Overview of the ICRP System of Internal and External Dosimetry

ICRP Symposium on Radiological Protection Dosimetry
Historical Review and Current Activities
February 18, 2016

W.E. Bolch
Department of Biomedical Engineering, University of Florida
Secretary of ICRP Committee 2
Leader, Task Group 96 on Computational Phantoms and Radiation Transport

ICRP Dose Quantities

Absorbed dose, D
The fundamental dose quantity given by

$$D = \frac{d\bar{\varepsilon}}{dm}$$

where $d\bar{\varepsilon}$ is the mean energy imparted to matter of mass dm by ionizing radiation. The SI unit for absorbed dose is joule per kilogram (J/kg) and its special name is gray (Gy).

Equivalent dose, H_T
The dose in a tissue or organ T given by:

$$H_T = \sum_R w_R D_{T,R}$$

where $D_{T,R}$ is the mean absorbed dose from radiation R in a tissue or organ T, and w_R is the radiation weighting factor. Since w_R is dimensionless, the unit for the equivalent dose is the same as for absorbed dose, J / kg, and its special name is sievert (Sv).

ICRP Dose Quantities

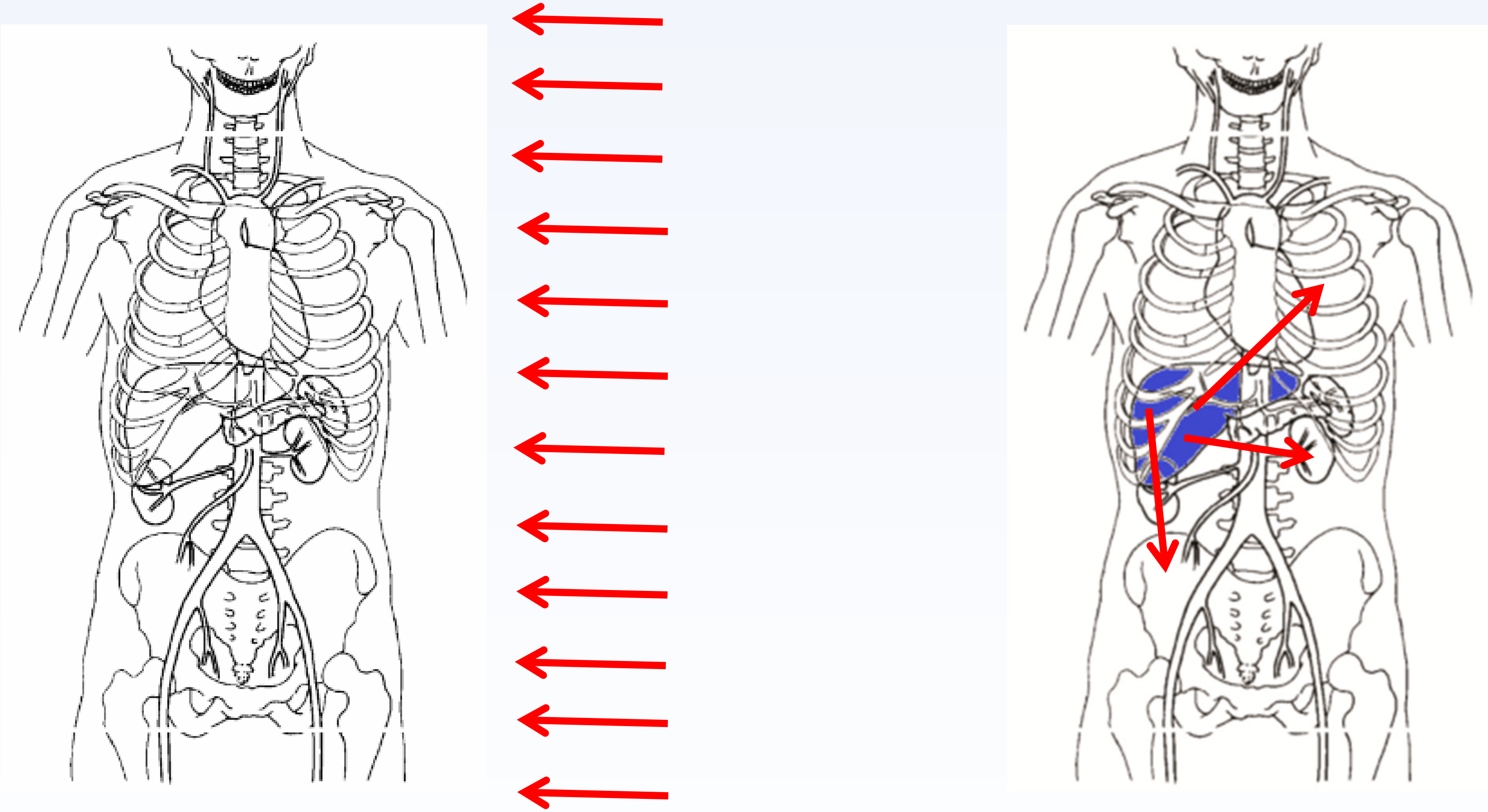
Effective dose, E

The tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body, given by the expression:

$$E = \sum_{\mathrm{T}} w_{\mathrm{T}} \sum_{\mathrm{R}} w_{\mathrm{R}} D_{\mathrm{T,R}} \quad \text{or} \quad E = \sum_{\mathrm{T}} w_{\mathrm{T}} H_{\mathrm{T}}$$

where H_T is the equivalent dose in a tissue or organ, T, and w_T is the tissue weighting factor. The unit for the effective dose is the same as for absorbed dose, J / kg, and its special name is sievert (Sv).

