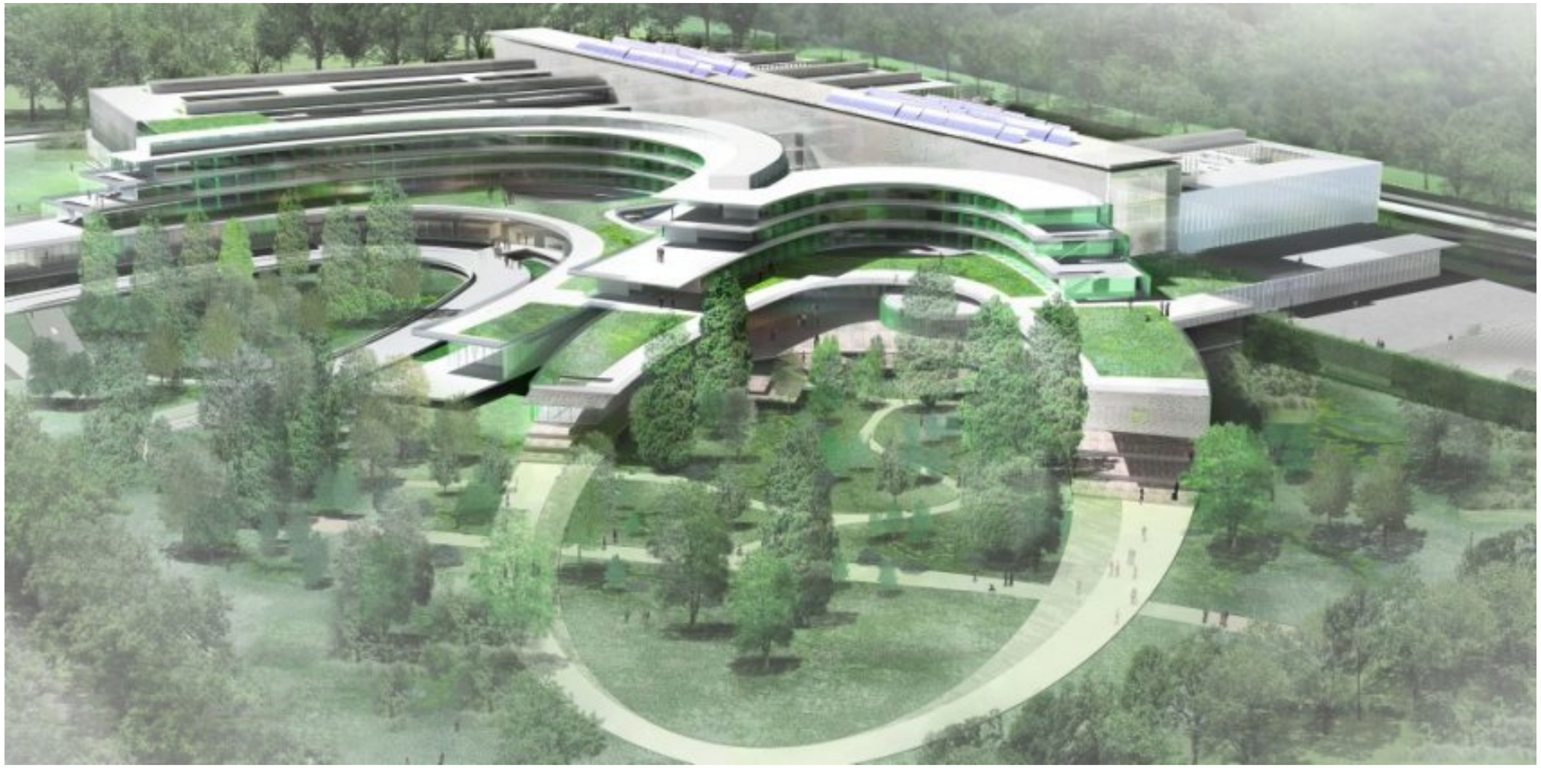
# From Model-based to Patient-specific dosimetry in Nuclear Medicine



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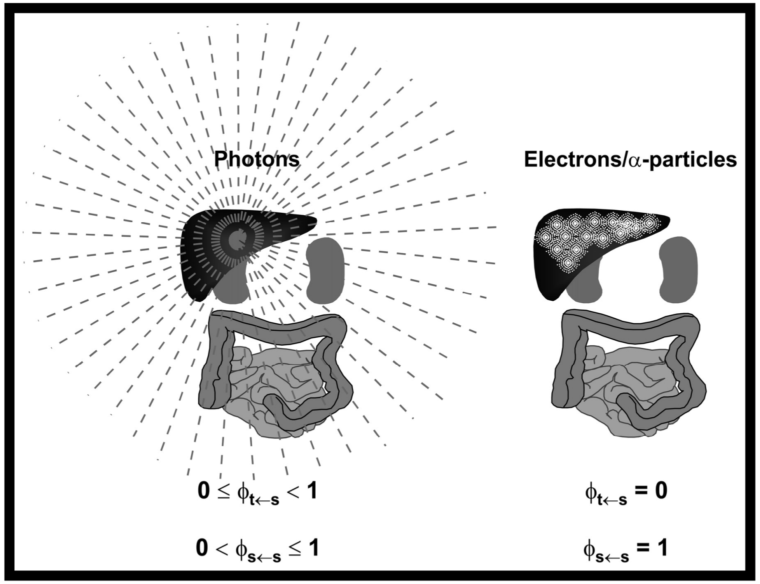
CRCT centre de recherches en cancérologie de Toulouse

Université Paul Sabatier TOULOUSE III

# Nuclear Medicine Dosimetry

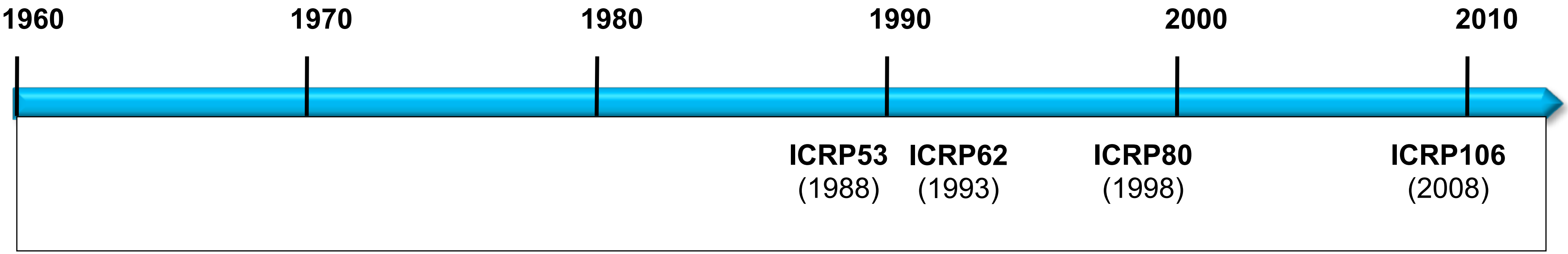
$$\overline{D}_k = \sum_h \tilde{A}_h \times S_{(k \leftarrow h)}$$

- MIRD formalism
  - Ã: Cumulated activity
    - Quantitative Imaging
    - Time-Activity Curve integration
  - S: Absorbed Dose Calculation




- And... global accuracy relies on both terms:
  - Improving Ã requires improving S (and vice-versa)

# Diagnostics dosimetry




«Radiation dose to patients from radiopharmaceuticals»

- 1988 ICRP Publication 53. Ann. ICRP 18 (1-4)
- 1993 Addendum 1 to ICRP Publication 53. Ann. ICRP 22(3)
- 1998 Addendum 2 to ICRP Publication 53. Ann. ICRP 28 (3)
- 2008 Addendum 3 to ICRP Publication 53. Ann. ICRP 38 (1-2)

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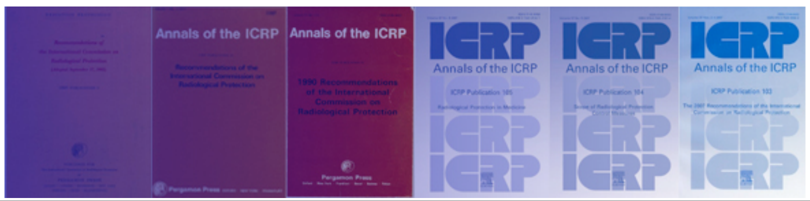
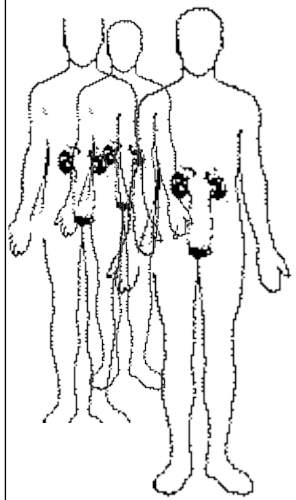
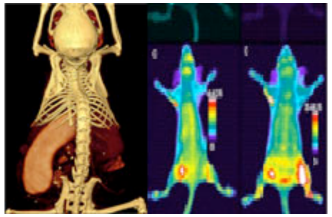
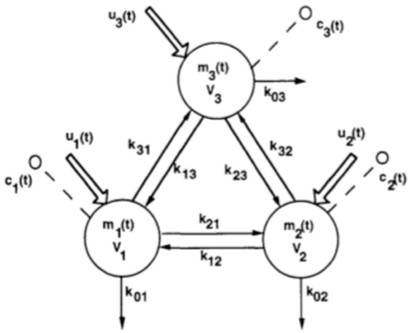


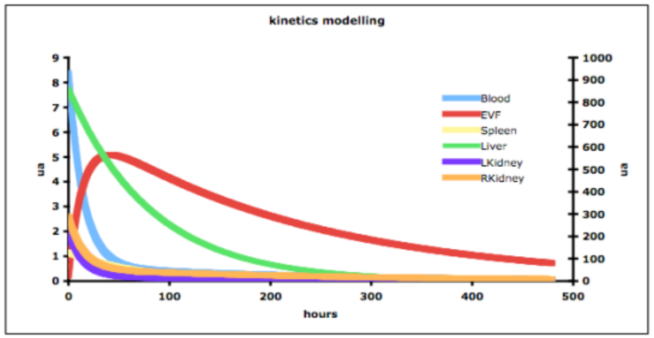
# ICRP Approach (Diagnostics)



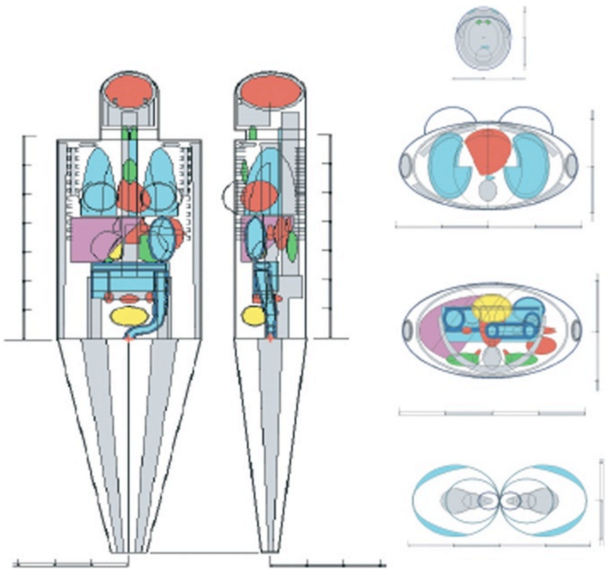


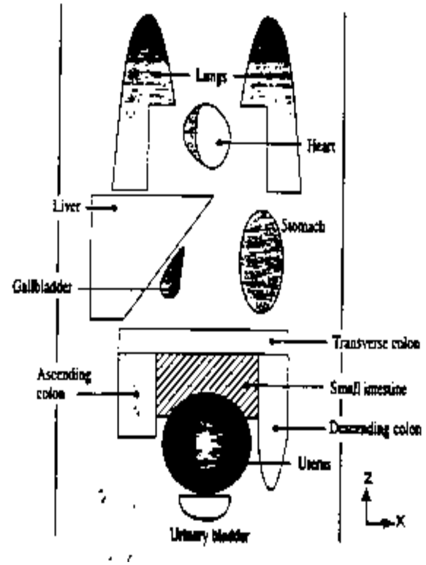
Ã



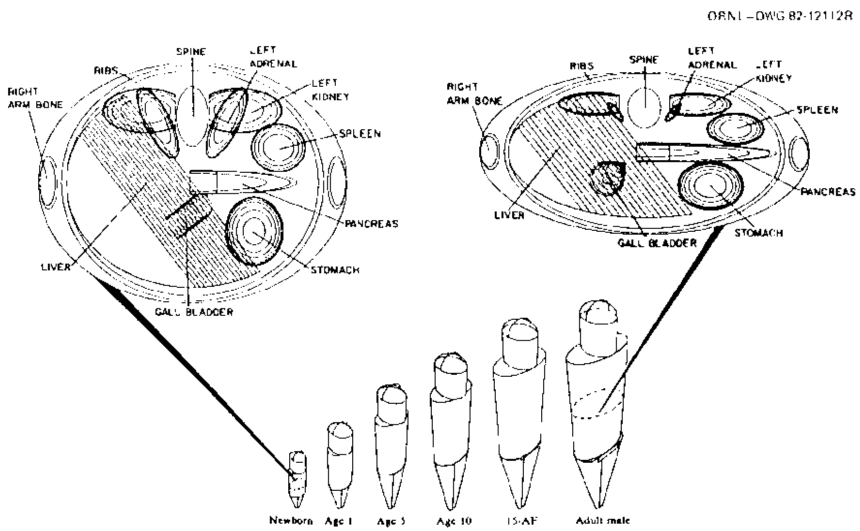



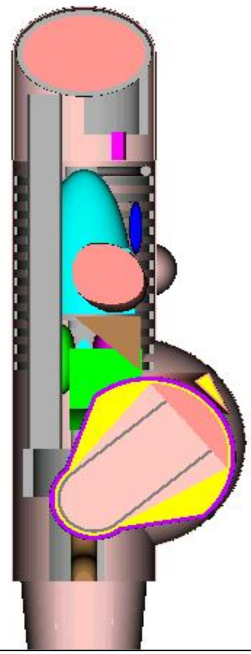
# ICRP Approach (Diagnostics)






