The Management of Imaging Procedure Dose
Nuclear Medicine Dose Indices

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Dosimetry in Nuclear Medicine

The main clinical application of diagnostic nuclear medicine is

- *functional imaging of normal and diseased tissues; and*
- *localization of malignant tissue and its metastatic spread*

In these applications, the amount of administered activity is such that the absorbed dose to both imaged and non-imaged tissues is typically very low.

Consequently, stochastic risks of cancer induction are greatly outweighed by the diagnostic benefit of the imaging procedure.

Dosimetry in Nuclear Medicine

Tissue doses and their stochastic risks can be quantified and placed in context of both their cumulative values over multiple imaging sessions, as well as against associated risks from other diagnostic procedures (fluoroscopy, CT, etc.)

The role of internal dosimetry in diagnostic nuclear medicine is thus to provide the basis for stochastic risk quantification. Once this risk is quantified, it may be used to optimize the amount of administered activity so as to…

- ***Maximize image quality / diagnostic information***
- ***Minimize patient risk***

Example – Benefit to Risk Ratio in NM?

Effectiveness of positron emission tomography in the preoperative assessment of patients with suspected non-small-cell lung cancer: the PLUS multicentre randomised trial

THE LANCET • Vol 359 • April 20, 2002 • www.thelancet.com

Background Up to 50% of curative surgery for suspected non-small-cell lung cancer is unsuccessful. Accuracy of positron emission tomography (PET) with 18-fluorodeoxyglucose (^{18}FDG) is thought to be better than conventional staging for diagnosis of this malignancy. Up to now however, there has been no evidence that PET leads to improved management of patients in routine clinical practice. We did a randomised controlled trial in patients with suspected non-small-cell lung cancer, who were scheduled for surgery after conventional workup, to test whether PET with ^{18}FDG reduces number of futile thoracotomies.

Example – Benefit to Risk Ratio in NM?

Effectiveness of positron emission tomography in the preoperative assessment of patients with suspected non-small-cell lung cancer: the PLUS multicentre randomised trial

THE LANCET • Vol 359 • April 20, 2002 • www.thelancet.com

Methods Before surgery (mediastinoscopy or thoracotomy), 188 patients from nine hospitals were randomly assigned to either conventional workup (CWU) or conventional workup and PET (CWU+PET). Patients were followed up for 1 year. Thoracotomy was regarded as futile if the patient had benign disease, explorative thoracotomy, pathological stage IIIA–N2/IIIB, or postoperative relapse or death within 12 months of randomisation. The primary outcome measure was futile thoracotomy. Analysis was by intention to treat.

Interpretation Addition of PET to conventional workup prevented unnecessary surgery in one out of five patients with suspected non-small-cell lung cancer.

Review by Pat Zanzonico (2010 SNM)

Data

- Conventional pre-op work-up → Thoracotomy: 81% (78 / 97)
  Thoracotomy futile: 41% (39 / 78)
- Conventional pre-op work-up w/ PET → Thoracotomy: 65% (60 / 92)
  Thoracotomy futile: 21% (19 / 60)
- Surgery (Sx)-related mortality: 6.5%
- w/ PET → Avoided futile Sx: 20%

Van Tinteren *et al*. Lancet 359: 1388, 2002

Extrapolation

- New lung cancers in US (2006): 174,470 /yr
- Conventional pre-op work-up → Futile-Sx deaths: 3,766 /yr
- Conventional pre-op work-up + PET → Futile-Sx deaths: 1,547 /yr
- *Gross* benefit of pre-op PET - Lives saved w/ PET: 2,219 /yr
- ^{18}FDG ED / 10 mCi: 7 mSv
- Excess cancer deaths: 61 /yr
- *Net* benefit of pre-op PET - Lives saved w/ PET: 2,158 /yr