The Effective Dose



"Hypothetical" uniform exposure of the reference person yielding same total detriment

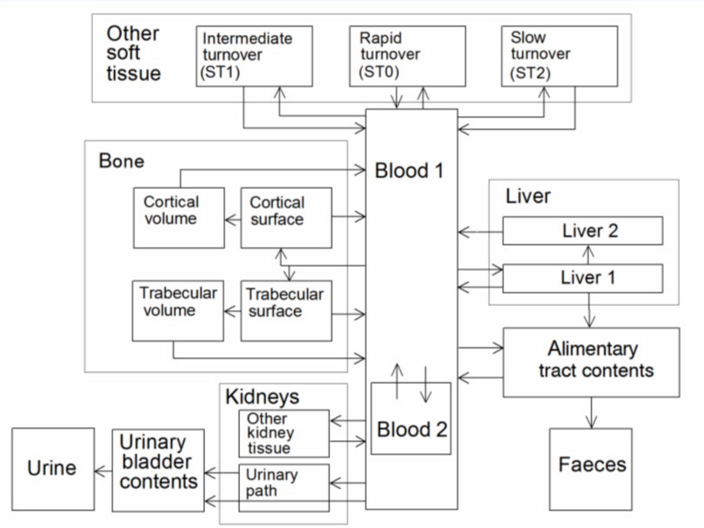
"Real" non-uniform exposure of the individual

This is the individual's "effective dose" E

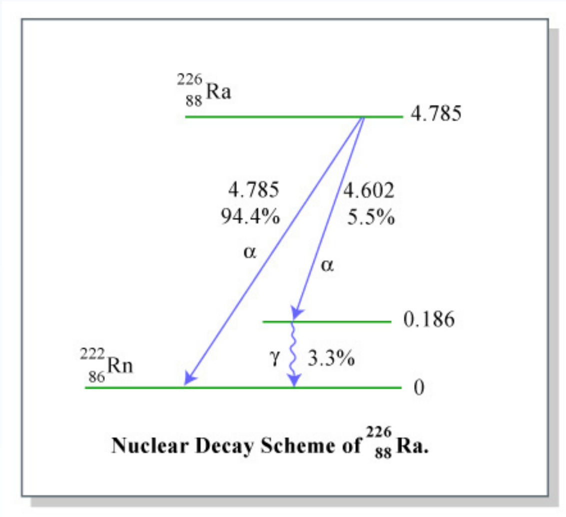
ICRP Dose Coefficients – Internal Exposures

Dose coefficient – Internal Exposures

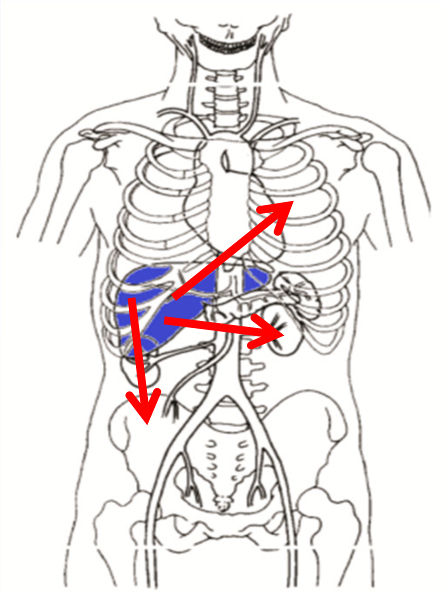
For adult workers, a dose coefficient is defined as either the committed equivalent dose in organ or tissue T per activity intake, $h_T(50)$, or the committed effective dose per intake, $e(50)$, where 50 is the dose-commitment period in years over which the dose is calculated. Note that elsewhere the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



Intake and Systemic Biokinetic Models



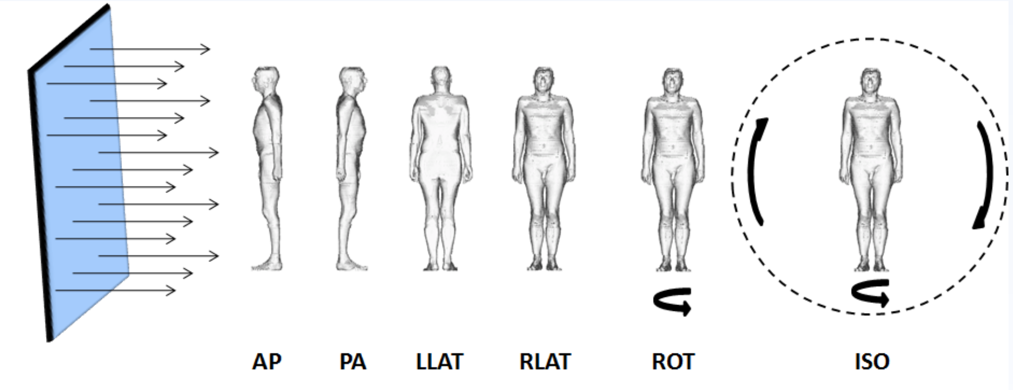
Radionuclide Decay Scheme



Anatomic Phantom and Radiation Transport Simulation

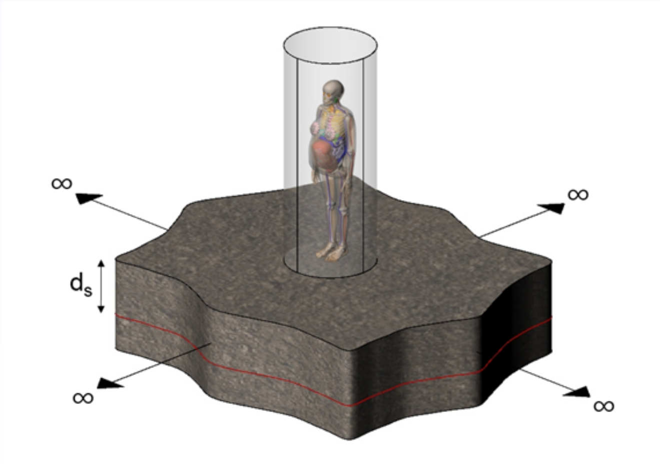
ICRP Dose Coefficients – External Exposures

Dose Coefficient – External Exposures
A coefficient relating a dose quantity – organ equivalent dose or effective dose – to a physical quantity. For external exposure, the physical quantity ‘fluence’ or ‘air kerma’ is chosen.