S



# Computing models

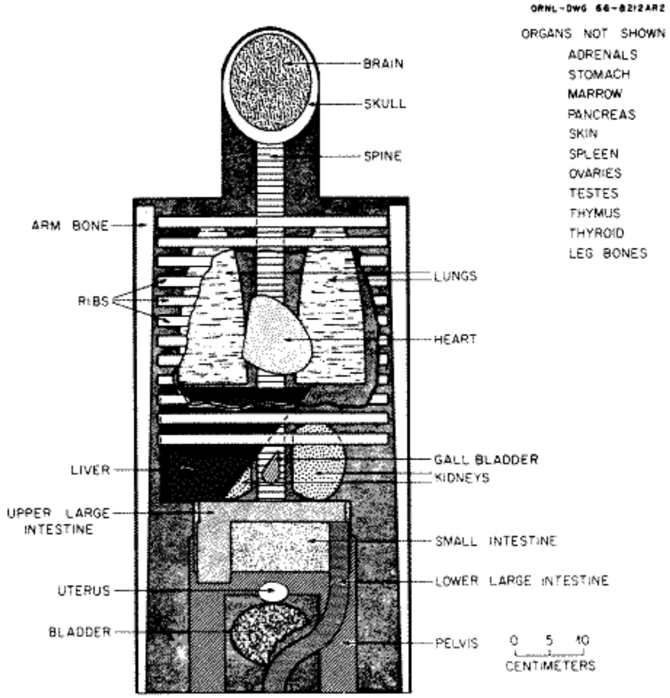
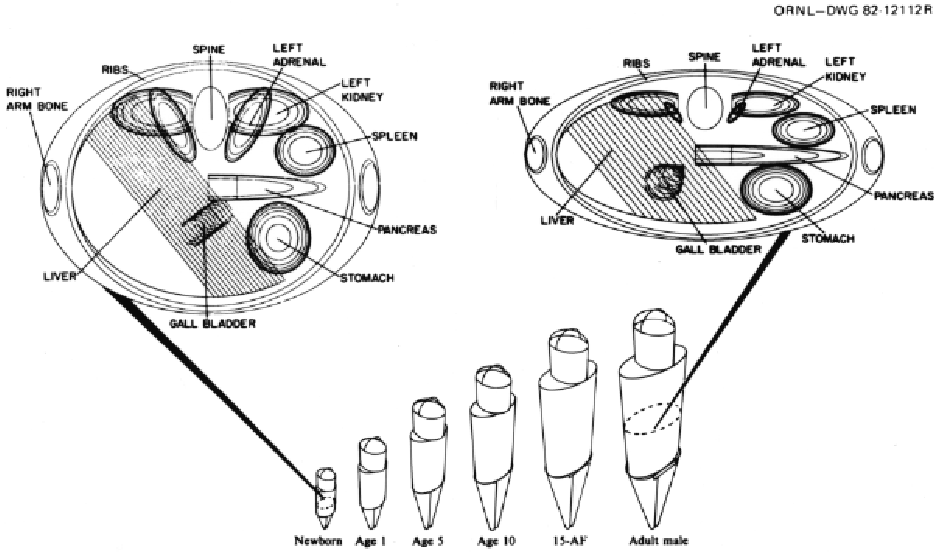
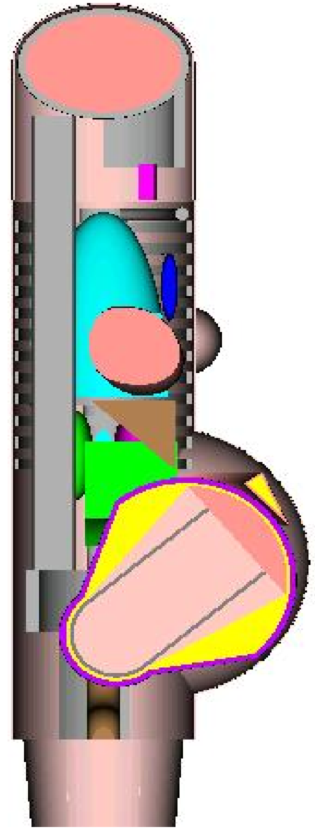



**Fig. A-3. Anterior view of the principal organs in the head and trunk of the adult phantom developed by Snyder et al. (1974).** Although the heart and head have been modified in this report, this schematic illustrates the simplicity of the geometries of the organs.

Snyder 1975




Cristy & Eckerman 1987



Stabin 1995

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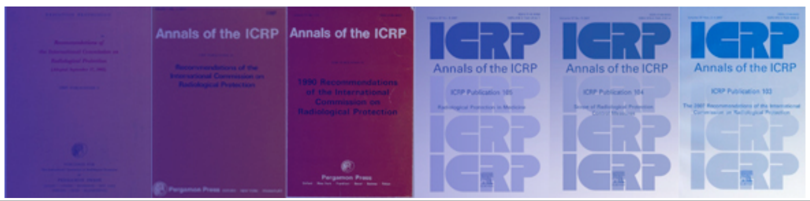
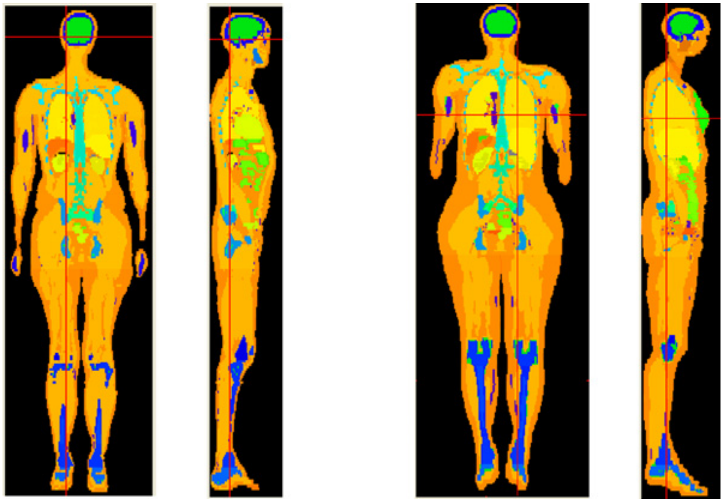
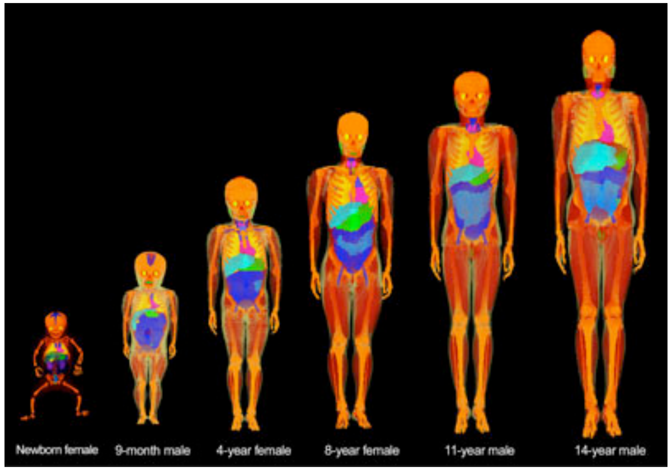


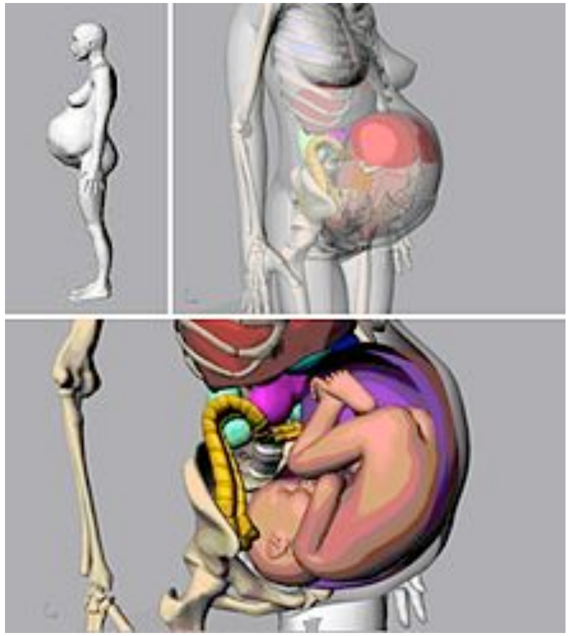
# Computing models



Reference Adult
male/female
ICRP 110




Paediatric series
Lee et al. (2010)
PMB 55(2):339-363



Pregnant female
Guo et al. (2010)
RPD 138(1):20-28

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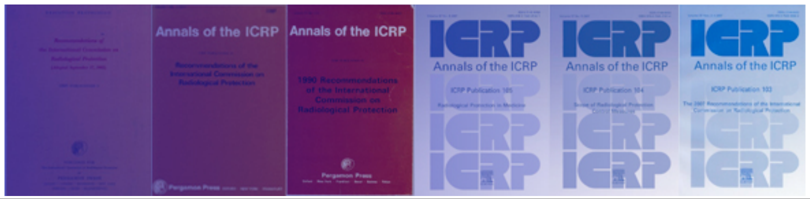
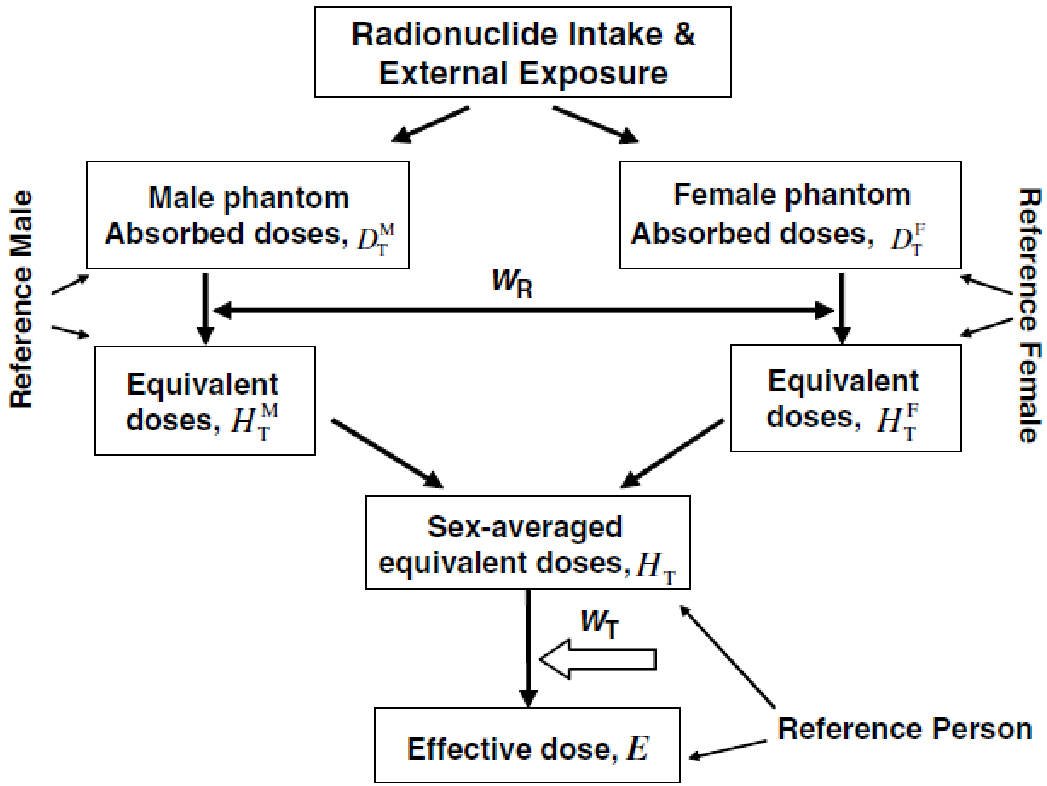
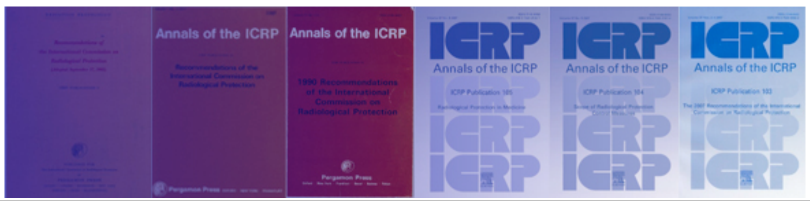


# ICRP Evolution

- Recent reference report (ICRP 103)
  - New computing models (ICRP 110 + … ?)
  - New calculation scheme
  - New weighting factors
- Transition phase! (ex: ICRP 106)

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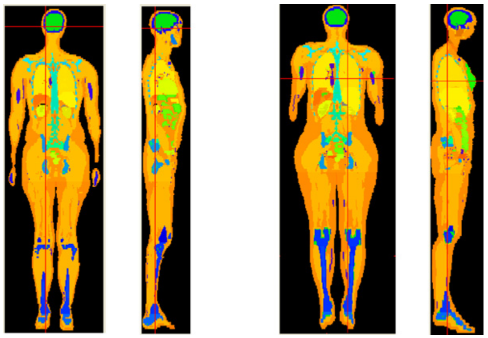
# New ICRP 110 models

**ORIGINAL RESEARCH** **Open Access**

## Effective dose to adult patients from 338 radiopharmaceuticals estimated using ICRP biokinetic data, ICRP/ICRU computational reference phantoms and ICRP 2007 tissue weighting factors

Martin Andersson[1*], Lennart Johansson[2], David Minarik[1], Sigrid Leide-Svegborn[1] and Sören Mattsson[1]

Andersson et al. EJNMMI Physics 2014 1:9



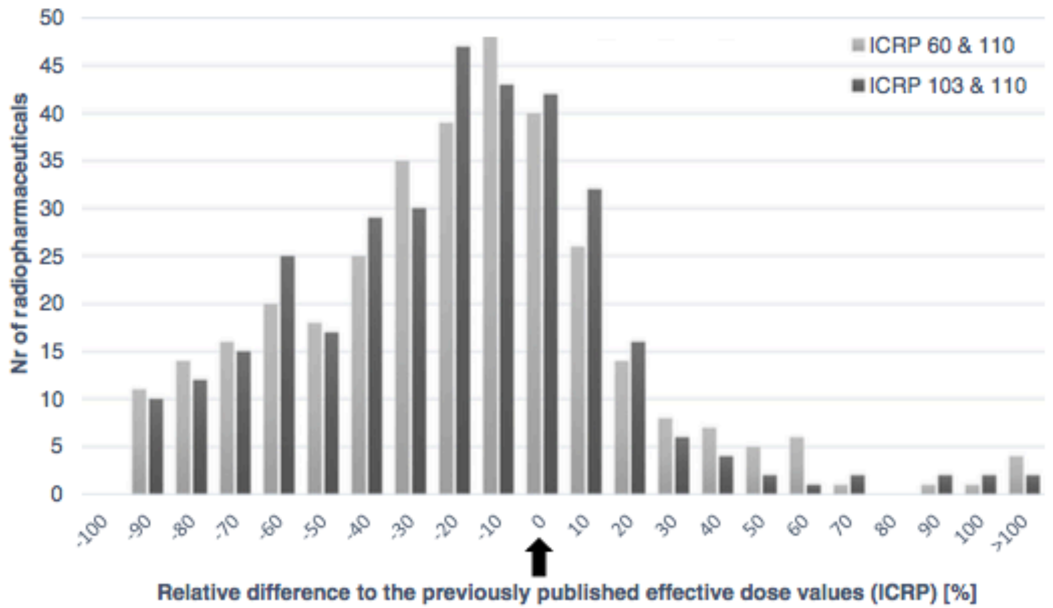



**Figure 1 A histogram of the relative difference between different dose values.** The relative difference between the old published effective dose per unit administered activity and the effective dose values calculated with the new phantom (ICRP 110) and with (1) the new (ICRP 103) and (2) the previous (ICRP 60) tissue weighting factors. The arrow indicates identical results between old and new estimations.

- Zankl et al. «Electron specific absorbed fractions for the adult male and female ICRP/ICRU reference computational phantoms» Phys Med Biol 2012, 57(14):4501–4526

- Andersson et al. «An internal radiation dosimetry computer program, IDAC2.0, for estimation of patient dose for radiopharmaceuticals» Radiat Prot Dosimetry 2013; doi: 10.1093/rpd/nct337

# Diagnostics dosimetry: Conclusion

| | | |
|---|---|---|
| | | |
| Group | Model | Model<br>ICRP - MIRD DER |
| | | |
| | | |

# Molecular Radiotherapy


**http://www.youtube.com/watch?v=GRRmX5eTa8s**

# Dosimetry for MRT:

| | | |
|---|---|---|
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | | |
| | | |

- *Patient-specific dosimetry requires AT LEAST a specific determination of $\tilde{A}_h$*

# Quantitative imaging: $\tilde{A}_h$

Is quantitative imaging for dosimetric purposes different from 'conventional' quantitative imaging in NM?

Quick answer: No...

...but some aspects are specific...

What kind of quantitative imaging is required for dosimetry?