B/R Ratio - 32

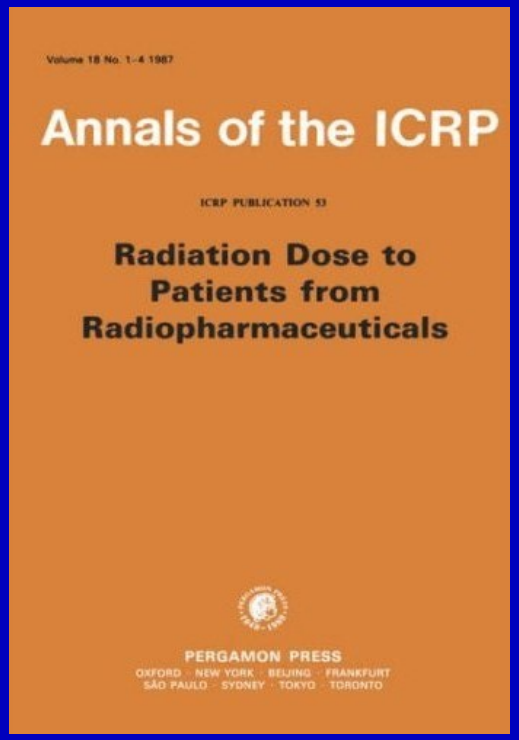
Quantities for Dose Tracking in Medical Imaging

A dose index is a measureable quantity that is indicative of patient expose, and which when multiplied by an appropriate dose coefficient, can yield an estimate of patient organ dose or whole-body effective dose.

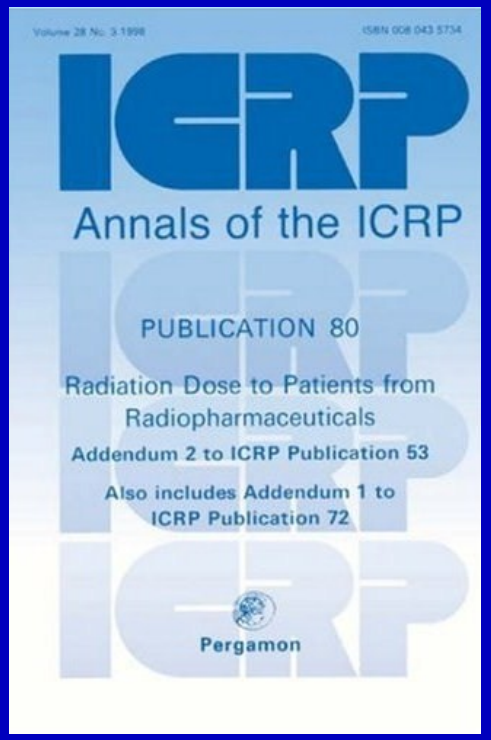
Imaging Procedure	Dose Index
Radiography	Entrance Skin Dose
Fluoroscopy	Dose Area Product
Computed Tomography	Volumetric CTDI
Nuclear Medicine	Injected Activity

$$Dose\ Quantity = (Dose\ Index) \times (Dose\ Coefficient)$$

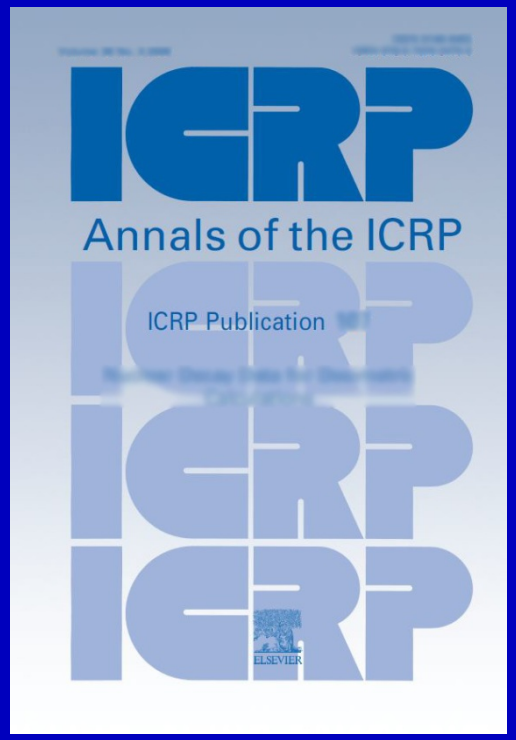
Dose Coefficients from ICRP



ICRP Publication 53 (1988)