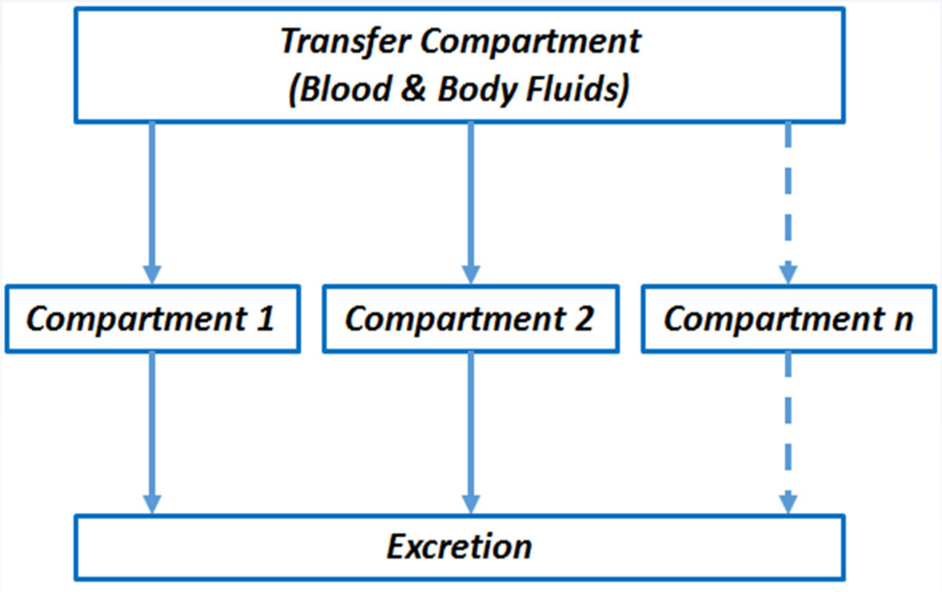


Idealized occupational radiation fields

Idealized environments of radionuclide contaminated air, water, or soils



Biokinetic Models - Publication 30



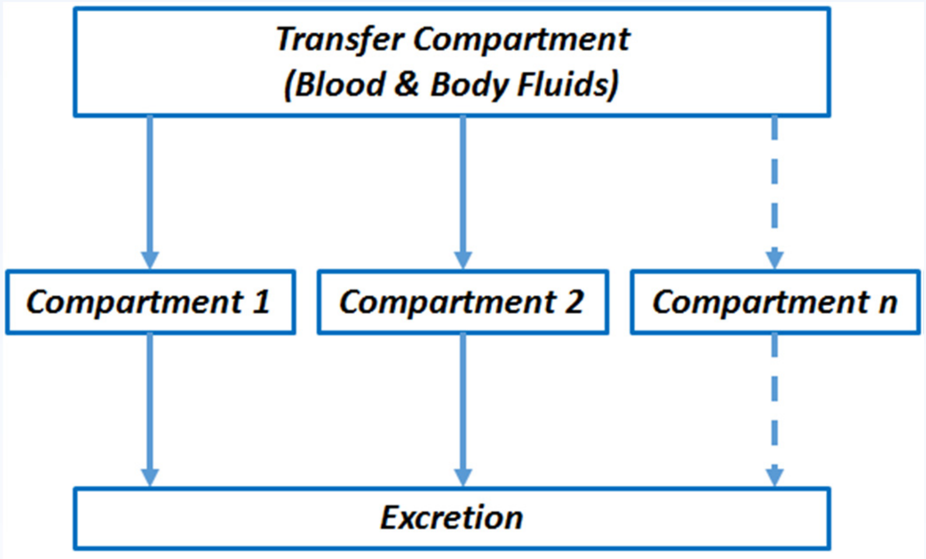
For ^{137}Cs, Publication 30 assumes total body uniform distribution modeled as two compartments:

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

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

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

Biokinetic Models - Publication 30

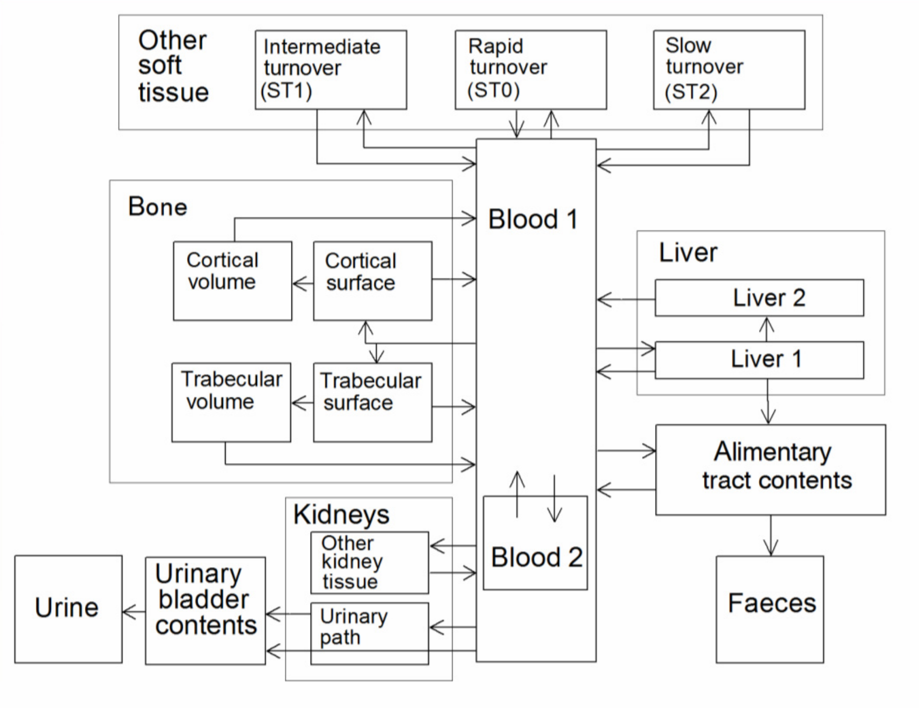


$$A_{TB}(t) = f_1 A_{blood}(0)\, exp\left(-\lambda_{eff_1} t\right) + f_2\, A_{blood}(0) exp\left(-\lambda_{eff_2} t\right)$$

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

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

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:

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

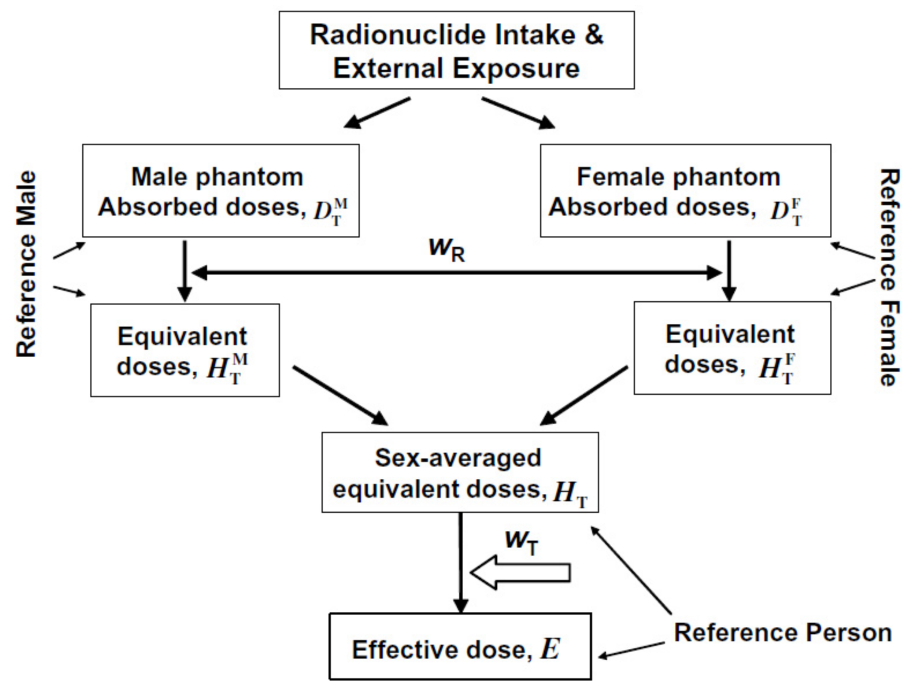
where the target region fractional weights $f(r_T, T)$ are the proportions of the equivalent dose in tissue T associated with target region r_T.

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 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;

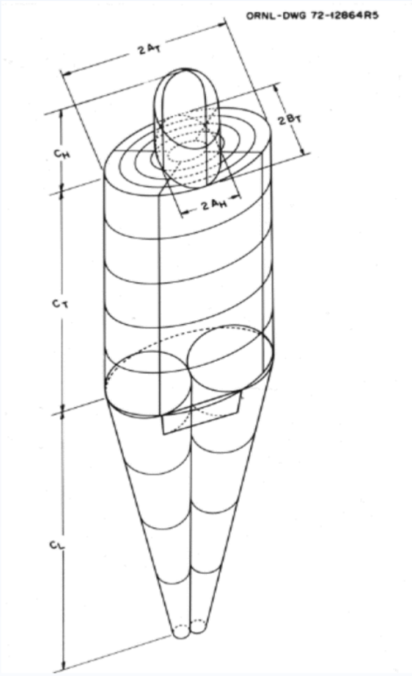
$Y_{R,i}$ is the yield of the i^{th} radiation of type R per nuclear transformation, [(Bq s)$^{-1}$];

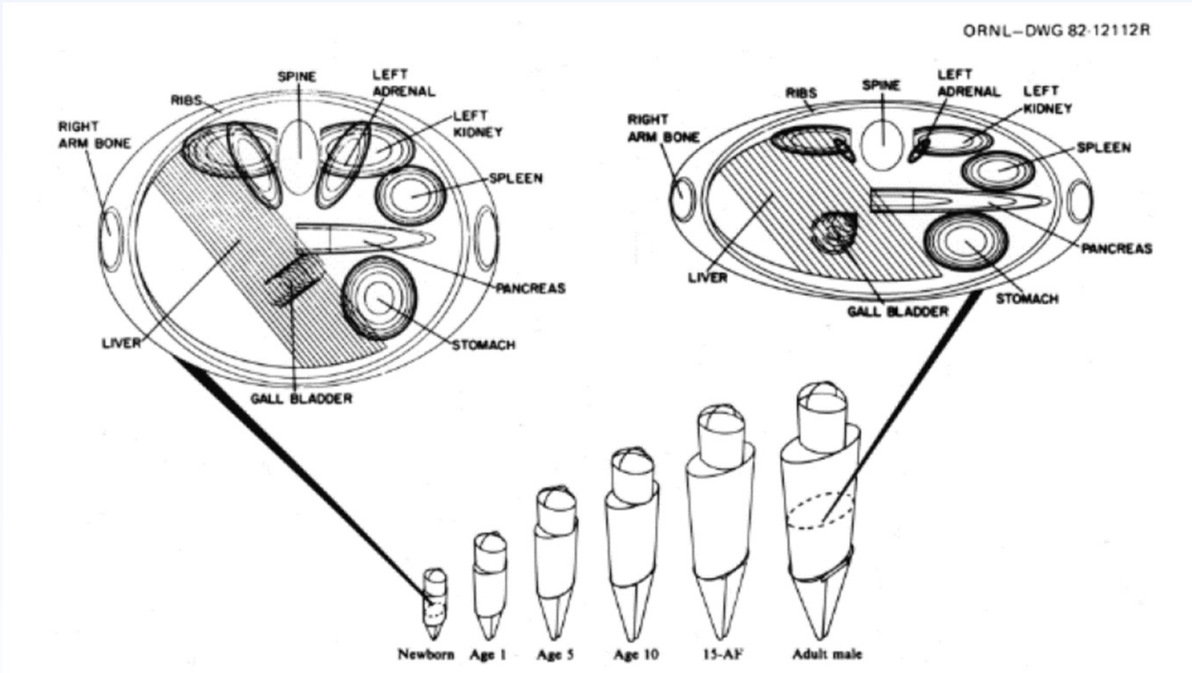
w_R is the radiation weighting factor for radiation type R; and

$\Phi\left(r_T \leftarrow r_S, E_{R,i}\right)$

is the specific absorbed fraction (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}).