# Quantitative imaging: $\tilde{A}_h$

- What quantitative imaging implies:
  - On principle: Absolute quantification
  - Activity concentration in all voxels (Bq/cc)
  - Corrections OK for the whole FOV
- For the whole patient (space)
- Follow radiopharmaceutical kinetics (time)

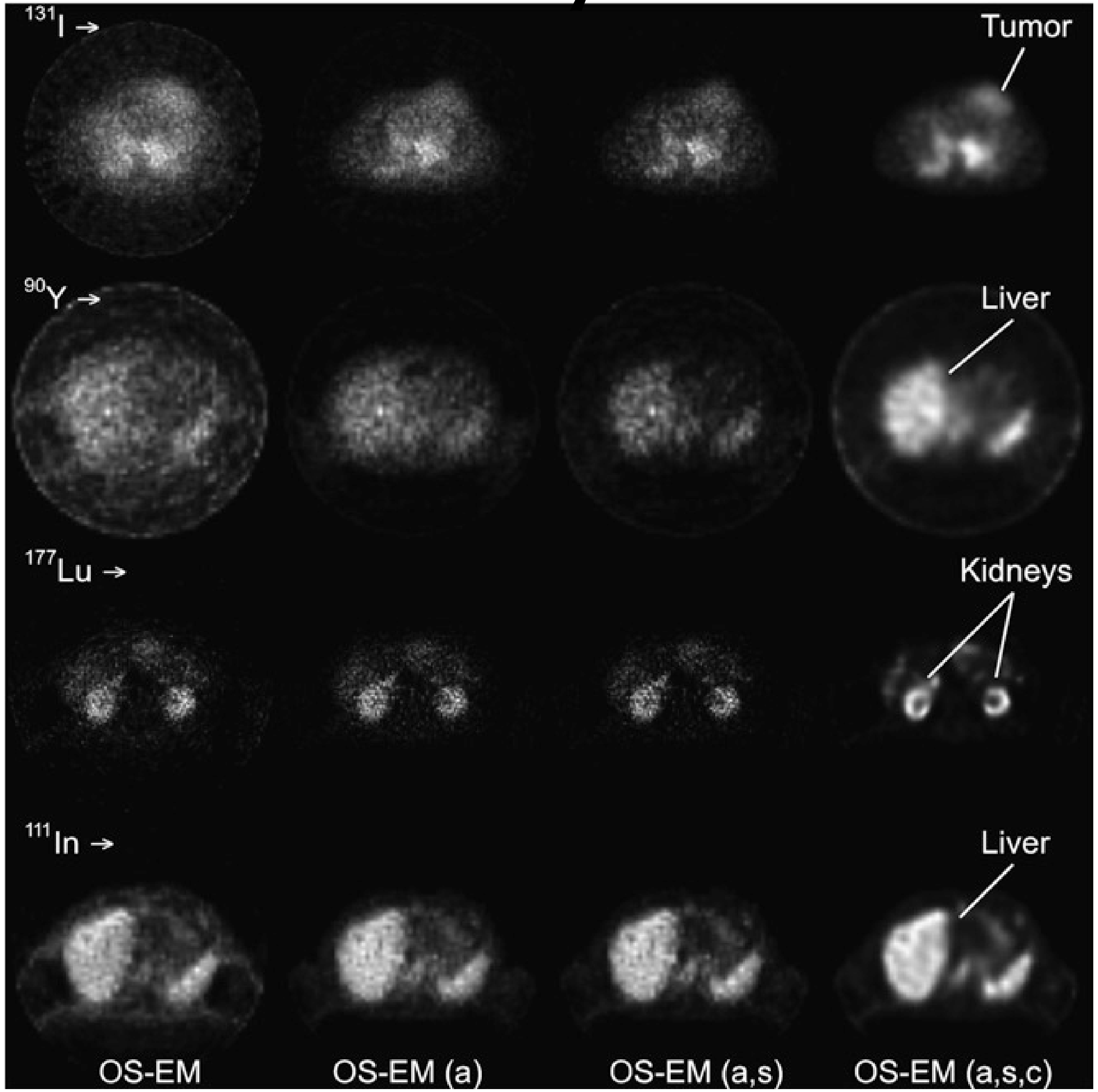
MIRD Phamphlet 16 (Siegel *et al*. JNM 40, 37s-61s, 1999)

# Assessing errors: the main issue?

- Methodologies have been proposed to correct for several effects that degrade the quantitative content of NM images
- Many references are available in the literature!
  - Some approaches were implemented in clinical practice
  - Most remain as 'one centre' approach
- So who's right?

Dewaraja YK et al. **2012**, **MIRD pamphlet No. 23**:
Quantitative SPECT for patient-specific 3-dimensional dosimetry in internal radionuclide therapy. *J Nucl Med* 53(8), pp. 1310-25

# SPECT: currently used isotopes




Dewaraja YK et al. **2012**, **MIRD pamphlet No. 23**:
Quantitative SPECT for patient-specific 3-dimensional dosimetry in internal radionuclide therapy. *J Nucl Med* 53(8), pp. 1310-25

# SPECT: currently used isotopes

| Study | Radionuclide | System | Reconstruction | accuracy |
|---|---|---|---|---|
| Zeintl et al., 2010 (*18*) | $^{99m}Tc$ | SPECT/CT | OS-EM, CDR, CT-derived AC, energy window–based SC, PVC | <6.8% error for 0.5- to 16-mL spheres |
| Dewaraja et al., 2010 (*37*) | $^{131}I$ | SPECT/CT | OS-EM, CDR, CT-derived AC, energy window–based SC | <17% error for 8- to 95-mL spheres; 31% for 4-mL sphere |
| Assie et al., 2010 (*23*) | $^{111}In$ | SPECT and CT separate | OS-EM, CT-derived AC, energy window–based SC, PVC | <20% error for organs and 2- to 32-mL spheres; 48% error for 0.5-mL sphere |
| Shcherbinin et al., 2008 (*49*) | $^{99m}Tc$, $^{111}In$, $^{123}I$, $^{131}I$ | SPECT/CT | OS-EM, CDR, CT-derived AC, analytic scatter modeling | 3%–5% error for 32-mL bottles |
| Minarik et al., 2008 (*95*) | $^{90}Y$ | SPECT/CT | OS-EM, CDR, CT-derived AC, ESSE | <11% error for liver and 100-mL sphere |
| Willowson et al., 2008 (*19*) | $^{99m}Tc$ | SPECT/CT | OS-EM, CT-derived AC, transmission-dependent SC, PVC | <4% error for liver and cardiac chambers |
| de Wit et al., 2006 (*59*) | $^{166}Ho$ | SPECT | OS-EM, CDR, $^{153}Gd$ transmission source–derived AC, Monte Carlo scatter modeling | 16% average error for 220-mL bottles |
| Du et al., 2006 (*62*) | $^{123}I$ | SPECT/CT | OS-EM, CDR, CT-derived AC, ESSE, PVC | <2% error for putamen and caudate regions of brain phantom |
| He at al, 2005 (*52*) | $^{111}In$ | SPECT/CT | OS-EM, CDR, CT-derived AC, ESSE, PVC | <12% error for organs and 8- to 23-mL spheres |
| Koral et al., 2005 (*50*) | $^{131}I$ | SPECT and CT separate | OS-EM, CDR, CT-derived AC, energy window–based SC, PVC | <7% average error for 100-mL sphere |

Dewaraja YK et al. **2012, MIRD pamphlet No. 23**:
Quantitative SPECT for patient-specific 3-dimensional dosimetry in internal radionuclide therapy. *J Nucl Med* 53(8), pp. 1310-25

# Dosimetry for MRT:

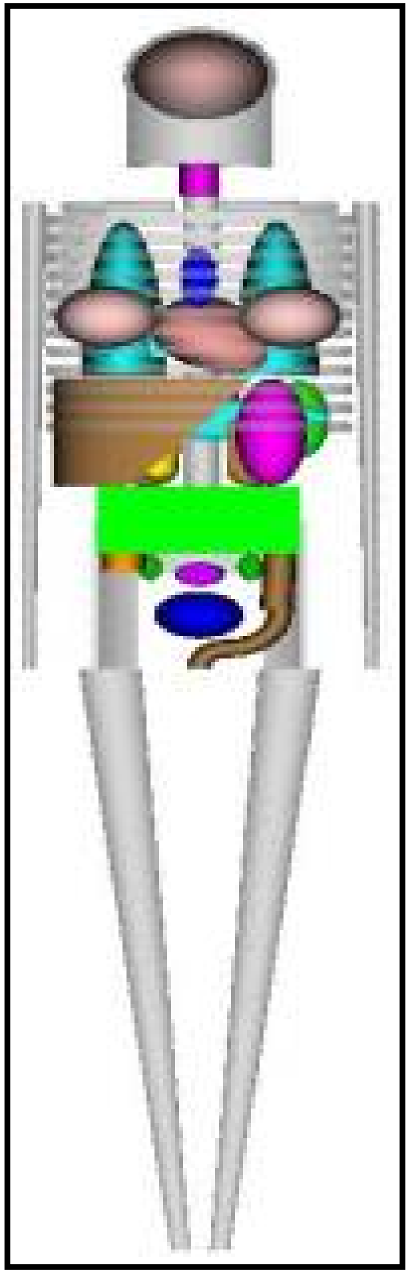
| | | |
|---|---|---|
| | | |
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | | |
| | | |

- *Possibly the most important source of uncertainty?*

# S factor calculation: $S_{(k \leftarrow h)}$

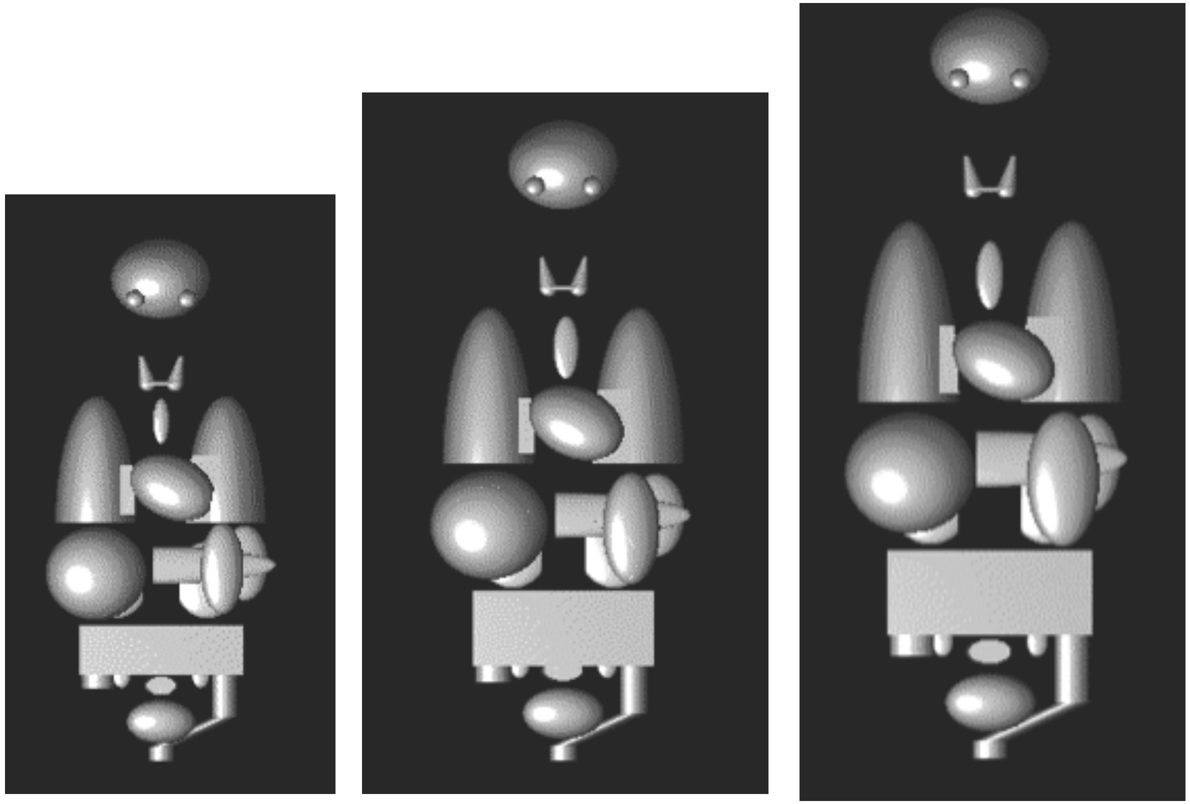
- From 'old' MIRD phantoms

MIRDOSE3
Olinda



# S factor calculation: $S_{(k \leftarrow h)}$

- From ‘old’ MIRD phantoms
- To more refined phantoms

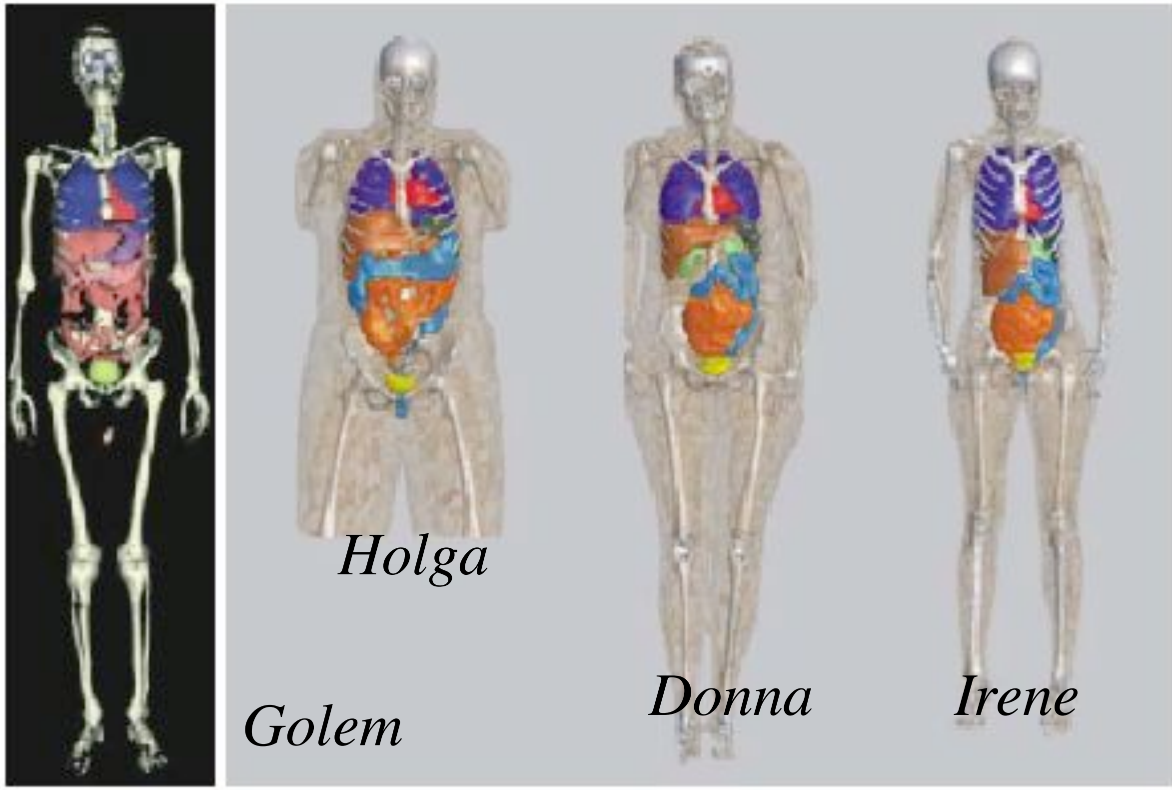


150 cm 160 cm 170 cm

Clairand et al. (2000) PMB **45**:2771-2785

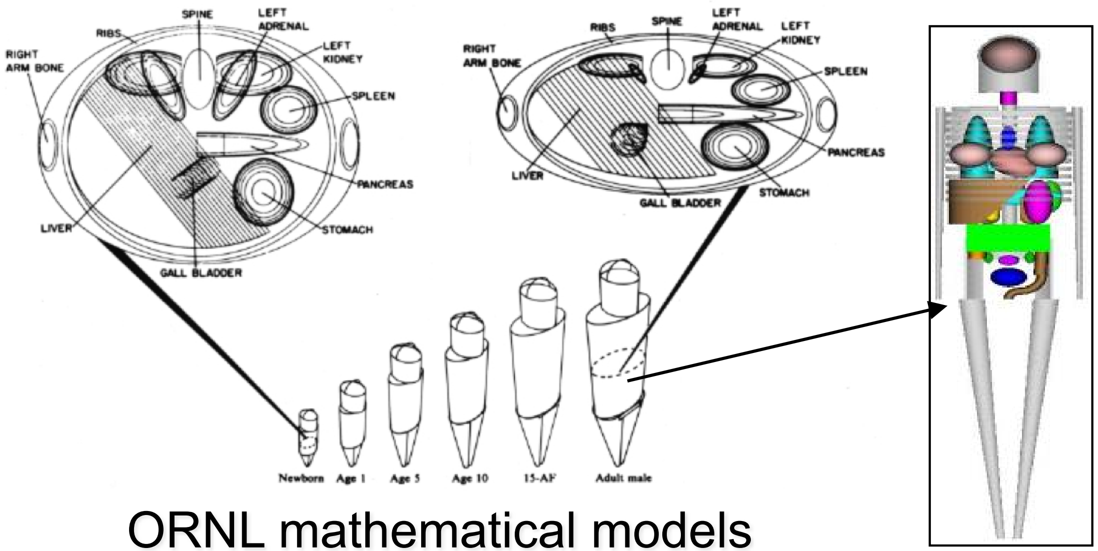
# S factor calculation: $S_{(k \leftarrow h)}$