ICRP Publication 80 (1998)



ICRP Publication 106 (2008)

Dose Coefficients from ICRP

Radiopharmaceutical	This publication	*Publication 80*	*Publication 53*
^{3}H-neutral fat, free fatty acids		x	
^{11}C-acetate	x		
^{11}C-amino acids (generic model)	x		
^{11}C-brain receptor substances (generic model)	x		
^{11}C-methionine	x		
^{11}C-thymidine		x	
^{11}C (realistic maximum model)	x		
^{14}C-neutral fat, free fatty acids		x	
^{14}C-urea		x	
^{15}O-water	x		
^{18}F-amino acids (generic model)	x		
^{18}F-brain receptor substances (generic model)	x		
^{18}F-FDG	x		
^{18}F-L-dopa	x		
^{18}F (realistic maximum model)	x		
^{51}Cr-EDTA		x	
^{67}Ga-citrate		x	
^{68}Ga-EDTA		x	
^{75}Se-amino acids	x		
^{75}Se-HCAT		x	

Dose Coefficients from ICRP

Radiopharmaceutical	This publication	*Publication 80*	*Publication 53*
^{99m}Tc-apticide	x		
^{99m}Tc-colloids (small)	x		
^{99m}Tc-EC	x		
^{99m}Tc-ECD	x		
^{99m}Tc-furifosmin	x		
^{99m}Tc-HIG		x	
^{99m}Tc-HM-PAO		x	
^{99m}Tc-IDA derivatives		x	
^{99m}Tc-MAA		x	
^{99m}Tc-MAG3		x	
^{99m}Tc-markers, non-absorbable		x	
^{99m}Tc-MIBI		x	
^{99m}Tc-monoclonal antibodies/fragments	x		
^{99m}Tc-pertechnegas		x	
^{99m}Tc-pertechnetate		x	
^{99m}Tc-phosphates and phosphonates		x	
^{99m}Tc-RBC		x	x
^{99m}Tc-Technegas		x	
^{99m}Tc-tetrofosmin (rest/exercise)	x		
^{99m}Tc-WBC		x	
^{111}In-HIG		x	

Dose Coefficients from ICRP

Radiopharmaceutical	This publication	*Publication 80*	*Publication 53*
^{111}In-monoclonal antibodies/fragments	x		
^{111}In-octreotide		x	
^{123}I-iodide			x
^{123}I-fatty acids (BMIPP/IPPA)	x		
^{123}I-brain receptor substances (generic model)	x		
^{123}I-iodo hippurate		x	
^{123}I-MIBG		x	
^{123}I-monoclonal antibodies/fragments	x		
^{124}I-iodide			x
^{125}I-iodide			x
^{131}I-iodide			x
^{131}I-iodo hippurate		x	
^{131}I-monoclonal antibodies/fragments	x		
^{131}I-norcholesterol		x	
^{201}Tl-ion	x		