Adult Specific Absorbed Fractions - Previous





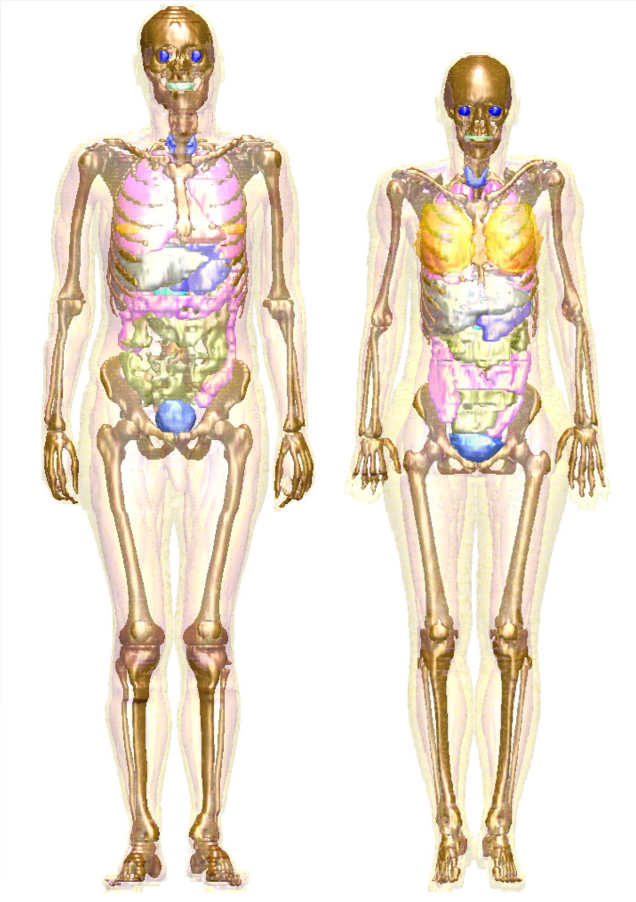
ICRP Publication 30

Appendix I of ICRP Publication 23 – MIRD Phantom

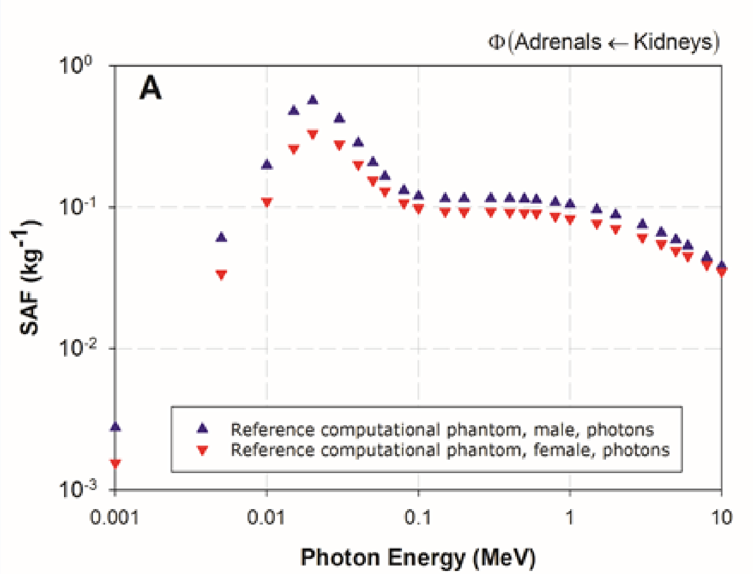
Subsequent ICRP Publications

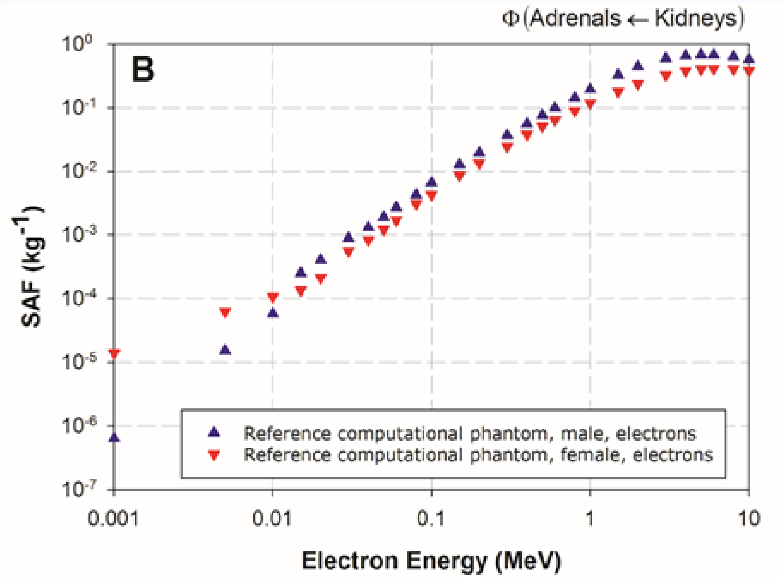
Specific Absorbed Fractions of Energy at Various Ages from Internal Photon Sources (ORNL TM-8381)

Adult Specific Absorbed Fractions - Current



Publication 110 Reference Phantoms





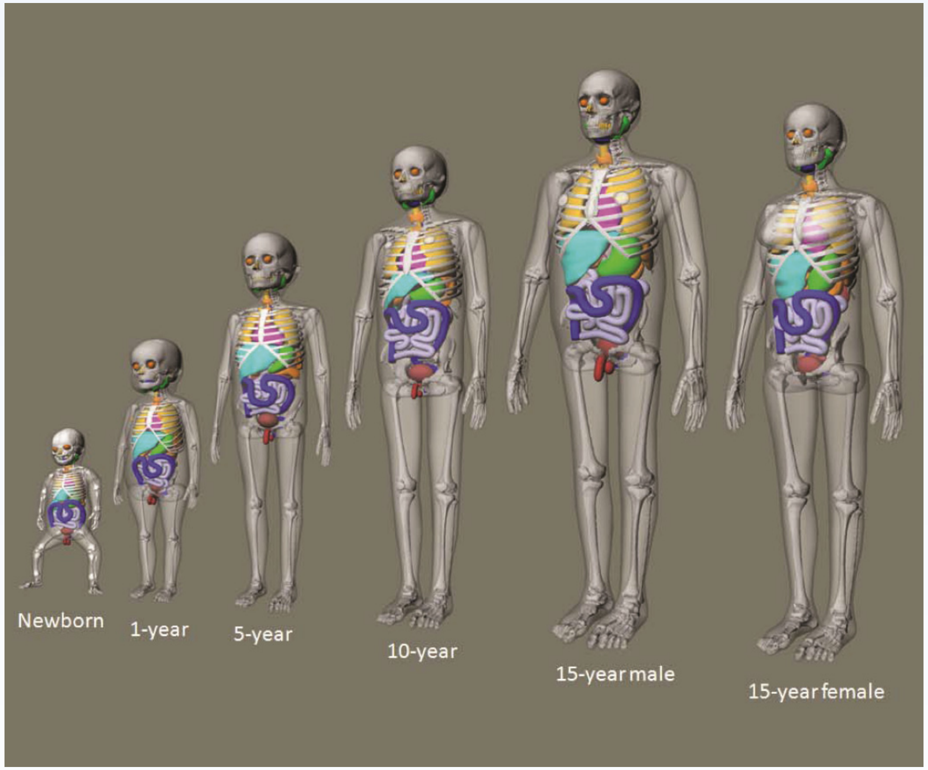
INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