- From 'old' MIRD phantoms
- To more refined phantoms
- To voxel-based phantoms




*Radiat. Env. Biophys (2001) 40:153-162*
*PMB (2002) 47:89-106*

# Mass Adjustment




ORNL mathematical models

(ORNL/8381)

Standard S values

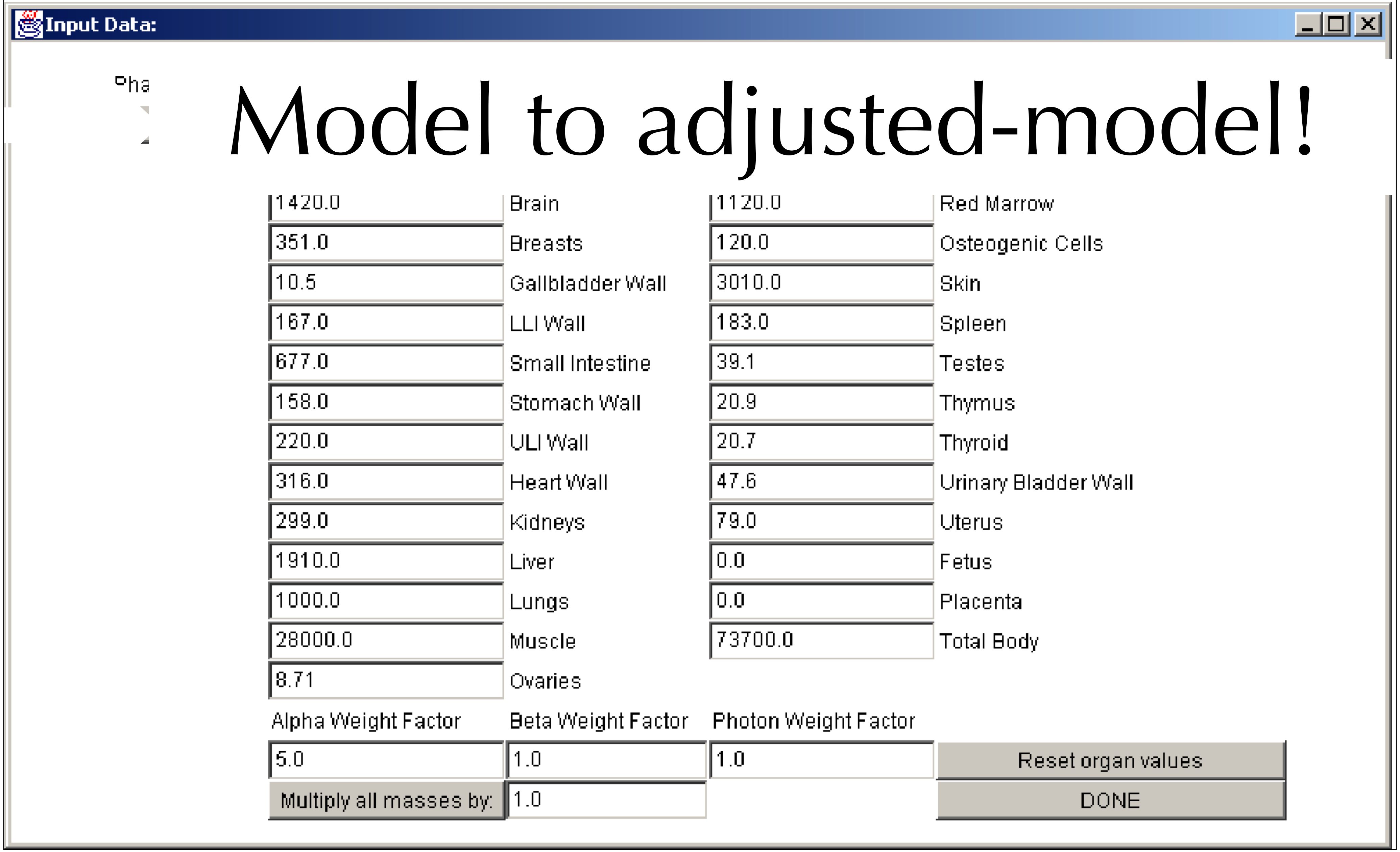
For SELF Irradiation Only

$$S_{r \leftarrow r}(patient) = S_{r \leftarrow r}(standard) \cdot \frac{Mass_r(standard)}{Mass_r(specific)}$$

Divoli et al. (2009) JNM 50(2):316-323

# OLINDA mass adjustment

Model to adjusted-model!



# Dosimetry for MRT:

| | | |
|---|---|---|
| | | |
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | Model ± adjusted | Model ± realistic |
| | | |

- *Still «model-based» dosimetry - but easily implemented in a clinical environment!*

# Dosimetry for MRT:

| | | |
|---|---|---|
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | Model ±<br>adjusted | Model ± realistic |
| Specific | | |

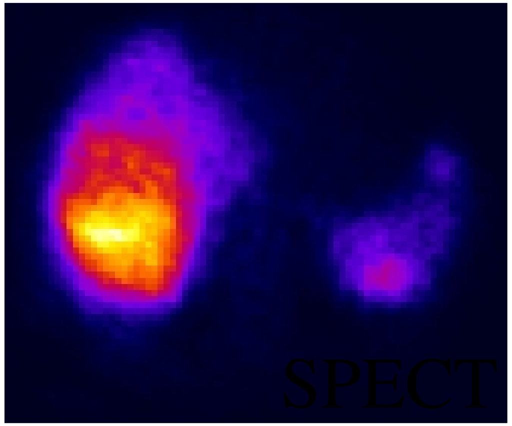
- *Patient-specific dosimetry requires AT LEAST a specific determination of $\tilde{A}_h$*

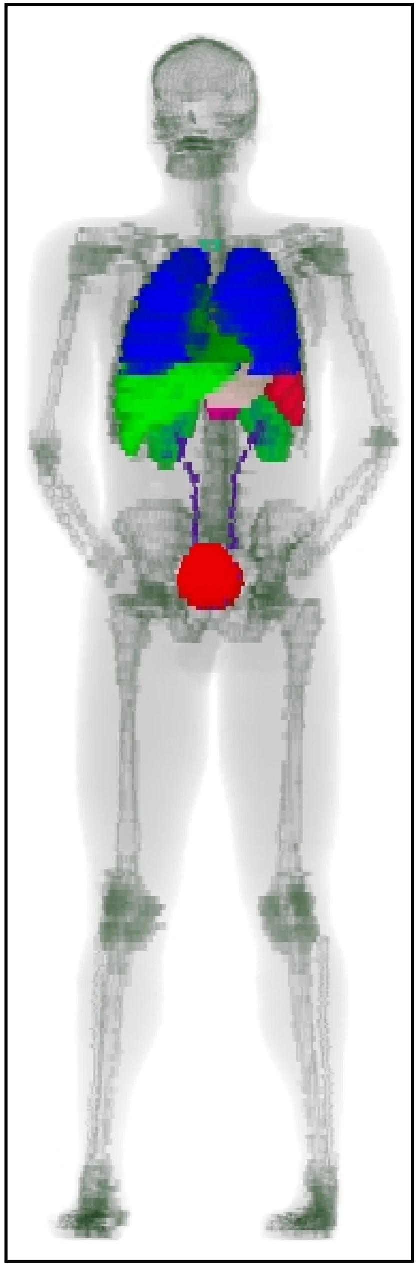
# Dosimetry for MRT:

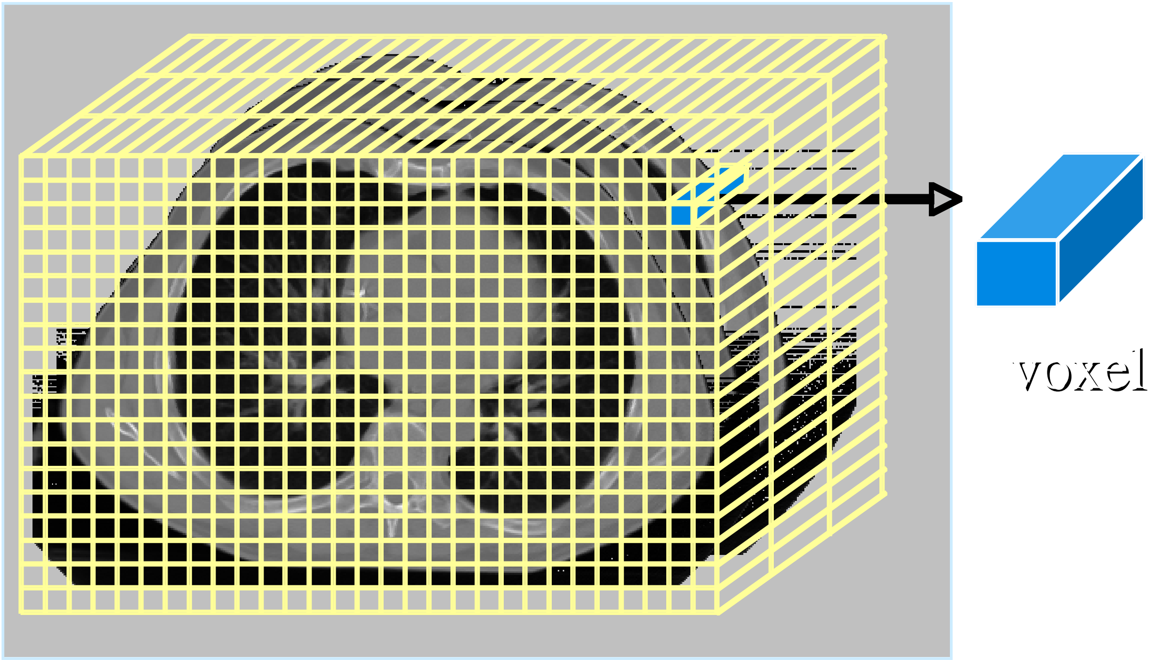
| | | |
|---|---|---|
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | Model ±<br>adjusted | Model ± realistic |
| Specific | Specific | |

- *Specific S factor determination requires patient-specific geometry assessment*

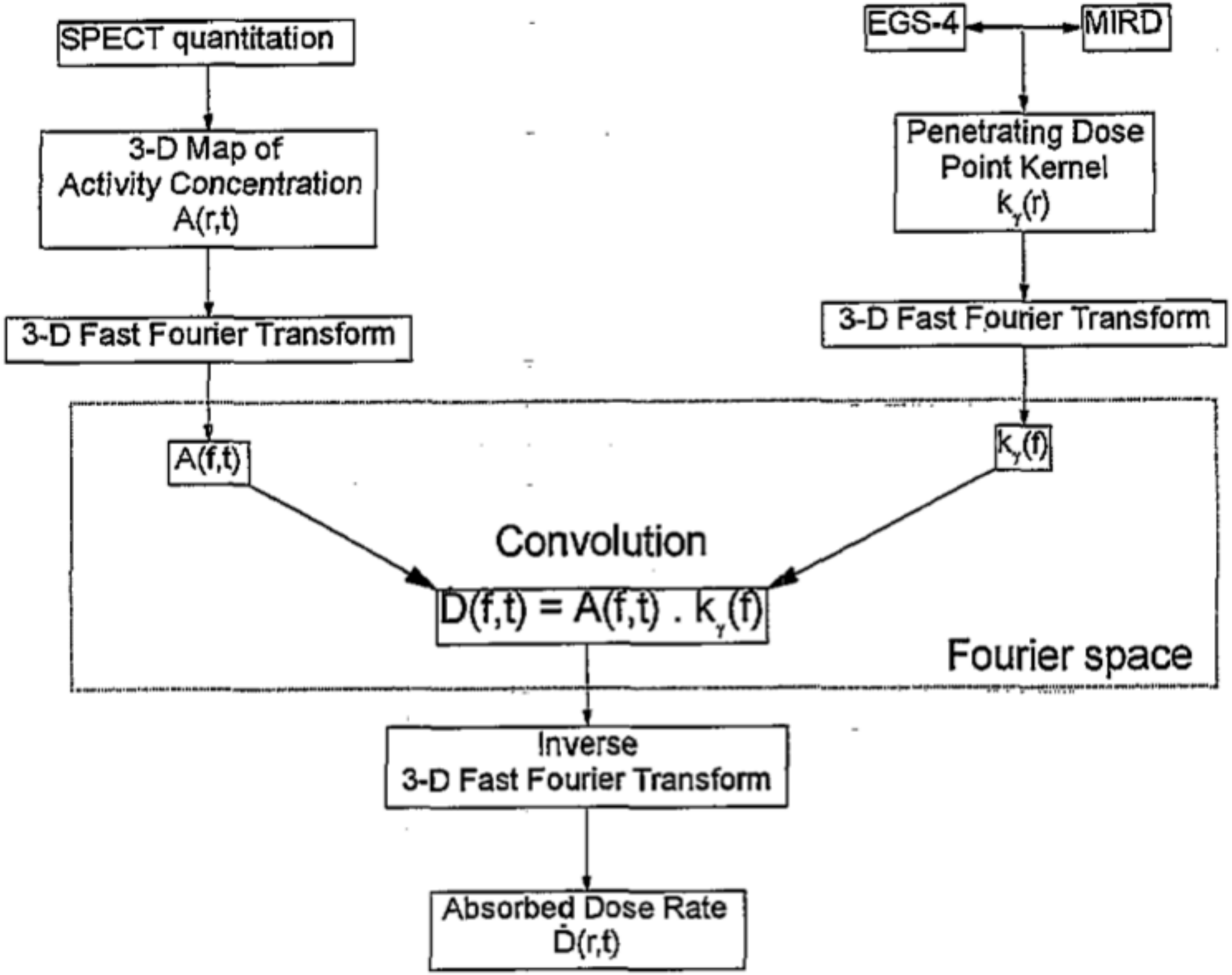
# Patient-Specific dosimetry:

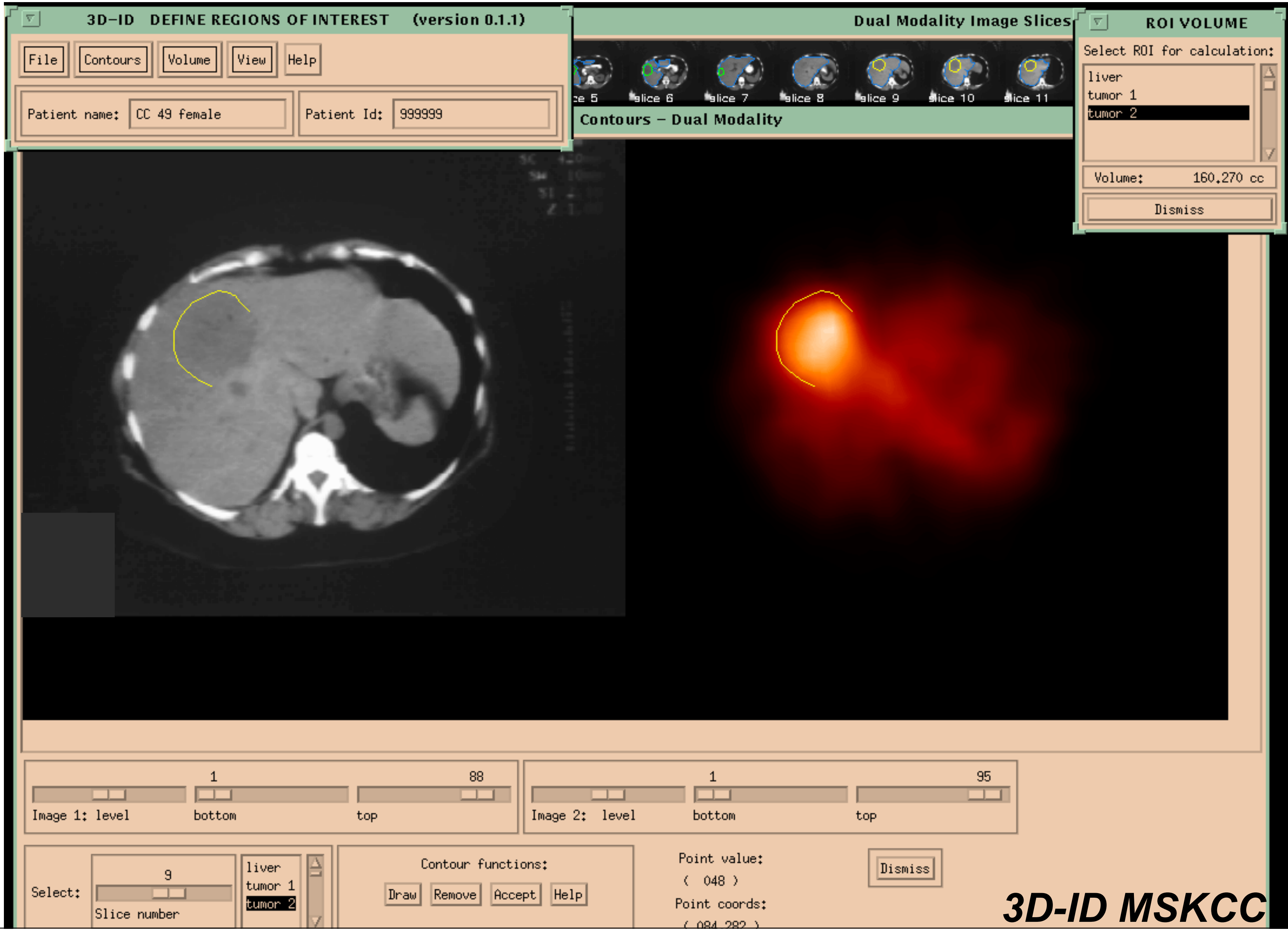


# Patient specific dosimetry

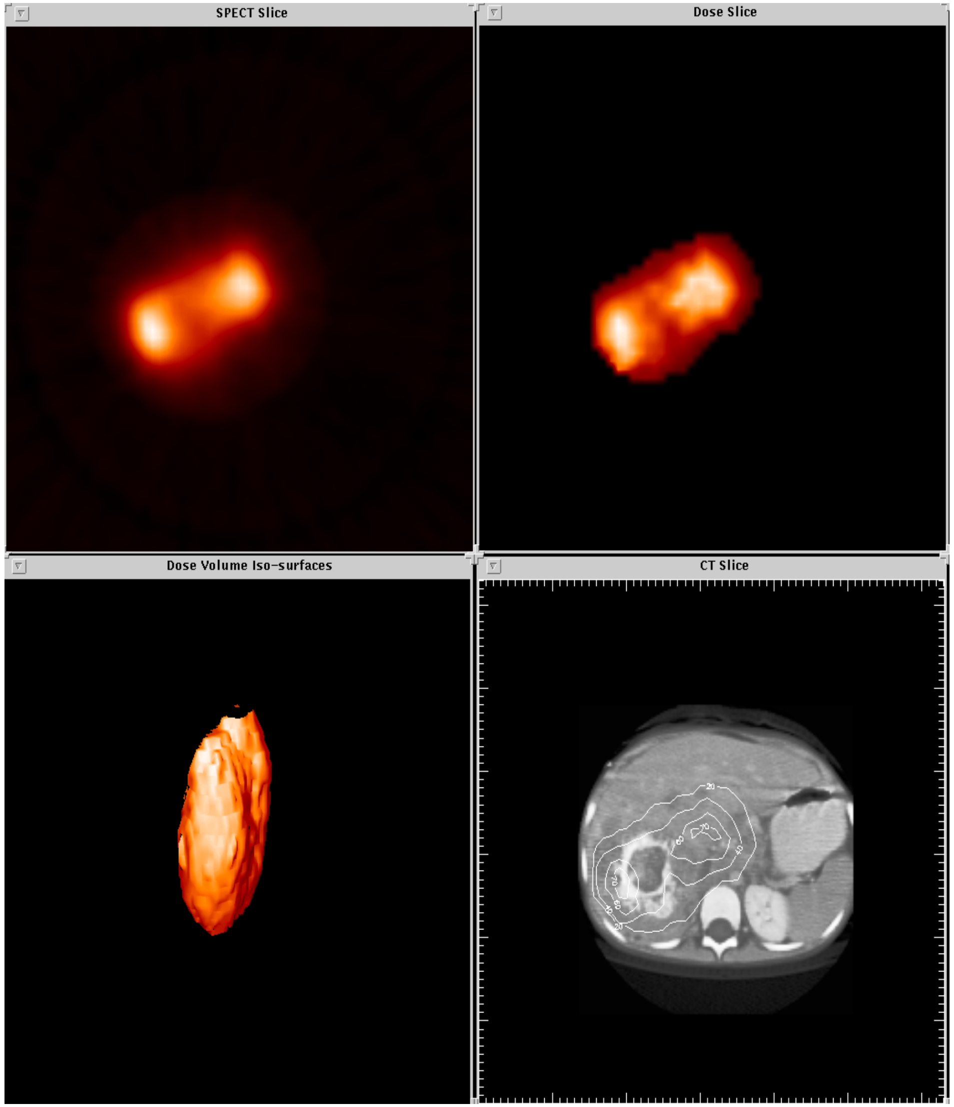


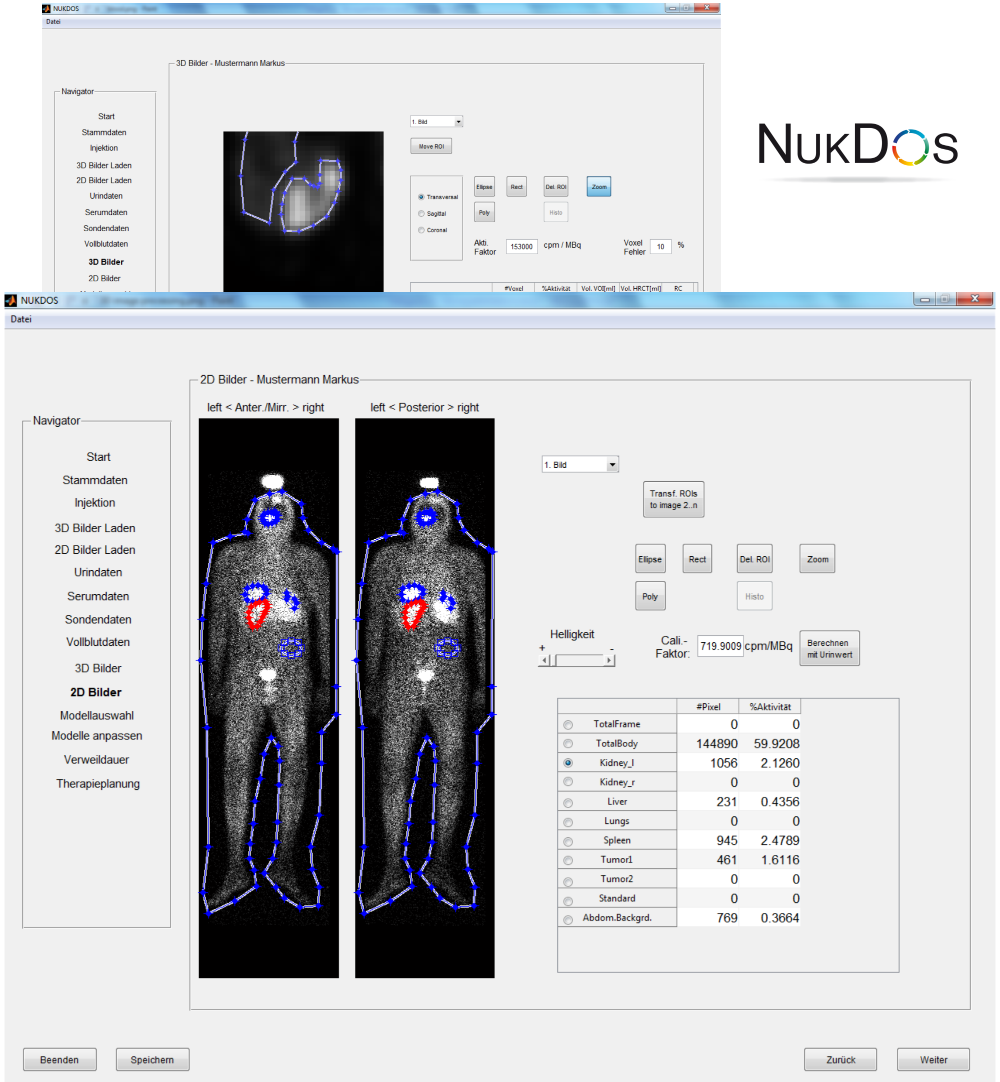

Giap et al. Phys Med Biol. 1995, Mar;40(3):365-81

# Patient specific dosimetry



# Therapy dosimetry




NukDos

RMDP (M Guy, RMH)

NukDos (M Laßmann, UKW)

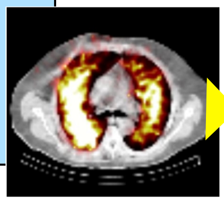
# Patient-specific clinical dosimetry

SPECT

CT

$d_0$, $d_1$, $d_3$, …

- Corrections:
  - dead time
  - attenuation
  - scatter
- Registration
- Calculation of $\tilde{A}$ map at the voxel level

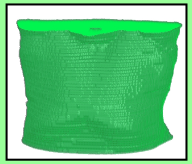


$^{131}I$

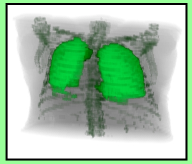
MCNPX

**OEDIPE software**

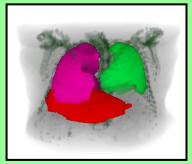
- Specific voxel-based geometry

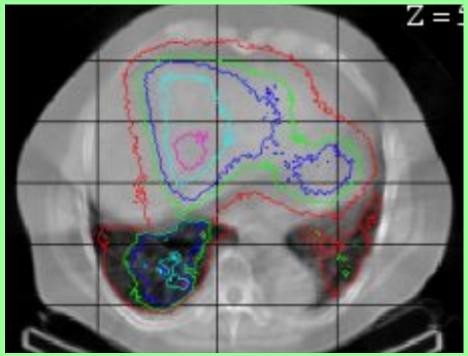


- Automatic segmentation (lungs, bone, soft tissue and air)



- Manual segmentation

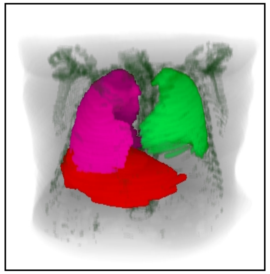


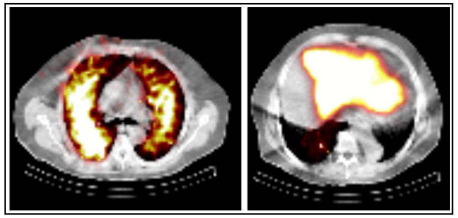


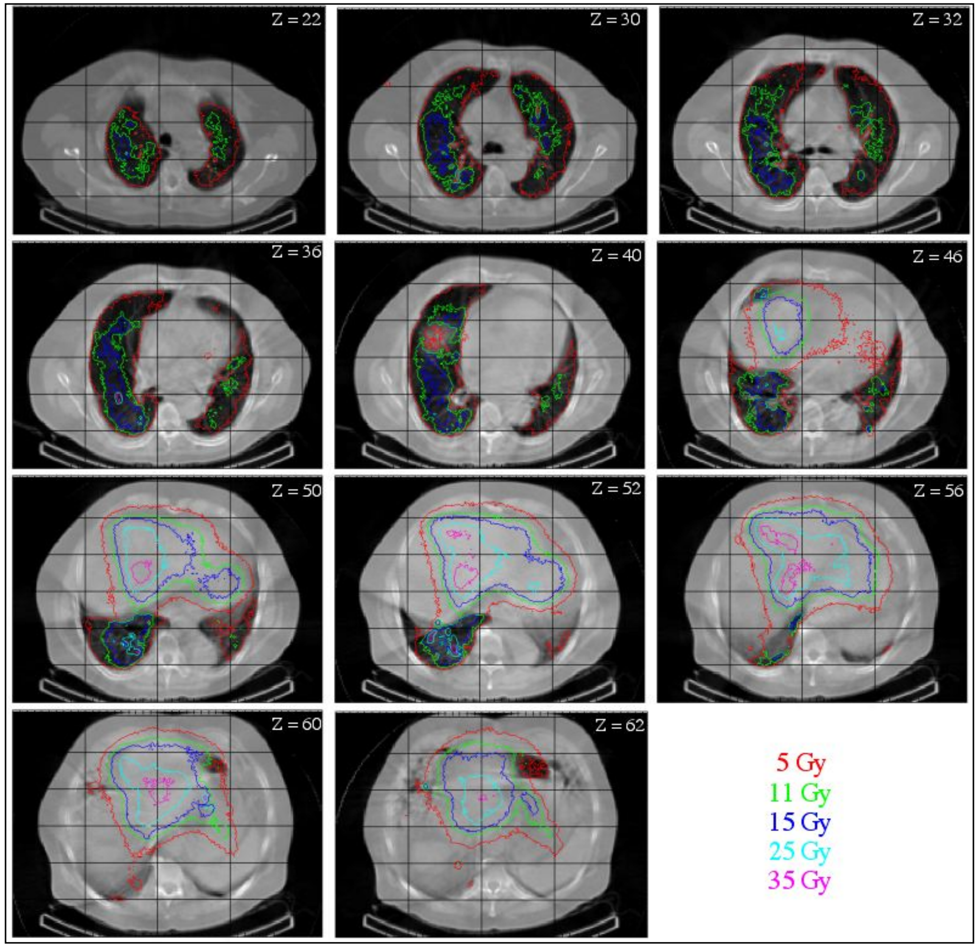
S Chiavassa et al. (2006) PMB 51:601-616

IRSN Inserm

# Application : LipioCis™








- 194 x 140 x 90 voxels
- (2.21 x 2.21 x 4.42 mm$^3$)
- Organ : 45 min (σ<2%)
- Voxel : 3.8 d (σ<10%)