Dose Coefficients for ^{18}F-FDG / ICRP 106

^{18}F 1.83 h

Organ	Absorbed dose per unit activity administered (mGy/MBq)				
	Adult	15 years	10 years	5 years	1 year
Adrenals	1.2E-02	1.6E-02	2.4E-02	3.9E-02	7.1E-02
Bladder	1.3E-01	1.6E-01	2.5E-01	3.4E-01	4.7E-01
Bone surfaces	1.1E-02	1.4E-02	2.2E-02	3.4E-02	6.4E-02
Brain	3.8E-02	3.9E-02	4.1E-02	4.6E-02	6.3E-02
Breasts	8.8E-03	1.1E-02	1.8E-02	2.9E-02	5.6E-02
Gallbladder	1.3E-02	1.6E-02	2.4E-02	3.7E-02	7.0E-02
Gastrointestinal tract					
Stomach	1.1E-02	1.4E-02	2.2E-02	3.5E-02	6.7E-02
Small intestine	1.2E-02	1.6E-02	2.5E-02	4.0E-02	7.3E-02
Colon	1.3E-02	1.6E-02	2.5E-02	3.9E-02	7.0E-02
(Upper large intestine	1.2E-02	1.5E-02	2.4E-02	3.8E-02	7.0E-02)
(Lower large intestine	1.4E-02	1.7E-02	2.7E-02	4.1E-02	7.0E-02)
Heart	6.7E-02	8.7E-02	1.3E-01	2.1E-01	3.8E-01
Kidneys	1.7E-02	2.1E-02	2.9E-02	4.5E-02	7.8E-02
Liver	2.1E-02	2.8E-02	4.2E-02	6.3E-02	1.2E-01
Lungs	2.0E-02	2.9E-02	4.1E-02	6.2E-02	1.2E-01
Muscles	1.0E-02	1.3E-02	2.0E-02	3.3E-02	6.2E-02
Oesophagus	1.2E-02	1.5E-02	2.2E-02	3.5E-02	6.6E-02
Ovaries	1.4E-02	1.8E-02	2.7E-02	4.3E-02	7.6E-02
Pancreas	1.3E-02	1.6E-02	2.6E-02	4.0E-02	7.6E-02
Red marrow	1.1E-02	1.4E-02	2.1E-02	3.2E-02	5.9E-02
Skin	7.8E-03	9.6E-03	1.5E-02	2.6E-02	5.0E-02
Spleen	1.1E-02	1.4E-02	2.1E-02	3.5E-02	6.6E-02
Testes	1.1E-02	1.4E-02	2.4E-02	3.7E-02	6.6E-02
Thymus	1.2E-02	1.5E-02	2.2E-02	3.5E-02	6.6E-02
Thyroid	1.0E-02	1.3E-02	2.1E-02	3.4E-02	6.5E-02
Uterus	1.8E-02	2.2E-02	3.6E-02	5.4E-02	9.0E-02
Remaining organs	1.2E-02	1.5E-02	2.4E-02	3.8E-02	6.4E-02
Effective dose (mSv/MBq)	1.9E-02	2.4E-02	3.7E-02	5.6E-02	9.5E-02

Other Resources for Dose Coefficients

Society of Nuclear Medicine and Molecular Imaging (SNMMI)

- ***Medical Internal Dose Committee (MIRD)***
  - ***Dose Estimate Reports – Published in the Journal of Nuclear Medicine (JNM)***

- ***RADAR Task Force***
  - ***Website – www.doseinfor-radar.com***
  - ***OLINDA / EXM software***

What is the basis for these dose coefficients?

First, we need to look at the MIRD Schema for nuclear medicine dose assessment:

MIRD Pamphlet No. 21: A Generalized Schema for Radiopharmaceutical Dosimetry—Standardization of Nomenclature

Wesley E. Bolch[1], Keith F. Eckerman[2], George Sgouros[3], and Stephen R. Thomas[4]

In collaboration with the SNM MIRD Committee: Wesley E. Bolch, A. Bertrand Brill, Darrell R. Fisher, Roger W. Howell, Ruby Meredith, George Sgouros, Stephen R. Thomas (Chair), and Barry W. Wessels.

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MIRD Schema – Absorbed Dose

Mean absorbed dose to tissue r_T from activity in tissue r_S

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

Time-integrated activity – total number of nuclear decays in r_S

$$\tilde{A}(r_S, T_D) = \int_0^{T_D} A(r_S, t)\, dt$$

Radionuclide S value – absorbed dose to r_T per nuclear decay in r_S

$$S(r_T \leftarrow r_S, t) = \frac{1}{M(r_T, t)} \sum_i E_i Y_i\, \phi(r_T \leftarrow r_S, E_i, t)$$

MIRD Schema – Dose Coefficient $d = D/A_0$

Time-dependent form:

$$d(r_T, T_D) = \sum_{r_S} \int_0^{T_D} a(r_S, t) S(r_T \leftarrow r_S, t) dt$$

Time-independent form:

$$d(r_T, T_D) = \sum_{r_S} \tilde{a}(r_S, T_D)\, S(r_T \leftarrow r_S)$$

$$\tilde{a}(r_S, T_D) = \int_0^{T_D} a(r_S, t) dt = \frac{1}{A_0} \int_0^{T_D} A(r_S, t) dt$$