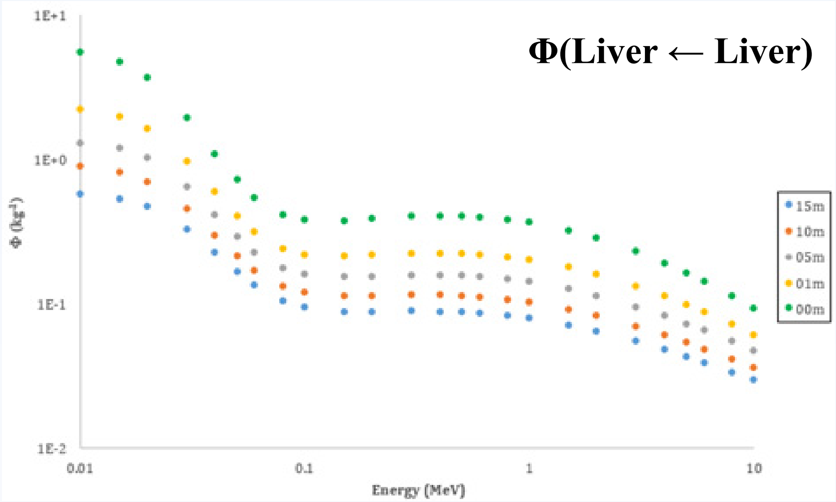
Adult Specific Absorbed Fractions

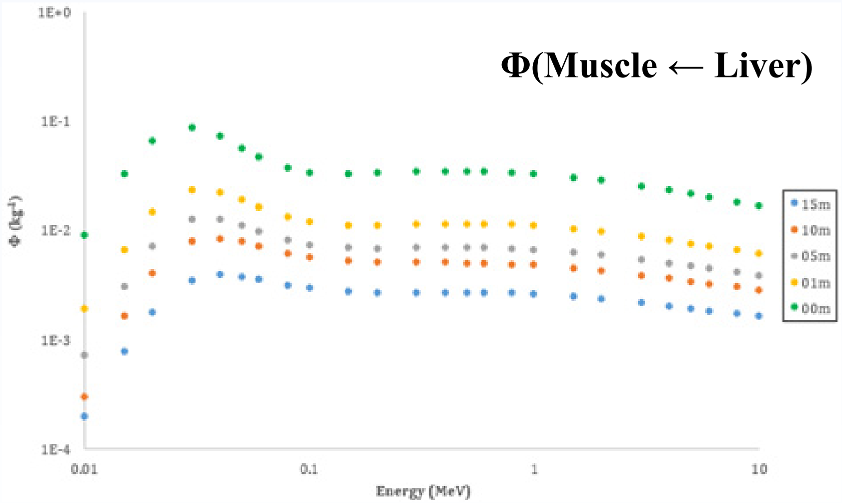
Examples of the many challenges within C2 Task Groups 95 and 96