S Chiavassa et al. (2006) PMB 51:601-616

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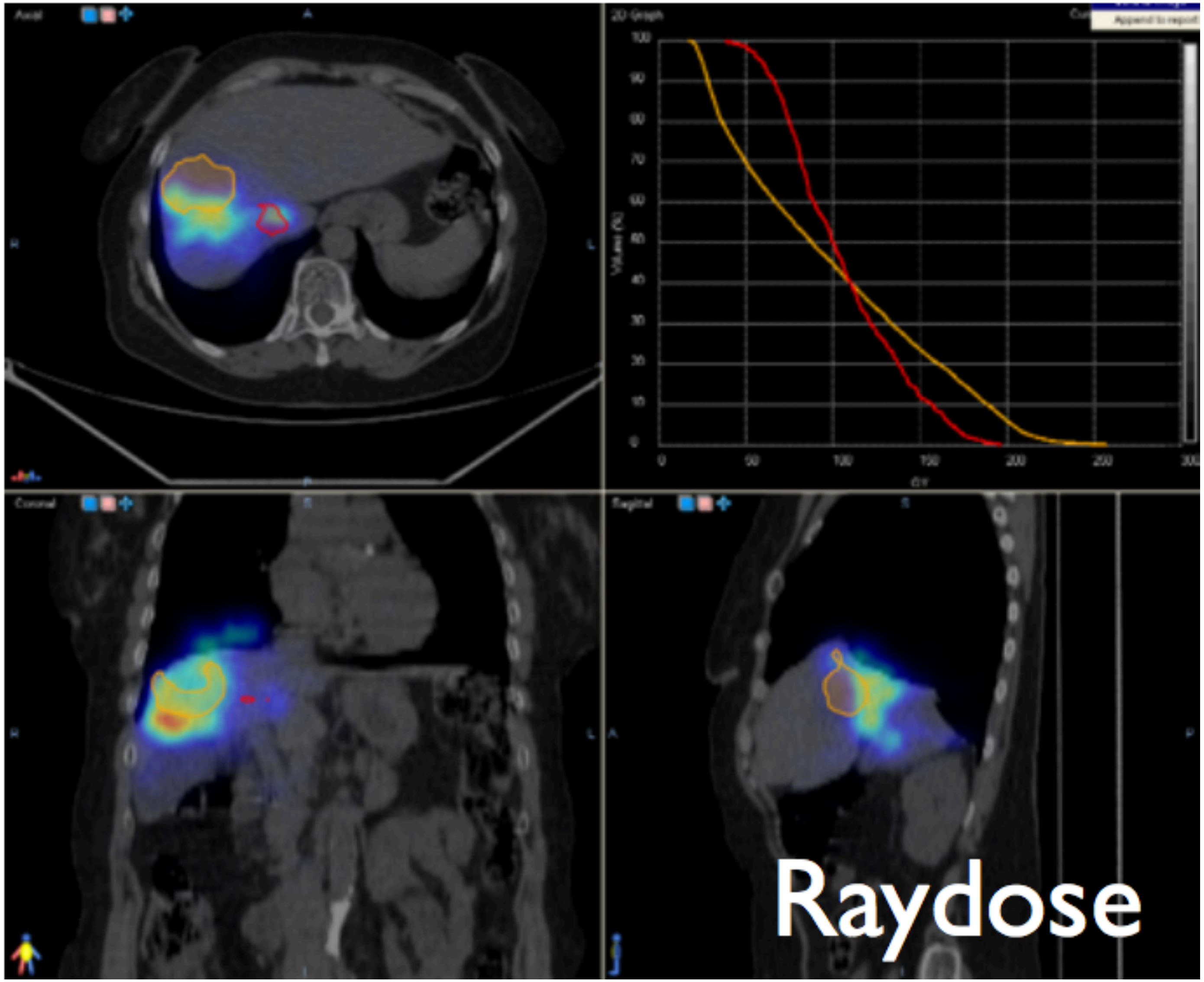
# Monte Carlo based dosimetry




Courtesy: E Spezi (Velindre, Cardiff)

Marcatili et al. Phys Med Biol 2013 58 2491-2508

# Monte Carlo based dosimetry

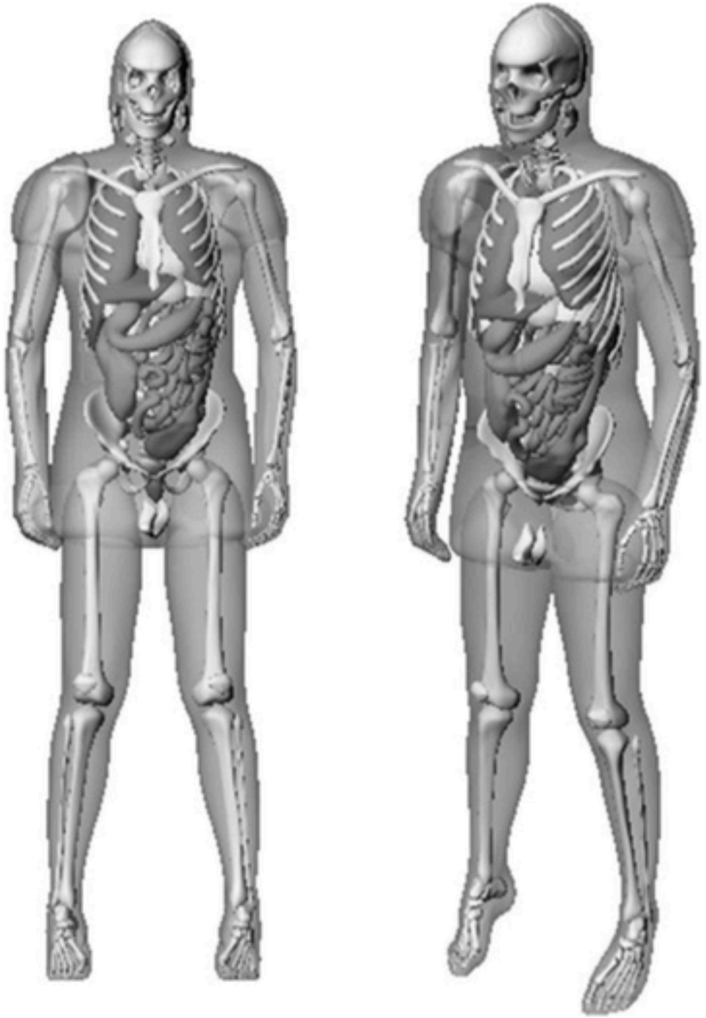


**FIG. 3.** Anterior views of the RADAR adult male NURBS phantom. NURBS, Non-Uniform Rational B-Spline; RADAR, Radiation Dose Assessment Resource.

CANCER BIOTHERAPY AND RADIOPHARMACEUTICALS
Volume 30, Number 1, 2015

DOI: 10.1089/cbr.2014.1713

***Original Article***

## VIDA: A Voxel-Based Dosimetry Method for Targeted Radionuclide Therapy Using Geant4

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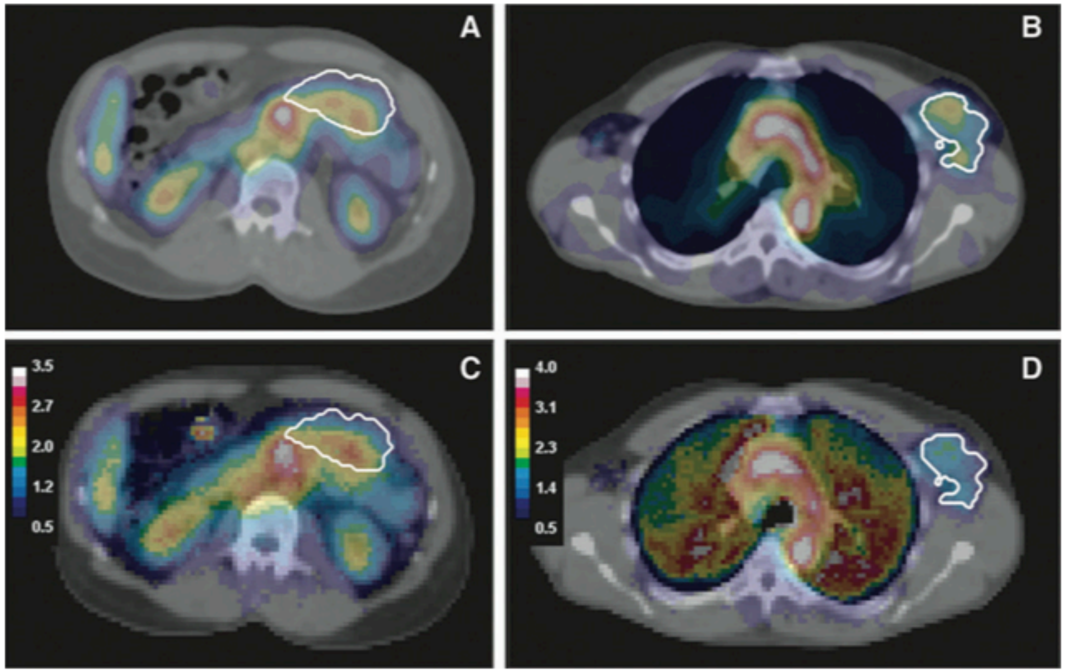


**FIG. 5.** Fused SPECT/CT images for patient 1 **(A)** and patient 2 **(B)** with matching 3D dose maps overlaid on CT for patient 1 **(C)** and patient 2 **(D)**. The dose maps are displayed in units of Gy. Color images available online at www.liebertpub.com/cbr

# Dosimetry for MRT:

| | | |
|---|---|---|
| Group | Model | Model<br>ICRP - MIRD DER |
| Specific | Model ±<br>adjusted | Model ± realistic |
| Specific | Specific | Specific |

- *Patient-specific dosimetry: ALL steps must be patient-specific*

# Conclusion

- Patient-specific dosimetry is feasible
- Huge literature in quantitative imaging/absorbed dose calculation (the methodology is there!)
- Patient-specific dosimetry requires ALL steps to be patient-specific
- BUT the biological/clinical end-point conditions the kind of approach that needs to be implemented!

# Acknowledgements


- L Ferrer (CLCC & CHU, Nantes)
- Glenn Flux (ICR/RMH, Sutton)
- EANM Dosimetry & Therapy Committees

Special issue:
«Dosimetry in nuclear medicine therapy»
*The Quarterly Journal of Nuclear Medicine and Molecular Imaging* 55(1-2), 2011

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# Thank you :-)

# Radiopharmaceutical dosimetry: Introduction & MIRD scheme

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# Nuclear Medicine Dosimetry

- For many years: diagnostic only

  For new radiopharmaceuticals
- $^{131}$I Thyroid therapy
- Targeted Radionuclide Therapy (or MRT)
  - Radioimmunotherapy (RIT)
  - mIBG, PRRT,
  - Bone pain palliation agents (Xofigo™), etc…
  - Microspheres (SirSpheres/TheraSpheres),

# Nuclear Medicine Dosimetry

- Diagnostic procedures
  - Low amount of radiation
  - Stochastic effects of radiations
  - Radiation safety (ALARA)
- Therapeutic procedures
  - Deterministic effects
  - Normal (critical) organ absorbed dose
  - Tumour absorbed dose

# Therapy vs. Diagnostic

- The goals are NOT the same
  - The required accuracy is NOT the same
- For diagnostics: an estimate is OK
- For therapy:
  - Comparative studies
  - Increase treatment efficacy/toxicity ratio
    - Pre-therapeutic study or during the treatment
  - Patient follow-up (absorbed dose accumulation)
    - Absorbed dose - effect relationship?

# The MIRD Scheme

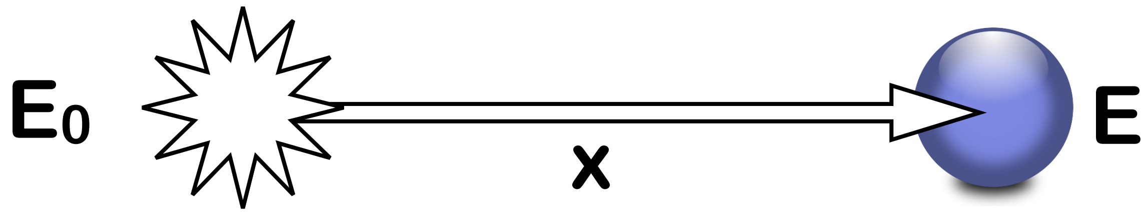
**MIRD = Medical Internal Radiation Dose Committee**

- Committee of the Society of Nuclear Medicine (USA)
  - Mix group (physicians + physicists)
- Publication via the SNM (JNM):
  - 25 Pamphlets
  - 20 Dose estimate reports
  - 3 Books

from 1968 to now...

- No web server (see www.snm.org)
- Main achievement: a global formalism for absorbed dose calculations in Nuclear Medicine

# Formalism




$$\phi(x, E_0) = \frac{E}{E_0}$$

**AF: Absorbed Fraction, dimensionless**

$$\Phi(x, E_0) = \frac{\phi(x, E_0)}{dm}$$

**SAF: Specific Absorbed Fraction, in $g^{-1}$**

# Absorbed dose definition

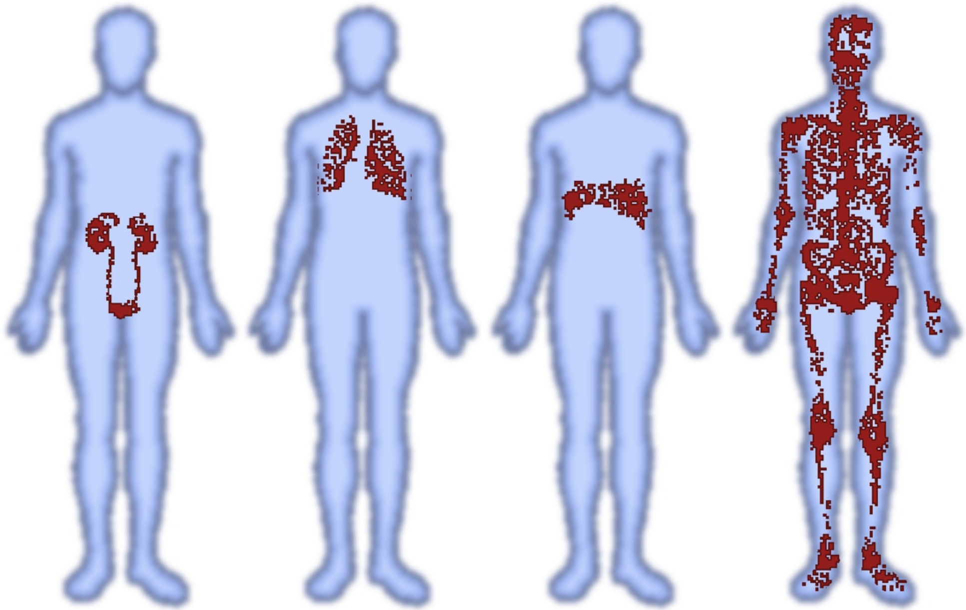
$$\overline{D} = \frac{E}{dm} = \frac{\phi(x, E_0) \cdot E_0}{dm} \qquad \overline{D} = \Phi(x, E_0) \cdot E_0$$

**Mean absorbed dose in Gy (J/kg)**

**This is obtained without simplifying hypothesis, Always true!**

# Volume Generalisation

Source $\boldsymbol{h}$ Target $\boldsymbol{k}$



$$\overline{D}(k \leftarrow h) = \frac{E}{m_k} = \frac{\phi(k \leftarrow h) \cdot E_0}{m_k} = \Phi(k \leftarrow h) \cdot E_0$$

$\overline{D}$ **Mean Absorbed Dose over target volume**

# Non penetrating radiation

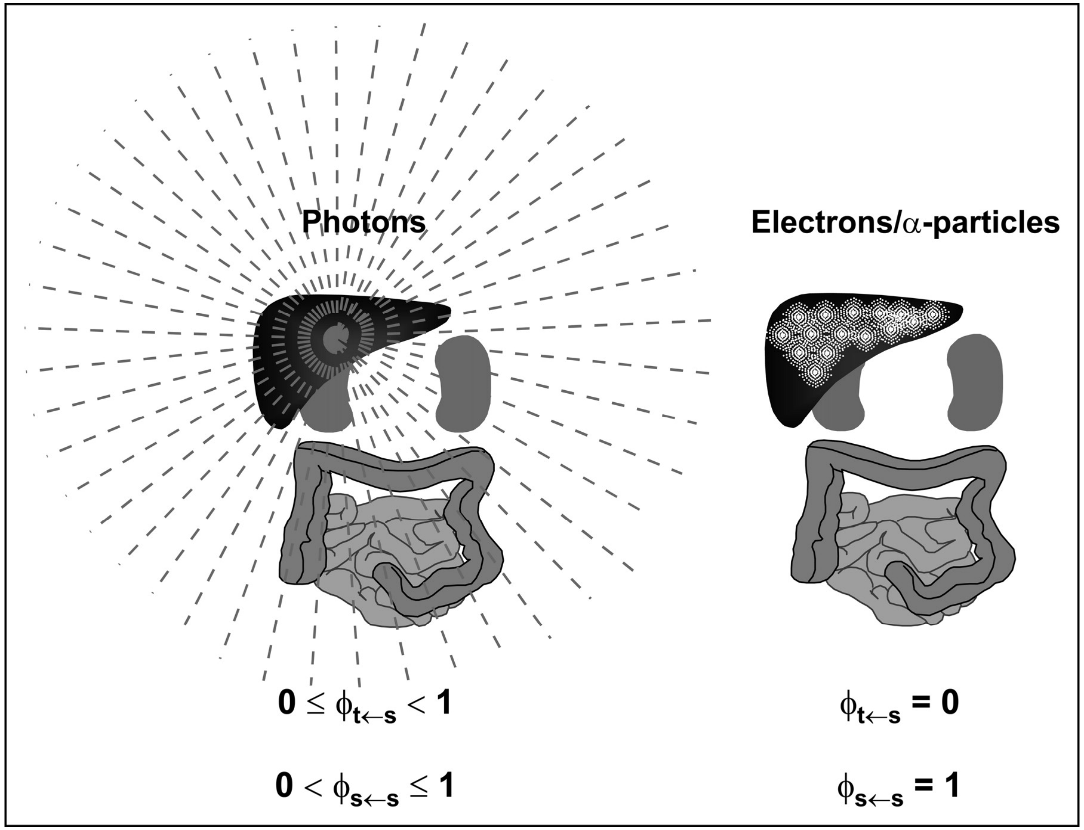
**Depends on:**

**Organ size**

**Particle range**

$$\phi_i(k \leftarrow h) = 0 \; if \; k \neq h$$

$$\phi_i(k \leftarrow h) = 1 \; if \; k = h$$




$$\overline{D}(k \leftarrow k) = \frac{\phi(k \leftarrow k) \cdot E_0}{m_k} = \frac{E_0}{m_k}$$

$$\overline{D}(k \leftarrow h) = 0$$

# Radionuclide generalisation

**The absorbed dose rate is the sum of all contributions:**

$$\overline{\dot{D}}(t)_{(k \leftarrow h)} = K \cdot A_h(t) \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h)$$

