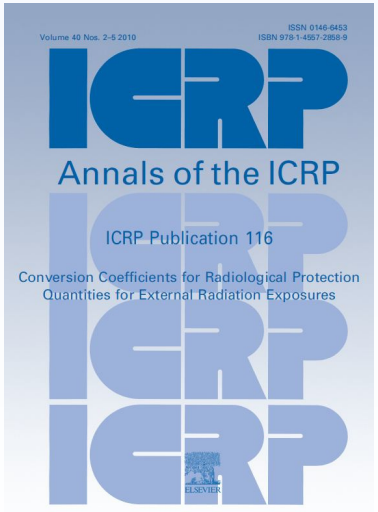
ICRP Dose Coefficients - External



Publication 74 (1996)

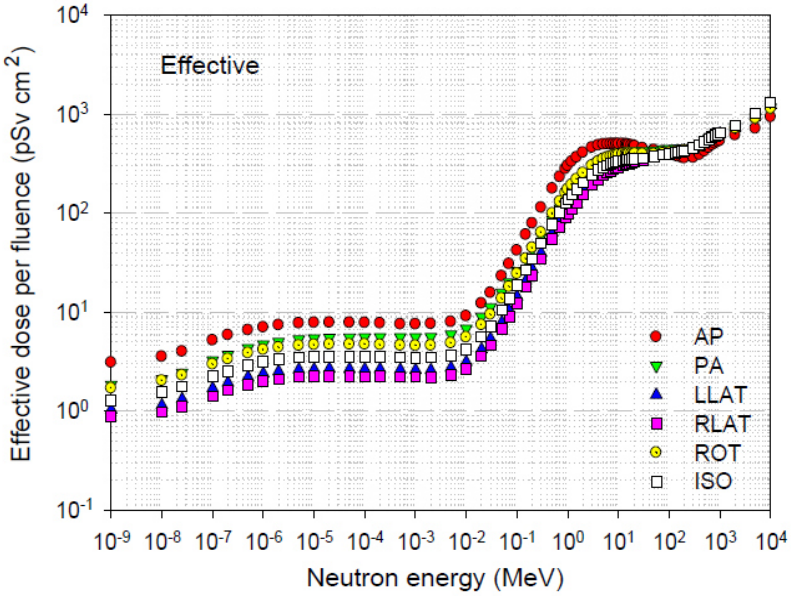
- Based upon review of published dose coefficients
- Mixture of stylized and voxel phantoms



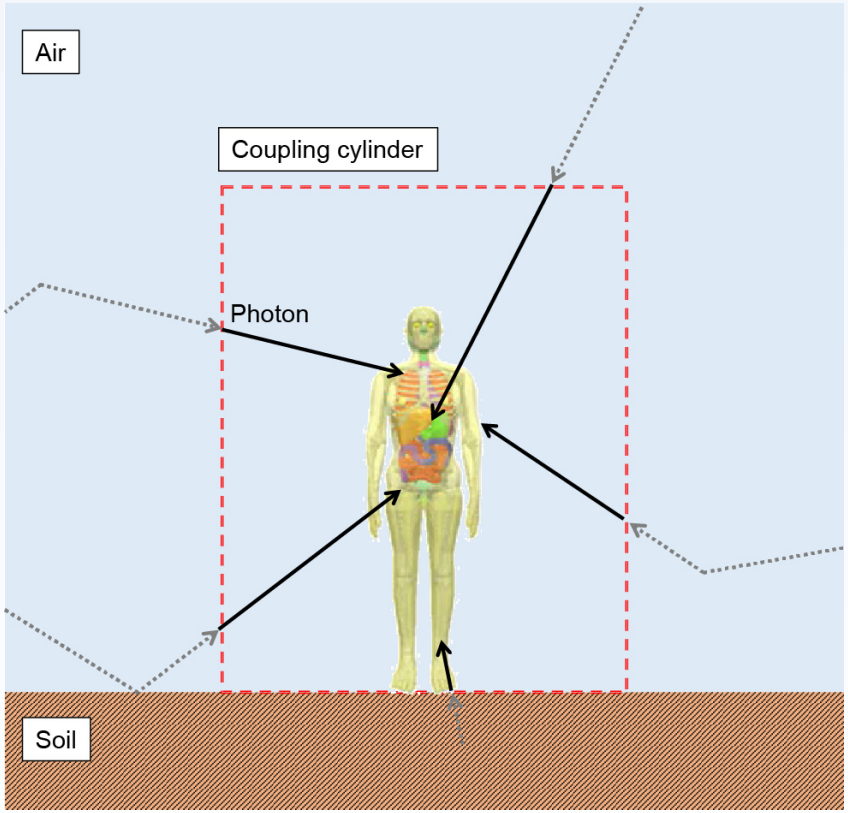


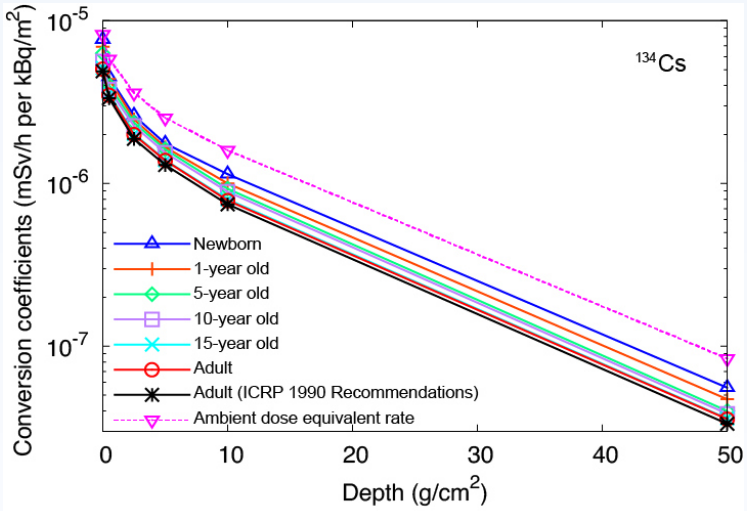
Publication 116 (2010)