MIRD Schema

To fully calculate organ doses, the following information is needed from the patient…

Biokinetic parameters

- *Identification of source organs*
- *The time dependent profile of activity in these organs $A(r_S, t)$*

Physics parameters

- *Energies and yields of all radiation particles emitted by the radionuclide*

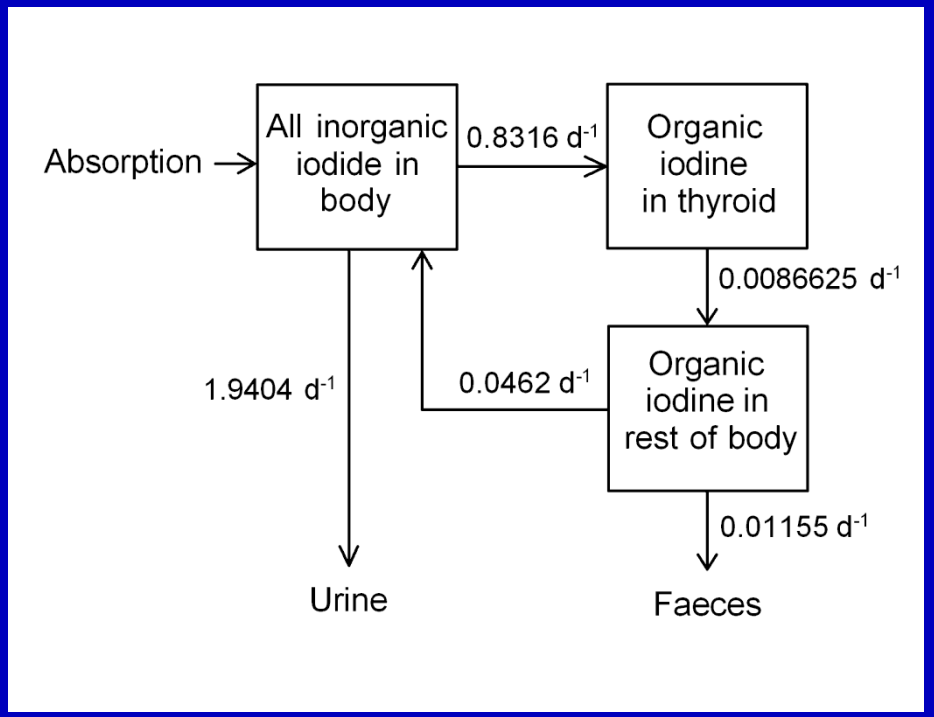
Anatomic parameters

- *Masses of all target organs in the patient*
- *Values of absorbed fraction $\phi(r_T \leftarrow r_S)$ for all r_S and r_T pairs*