**Sometimes seen as:**

$$\overline{\dot{D}}(t)_{(k \leftarrow h)} = A_h(t) \cdot \Delta \cdot \Phi(k \leftarrow h)$$

# Integration over time

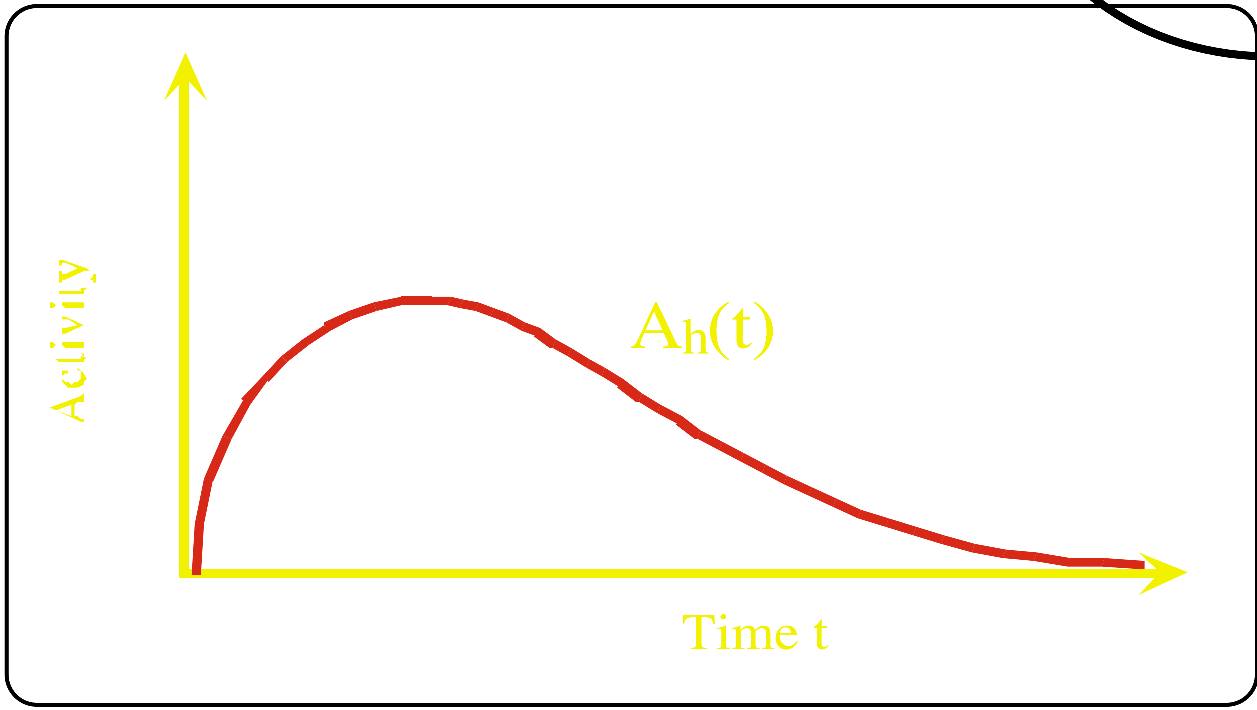
$$\overline{D}_{(k \leftarrow h)} = \int_{t_1}^{t_2} \overline{\dot{D}}(t)_{(k \leftarrow h)} dt$$

$$\overline{D}_{(k \leftarrow h)} = \int_{t_1}^{t_2} K \cdot A_h(t) \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h) dt$$

$\overline{D}_{(k \leftarrow h)}$ **Mean absorbed dose (Gy) in target k from source h**

# Integration over time (2)

$$\overline{D}_{(k\leftarrow h)} = K \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h) \cdot \int_{t_1}^{t_2} A_h(t)\,dt$$



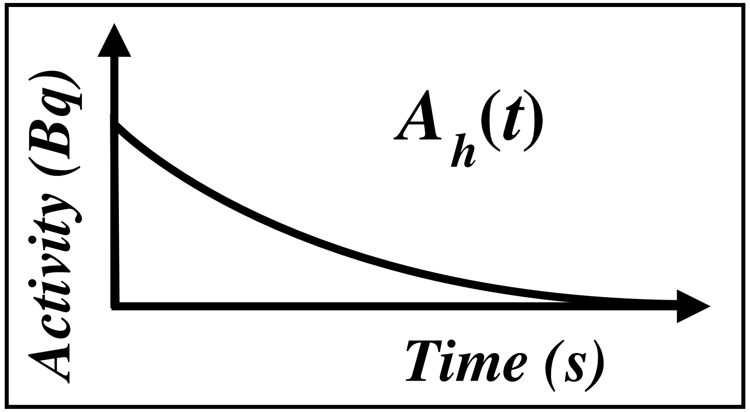

$$\tilde{A}_h = \int A_h(t)\,dt$$

**Cumulated activity (Bq.s or µCi.h)**
**'time integral of the activity'**

# Cumulated activity

***Activity detected decreases because:***

- ***Vector washout (biological half-life)***
- ***Radioactive decay (physical half-life)***



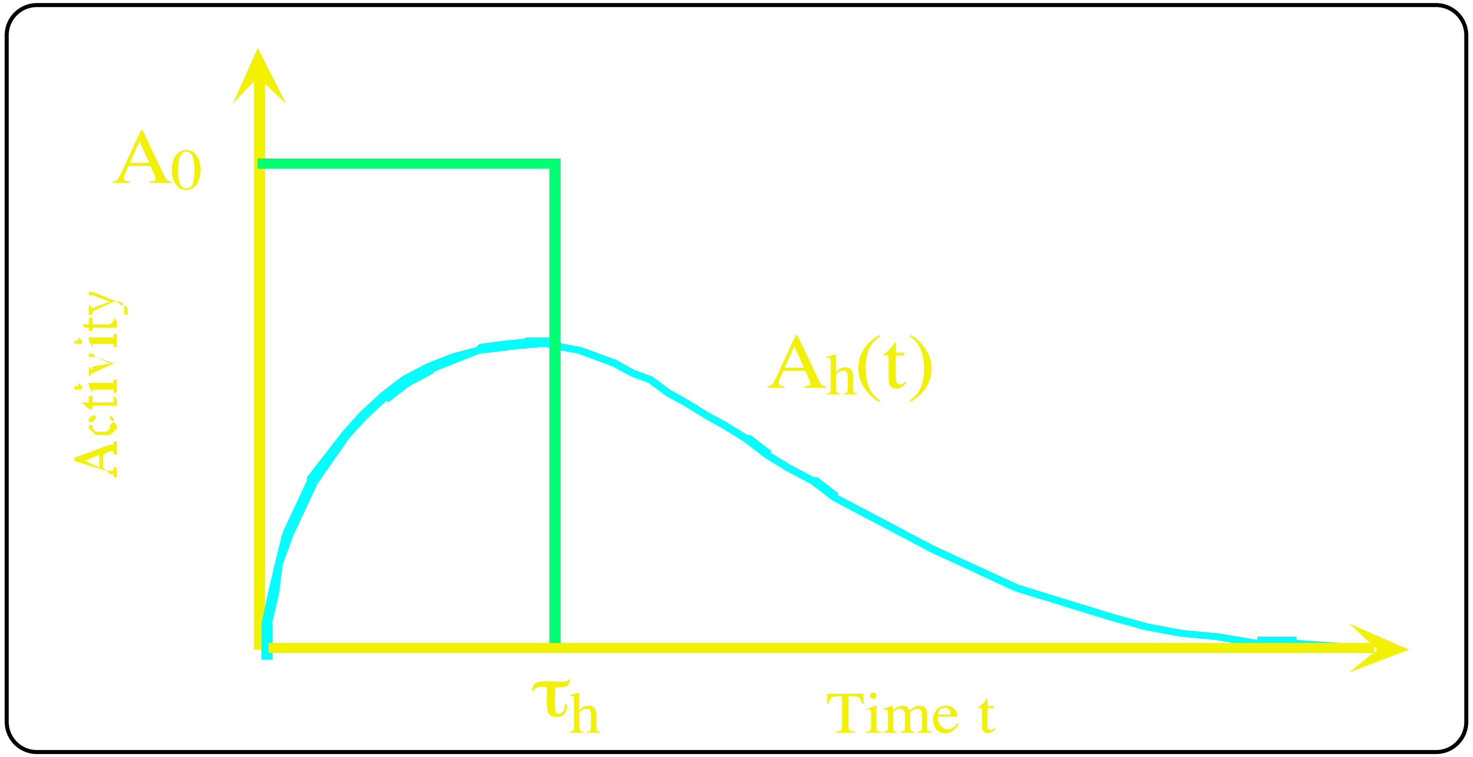

$$A_h(t) = A_0 \times e^{-(\lambda_{phy} + \lambda_{bio})t}$$

$$\tilde{A}_h = 1{,}443 \times A_0 \times T_{eff}$$

$$\frac{1}{T_{eff}} = \frac{1}{T_{bio}} + \frac{1}{T_{phy}}$$

$T_{eff}$ **is the effective half-life**

# Residence time: $\tau_h$




**$A_0$ is the injected activity**

$$\tau_h = \frac{\tilde{A}_h}{A_0}$$

$\tilde{A}_h$ in Bq.s
$A_0$ in Bq

} $\tau_h$ in s

# Fundamental MIRD equation

Source ***h*** Target ***k***

$$\overline{D}_{(k \leftarrow h)} = K \cdot \tilde{A}_h \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h)$$

**Summary: mean absorbed dose (Gy)**

**Source h**

**Target k**

**$\tilde{A}_h$ nuclear transitions in source h (Bq.s)**

# Simplified MIRD equation

$$\overline{D}_{(k \leftarrow h)} = K \cdot \tilde{A}_h \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h)$$

**Group all terms independent of time:**

$$S_{(k \leftarrow h)} = K \cdot \sum_i n_i E_i \cdot \Phi_i(k \leftarrow h)$$

**MIRD Simplified Equation:**

$$\overline{D}_{(k \leftarrow h)} = \tilde{A}_h \cdot S_{(k \leftarrow h)} \quad \textbf{or:} \quad \frac{\overline{D}_{(k \leftarrow h)}}{A_0} = \tau_h \cdot S_{(k \leftarrow h)}$$

## Absorbed dose calculation:

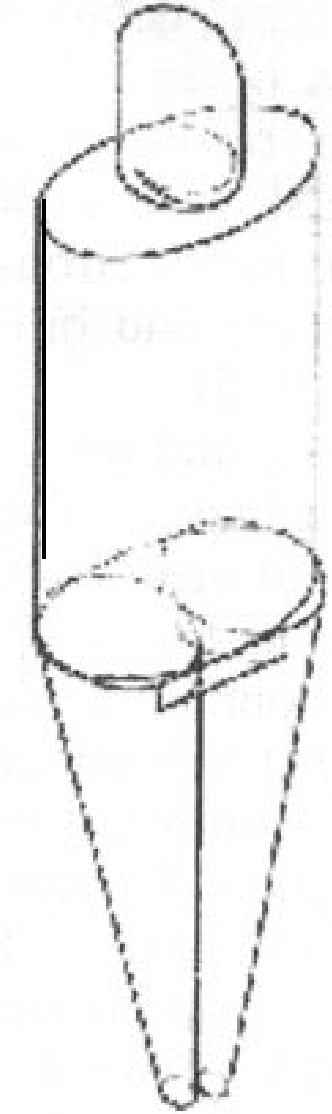
$$\overline{D}_{(k\leftarrow h)} = \tilde{A}_h \cdot S_{(k\leftarrow h)}$$

- Determination of $\tilde{A}_h$
  - Quantitative imaging
  - TAC fitting
- Use the relevant S factor
  - Absorbed dose calculations

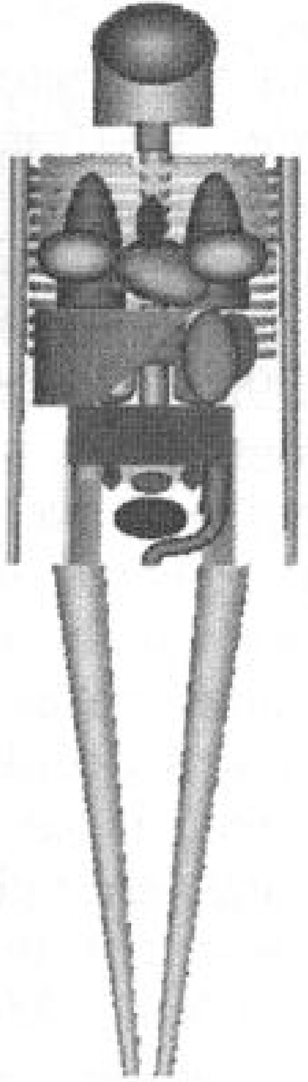
# Work of the MIRD committee

- Calculation scheme for radiopharmaceutical dosimetry
- S value calculations
  - For several radionuclides
  - For several geometries
  - Using anthropomorphic phantoms
  - MIRD pamphlet 11

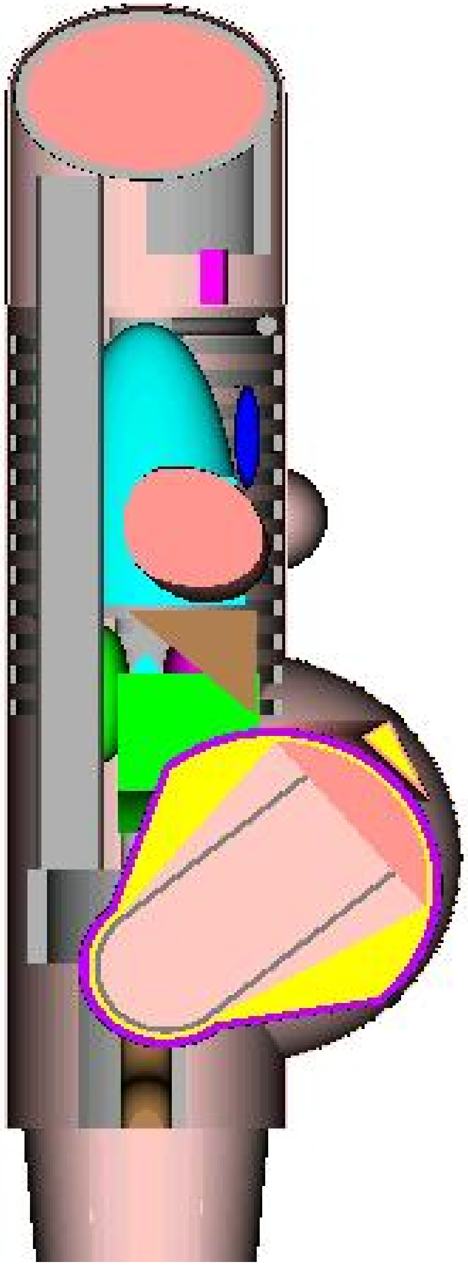
# Anthropomorphic phantoms

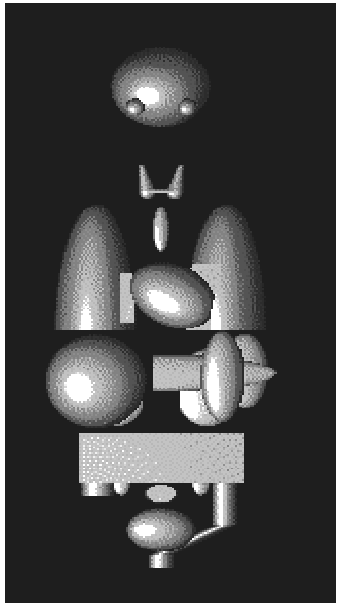


(a)