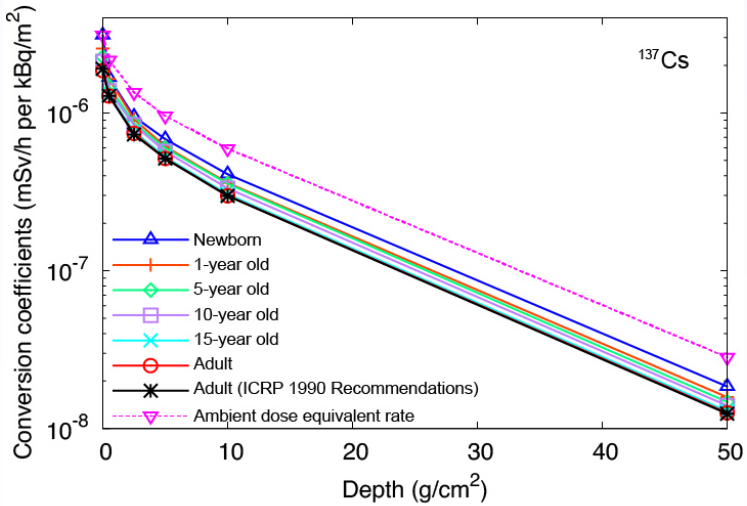
- Based upon new MC calculations using the Publication 110 phantom
- Extensive benchmarking of various MC transport codes



ICRP Task Group 90
Age-Dependent Dose Coefficient for Env. Exposures

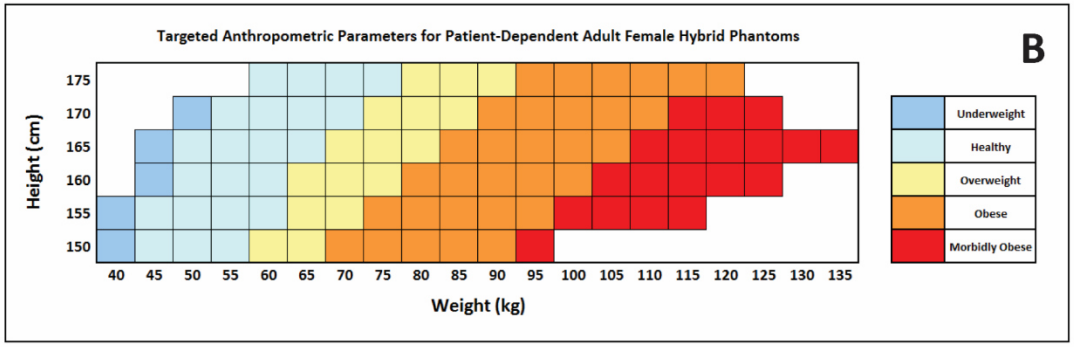


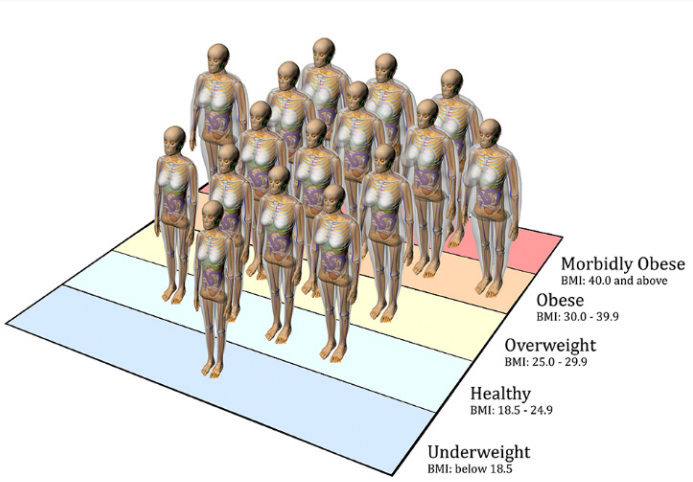




Potential Future Efforts

- It is emphasized that Reference Dose Coefficients are to be applied under the ICRP System of Radiological Protection.
- However, the research methods used by the ICRP in establishing reference dose coefficients may be expanded to provide tools for individualized dose reconstruction following accidental occupational or environmental releases.
- For example, an expanded library of phantoms – modeling variations in subject height, weight, and thus body morphometry – can be applied to more "personalize" the dose assessment.





Potential Future Efforts

- Phantom libraries may thus be used to establish non-reference values of external dose coefficients and non-reference values of internal SAFs. Adjustments of biokinetic models are more problematic in terms of individualized assessment of kinetic parameters.

- It must be noted, however, that even though the dose estimate may be refined beyond that given by ICRP reference models, individual estimates of radiation-induced cancer or other risk are highly uncertain.

Thank you for your attention