1. Biokinetic Parameters

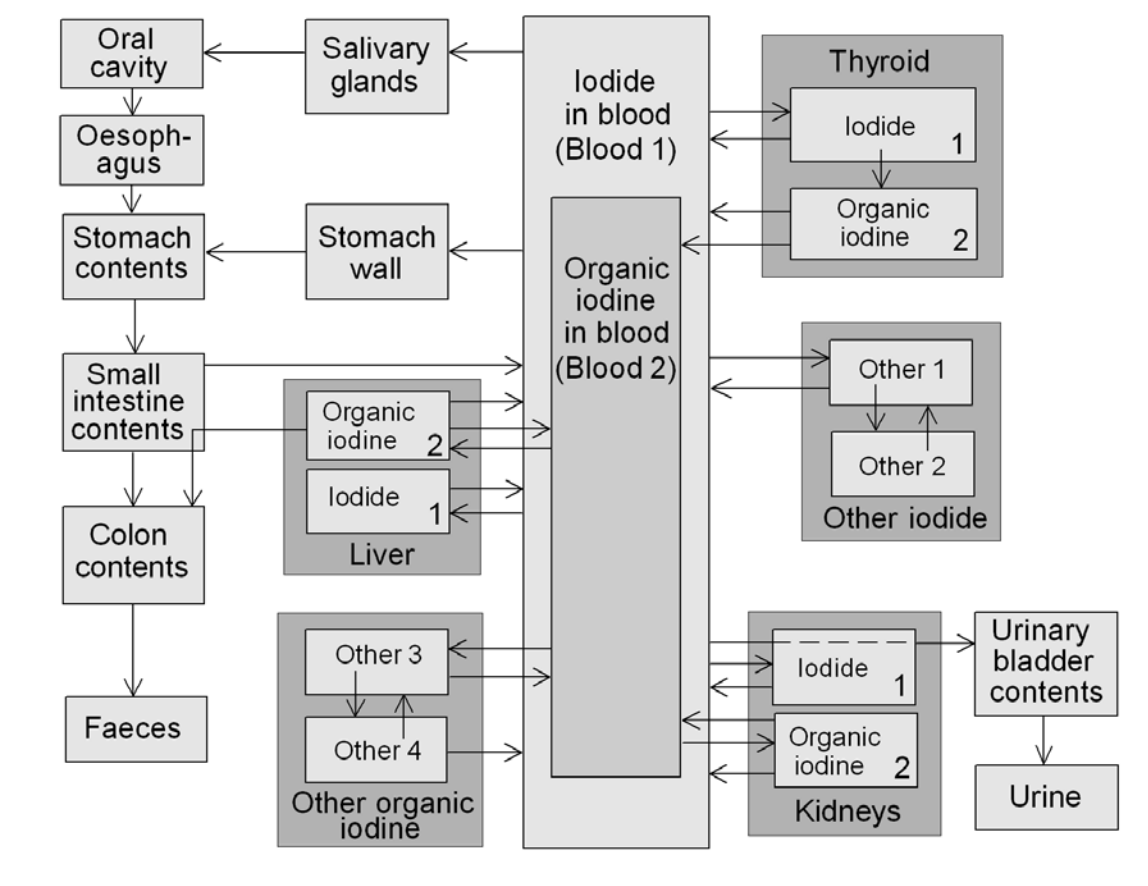
The ICRP dose coefficients are based upon standardized biokinetic models for "reference" patients. Typically, no adjustments are made for age-dependence of biokinetic parameters – only organ masses are changed with age.

Example – Biokinetic model of iodine used by the ICRP in previous publications



1. Biokinetic Parameters

***Example* – Biokinetic model of iodine presently used by the ICRP**



1. Biokinetic Parameters

***Example** – Biokinetic model of iodine presently used by the ICRP*

***Note** – these transfer rates are fixed and constant, and thus not adjustable to individual patients*

Table 5-4. Baseline parameter values for the biokinetic model for systemic iodine, applicable to a reference worker.

Pathway	Transfer coefficient (d^{-1})
Blood 1 to Thyroid 1	7.26[a]
Blood 1 to Urinary bladder contents	11.84
Blood 1 to Salivary gland	5.16
Blood 1 to Stomach wall	8.60
Blood 1 to Other 1	600
Blood 1 to Kidneys 1	25
Blood 1 to Liver 1	15
Salivary gland to Oral cavity	50
Stomach wall to Stomach contents	50
Thyroid 1 to Thyroid 2	95
Thyroid 1 to Blood 1	36
Thyroid 2 to Blood 2[b]	0.0077
Thyroid 2 to Blood 1	0[c]
Other 1 to Blood 1	330
Other 1 to Other 2	35
Other 2 to Other 1	56
Kidneys 1 to Blood 1	100
Liver 1 to Blood 1	100
Blood 2 to Other 3	15
Other 3 to Blood 2	21
Other 3 to Other 4	1.2
Other 4 to Other 3	0.62
Other 4 to Blood 1	0.14
Blood 2 to Kidneys 2	3.6
Kidneys 2 to Blood 2	21
Kidneys 2 to Blood 1	0.14
Blood 2 to Liver 2	21
Liver 2 to Blood 2	21
Liver 2 to Blood 1	0.14
Liver 2 to Right colon contents	0.08

1. Biokinetic Parameters

For individual patients, however, nuclear medicine imaging is performed via…

- *2D planar imaging, or*
- *3D SPECT imaging, or*
- *3D PET imaging*

and thus direct data on the patient's own metabolism and biodistribution of the radiopharmaceutical are explicitly measured. No reliance is made on a standardized biokinetic model.