- 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



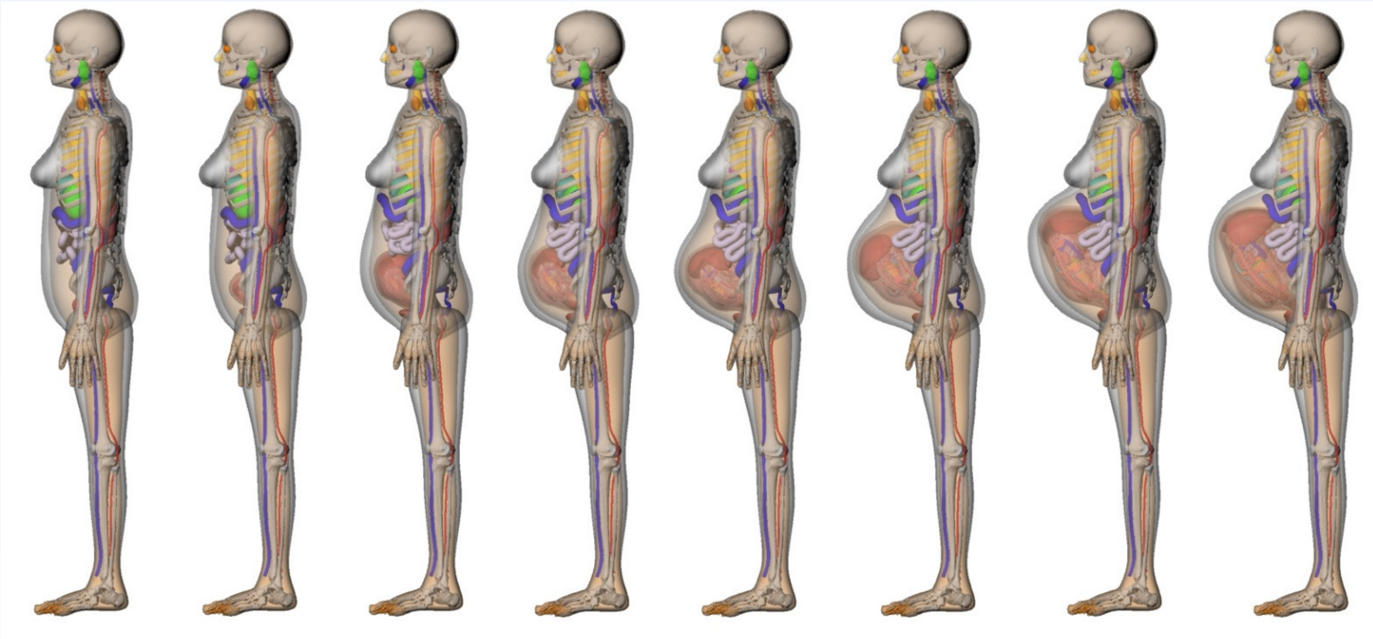




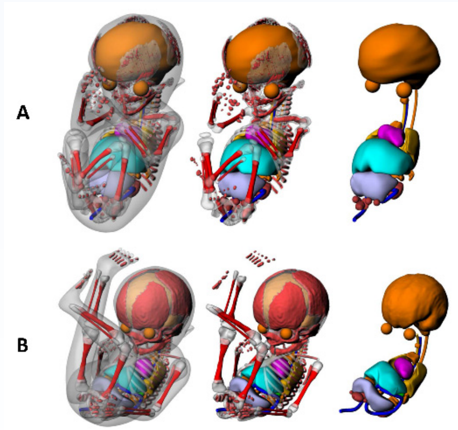
ICRP Series of Pediatric Reference Phantoms

- 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

Pregnant Female Specific Absorbed Fractions



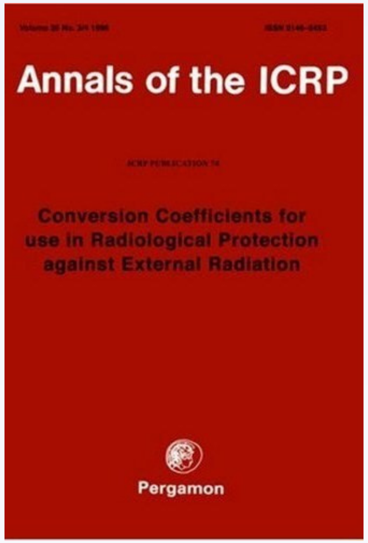
Models at 8 week to 38 weeks post-conception



ICRP Series of Fetal and Pregnant Female Phantoms

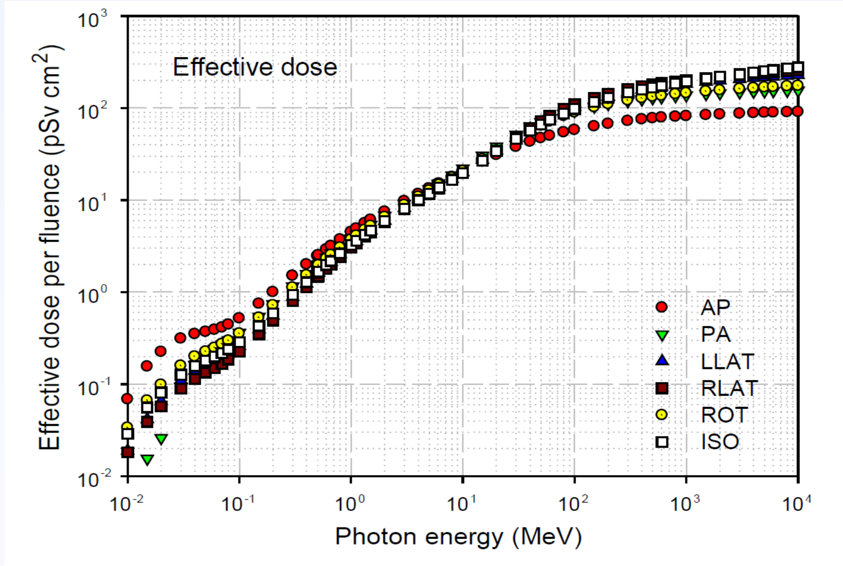
- Derived from UF hybrid phantom series developed for the SOLO Project
- Primary photon and electron SAFs beginning currently
- QA to be completed under TG 96
- *Support* – U.S. Environmental Protection Agency

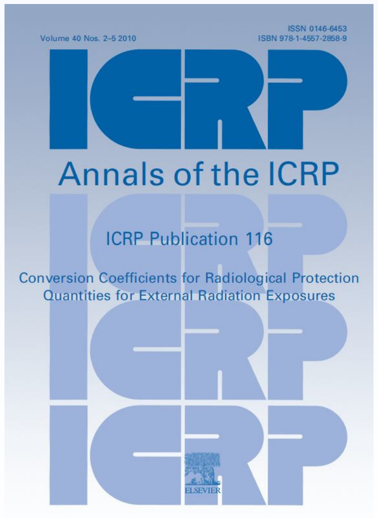
ICRP Dose Coefficients - External



Publication 74 (1996)

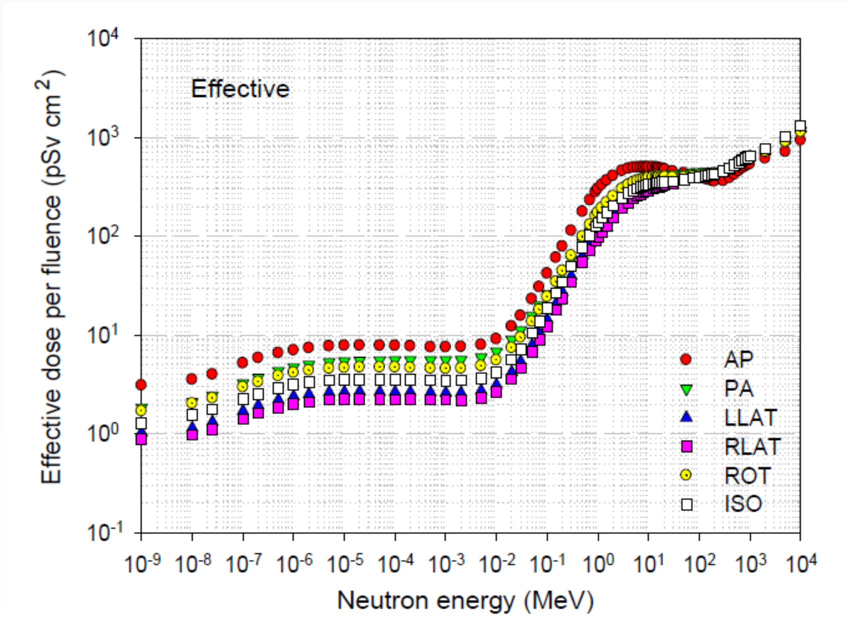
- Based upon review of published dose coefficients
- Mixture of stylized and voxel phantoms