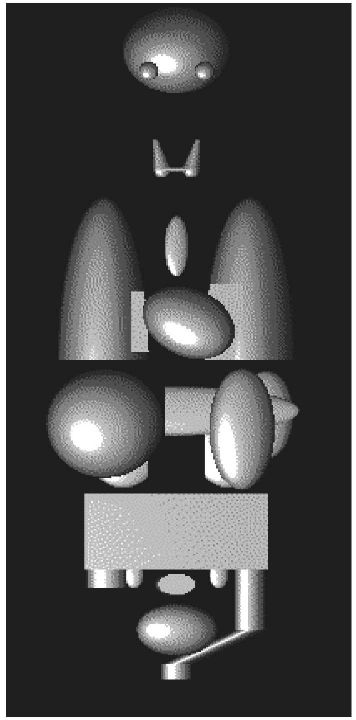


(b)



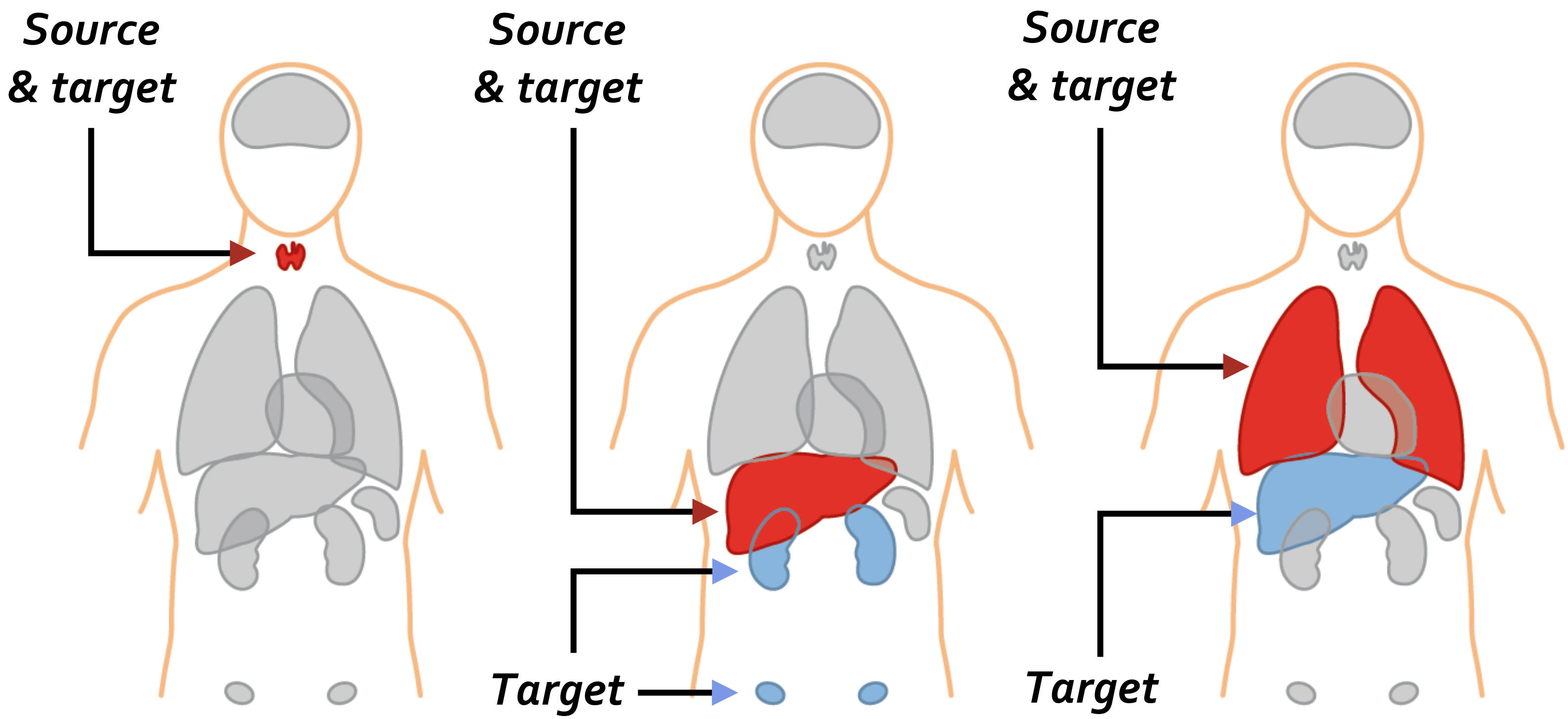


150 cm



170 cm

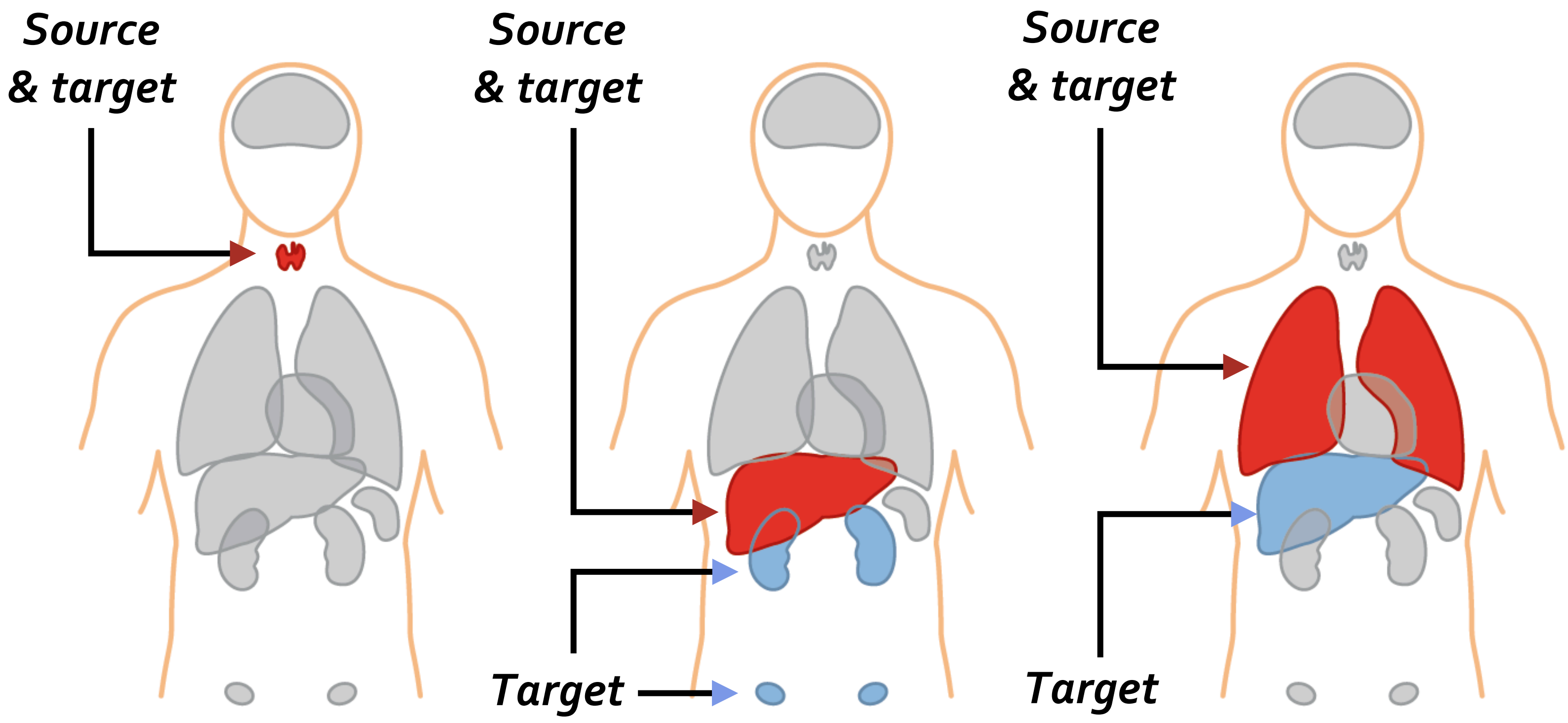
# Using the MIRD scheme




$^{131}$I-iodide $^{99m}$Tc-colloïd $^{133}$Xe-Saline

**In «real» life: there will be different radiation sources,**
**And absorbed dose needs to be calculated for ≠ targets…**
**Depends on the application…**

# Using the MIRD scheme




$^{131}$I-iodide $^{99m}$Tc-colloïd $^{133}$Xe-Saline

$$\overline{D}_k = \sum_h \tilde{A}_h \times S_{(k \leftarrow h)}$$

# MIRD Pamphlet 21: New nomenclature

**TABLE 1.** Quantities, Parameters, Symbols, and Units Used in the MIRD and ICRP Dosimetry Schema (Listed in Order of Appearance in Equations 1–17)

| Quantity or parameter | MIRD Pamphlet 21 | MIRD Primer (1991) (*4*) | ICRP publications (*7,8,18*) | Units or special name |
|---|---|---|---|---|
| Source region (or tissue) | $r_S$ | $r_h$ | $S$ | |
| Target region (or tissue) | $r_T$ | $r_k$ | $T$ | |
| Absorbed dose rate to target region | $\dot{D}(r_T, t)$ | $\dot{D}(r_k)$ or $\dot{D}_k$ | $\dot{D}_{T,R}$ | Gy $s^{-1}$ |
| Activity in source region | $A(r_S, t)$ | $A_h(t)$ | $q_S(t)$ | Bq |
| Absorbed dose rate per unit activity | $S(r_T \leftarrow r_S, t)$ | $S(r_k \leftarrow r_h)$ | Not defined | Gy $(Bq\ s)^{-1}$ |
| Dose-integration period | $T_D$ | Assumed to be $\infty$ | $\tau$ | s |
| Absorbed dose to target | $D(r_T, T_D)$ | $\bar{D}(r_k)$ or $\bar{D}_k$ | $D_{T,R}$ | Gy |
| Administered activity | $A_0$ | $A_0$ | $q_0$ | Bq |
| Fraction of administered activity in the source region | $a(r_S, t) = A(r_S, t)/A_0$ | $f_h(t)$ | Not defined | Unitless |
| Absorbed dose coefficient | $d(r_T, T_D)$ | Not defined | $d_T(\tau)$ | Gy $Bq^{-1}$ |
| Mean energy of the $i^{th}$ transition | $E_i$ | $E_i$ | $E_i$ | J or MeV |
| Number of $i^{th}$ transitions per nuclear transformation | $Y_i$ | $n_i$ | $Y_i$ | $(Bq\ s)^{-1}$ |
| Mean energy of the $i^{it}$ transition per nuclear transformation | $\Delta_i$ | $\Delta_i$ | $\Delta_i$ | J $(Bq\ s)^{-1}$ or MeV $(Bq\ s)^{-1}$ |
| Absorbed fraction | $\phi(r_T \leftarrow r_S, E_i, t)$ | $\phi(r_k \leftarrow r_h)$ | $AF(T \leftarrow S, E_i)$ | Unitless |
| Mass of target region | $M(r_T, t)$ | $m_k$ | $m_T$ | kg |
| Specific absorbed fraction | $\Phi(r_T \leftarrow r_S, E_i, t)$ | $\Phi(r_k \leftarrow r_h)$ | $SAF(T \leftarrow S, E_i)$ | $kg^{-1}$ |

*Journal of Nuclear Medicine* Vol. 50 No. 3 477-484 (2009)

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| Quantity or parameter | MIRD Pamphlet 21 | MIRD Primer (1991) (4) | ICRP publications (7,8,18) | Units or special name |
|---|---|---|---|---|
| Time-integrated activity in source region* | $\tilde{A}(r_S, T_D)$ | $\tilde{A}_h$ | $U_S$ | Bq s |
| Time-integrated activity coefficient† | $\tilde{a}(r_S, T_D)$ | $\tau$ | Not defined | s |
| Equivalent dose to target | $H(r_T, T_D)$ | Not defined | $H_T$ | Sv |
| Radiation weighting factor | $w_R$ | Not defined | $w_R$ | Unitless |
| Absorbed dose to target by radiation type R | $D_R(r_T, T_D)$ | Not defined | $D_{T,R}$ | Gy |
| Radiation-weighted S | $S_w(r_T \leftarrow r_S, t)$ | Not defined | $SEE(T \leftarrow S)$ | Sv (Bq s)$^{-1}$ |
| Equivalent dose coefficient | $h(r_T, T_D)$ | Not defined | $h_T(\tau)$ | Sv Bq$^{-1}$ |
| Effective dose | $E$ | Not defined | $E$ | Sv |

*This quantity was termed *cumulated activity* in 1991 MIRD Primer.
†This quantity was termed *residence time* in 1991 MIRD Primer.

*Journal of Nuclear Medicine* Vol. 50 No. 3 477-484 (2009)

# Quick discussion on the new nomenclature

$$\bar{D}_{(r_k)} = \tilde{A}_h \cdot S_{(r_k \leftarrow r_h)}$$

$$\bar{D}(r_T, T_D) = \tilde{A}(r_S, T_D) \cdot S(r_T \leftarrow r_S, t)$$

- **Explicit mention of irradiation time ($T_D$)**
- **More "ICRP compliant" (radiation weighting factor, Effective Dose,…)**

$\tilde{A}(r_S, T_D)$ **« Time-integrated activity » vs. «cumulated activity»**

$\tilde{a}(r_S, T_D)$ **« Time-integrated activity coefficient » vs. «residence time»**

## Be careful with the new nomenclature…

# Conclusion

- The MIRD FORMALISM is valid for both diagnostics and therapy...
- MIRD S values:
  - Impressive database
  - Can be used (for diagnostic) easily (tables)
  - For radiation safety
  - For a model rather than YOUR patient
- Therapy requires patient-specific dosimetry:
  - Quantitative imaging ($\tilde{A}$)
  - Patient-specific S values

# Conclusion

**MIRD formalism ≠ MIRD S Factors**

*One can use the MIRD formalism*
*AND compute one's OWN S Factors*

**As a consequence:** ***Writing «dosimetry was performed using the MIRD formalism is NOT sufficient!***

**The dosimetric approach should be described:**

**How Ã was obtained**
**How S was obtained**

*Cf: EANM Dosimetry Committee Guidance document (2010): «Good practice of clinical dosimetry reporting»*

# Reference books

**MIRD primer for absorbed dose calculations** Loevinger R, Budinger TF and Watson EE, The society of nuclear medicine, N.Y 1988, rev 1991

- Describes the MIRD scheme

**MIRD radionuclide data and decay schemes** Eckerman KF, Endo A, The society of nuclear medicine, N.Y. 2008

- Radionuclide data, particle type, energy, physical half-life, etc...

**MIRD Cellular S Values** Goddu SM, Howell RW, Bouchet LG, Bolch WE et Rao DV. The society of nuclear medicine, N.Y. 1998

- S values for many radionuclides at the cell level