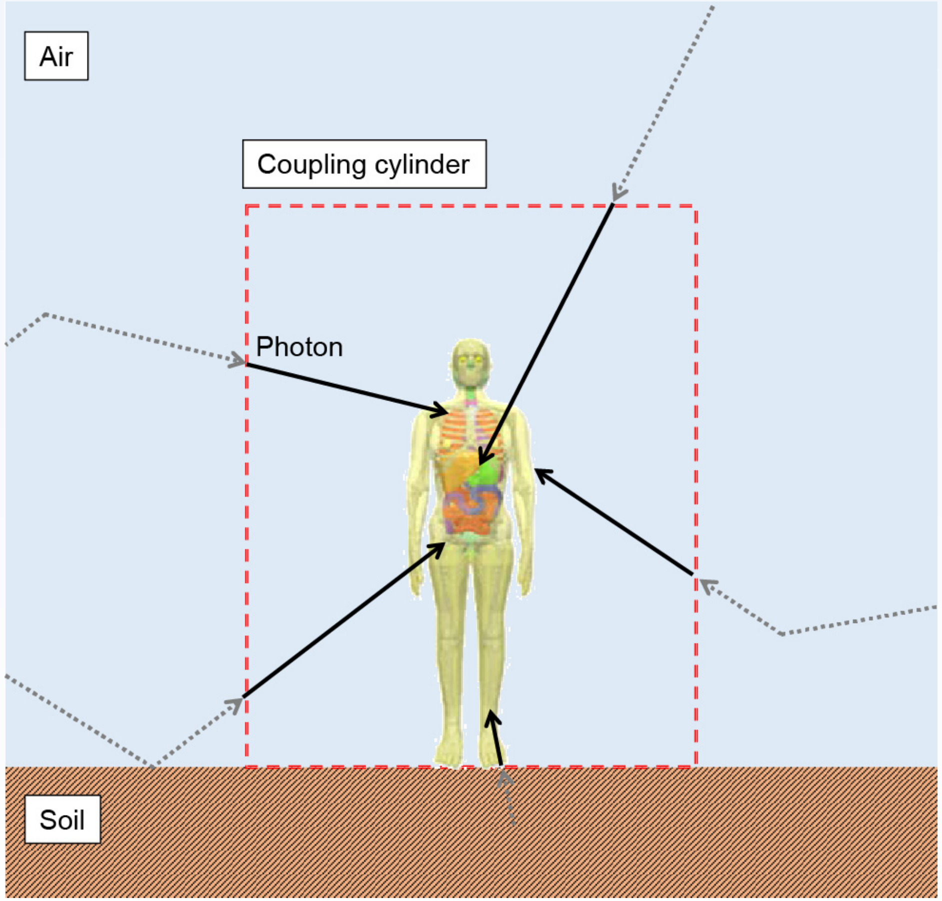
Publication 116 (2010)

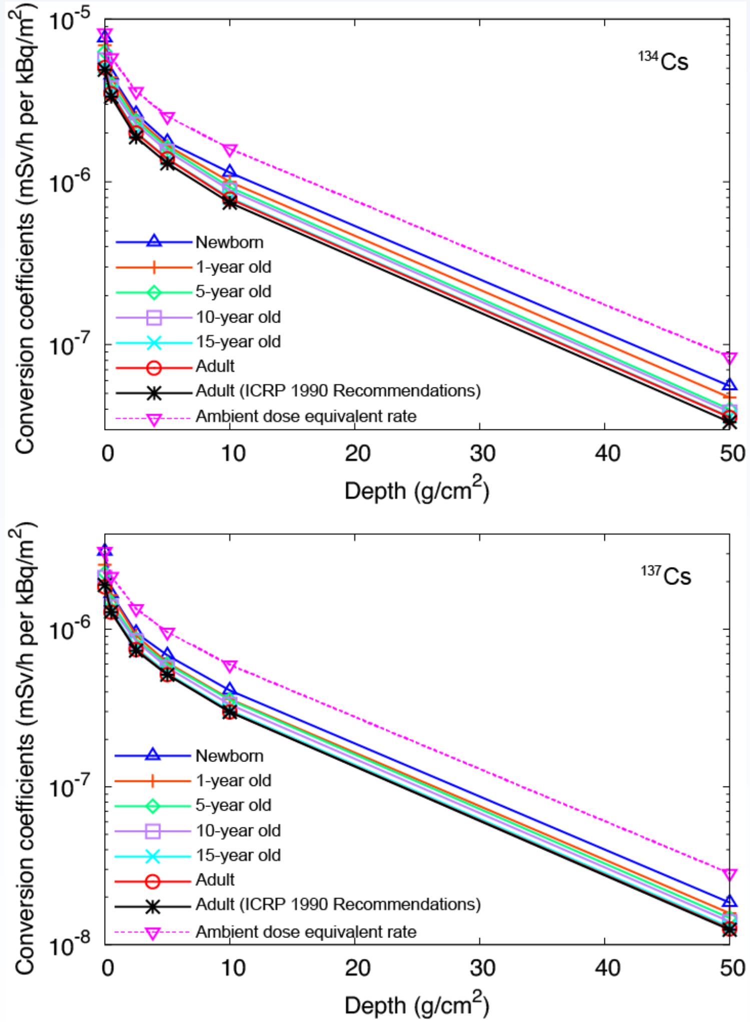
- Based upon new MC calculations using the Publication 110 phantom
- Extensive benchmarking of various MC transport codes



ICRP Task Group 90

Age-Dependent Dose Coefficient for Env. Exposures





Thank you for your attention

東京大学
THE UNIVERSITY OF TOKYO