1. Biokinetic Parameters

The problem is the number of images!

For general diagnostic examinations, only a single image is taken at a time of optimal radiopharmaceutical uptake.

For dosimetric evaluations, however, multiple images are needed to obtain the time-activity curve $A(r_s, t)$. This is typically only viable during drug development or within a research clinical trial protocol.

Conclusion - This is a prime reason why one cannot go beyond injected activity as a dose index for patient dose tracking.

1. Biokinetic Parameters

Imaging Uncertainties

Comparison of conventional, model-based quantitative planar, and quantitative SPECT image processing methods for organ activity estimation using In-111 agents

Bin He and Eric C Frey

Russell H Morgan Department of Radiology and Radiological Science, Johns Hopkins Medical Institutions, Baltimore, MD 21287-0859, USA

INSTITUTE OF PHYSICS PUBLISHING

Phys. Med. Biol. **51** (2006) 3967–3981

1. Biokinetic Parameters

Imaging Uncertainties

Results from Physical Phantom Measurements

Table 1. The relative errors[a] of organ activity estimates based on different processing methods for the physical phantom experiment.

Method/organs	Heart (%)	Lungs (%)	Liver (%)	Large sphere (%)	Small sphere (%)	Whole body (%)
CPlanar	−3.21	−17.22	−2.51	−7.02	−28.95	0.00
QSPECT	−0.59	4.26	2.15	−5.05	−3.06	0.80
QPlanar	0.90	7.61	3.22	−1.16	−0.59	1.07

[a] Calculated by (estimated activity − true activity)/true activity × 100%. Negative signs indicate underestimation compared to the true activity.

1. Biokinetic Parameters

Imaging Uncertainties

Results from Monte Carlo Simulations

Table 2. The relative errors[a] of organ activity estimates based on different correction methods for the MCS phantom experiment.

Method\organs	Heart (%)	Lungs (%)	Liver (%)	Kidneys (%)	Spleen (%)	Marrow (%)	Blood vessels (%)
CPlanar (none)	52.16 ± 0.41	256.29 ± 0.46	25.73 ± 0.23	204.52 ± 1.10	144.32 ± 1.07	211.54 ± 0.67	380.44 ± 0.91
CPlanar (ideal)	7.16 ± 0.29	−2.44 ± 0.19	11.62 ± 0.22	−2.10 ± 0.46	−1.81 ± 0.63	−6.03 ± 0.26	−8.35 ± 0.28
CPlanar (realistic)	14.76 ± 0.53	9.40 ± 0.29	−8.35 ± 0.27	13.90 ± 2.08	45.59 ± 1.72	−47.62 ± 0.65	5.77 ± 0.32
QSPECT	−0.46 ± 0.68	−1.84 ± 0.94	−1.34 ± 0.35	−3.42 ± 1.54	−0.39 ± 1.20	2.14 ± 0.74	1.36 ± 0.84
QPlanar	−1.76 ± 0.31	13.36 ± 0.34	−0.20 ± 0.16	−4.03 ± 0.86	−1.39 ± 0.71	3.35 ± 0.52	1.59 ± 0.81
QPlanar (short scan)	−1.81 ± 1.20	13.82 ± 1.18	−0.21 ± 0.68	−3.55 ± 4.27	−1.30 ± 3.06	3.14 ± 1.84	1.44 ± 2.50

[a] Calculated by (estimate − true)/true × 100%. Negative signs indicate underestimation compared to the true.

1. Biokinetic Parameters

Individual Patient Variations

Uncertainties in Internal Dose Calculations for Radiopharmaceuticals

Michael G. Stabin

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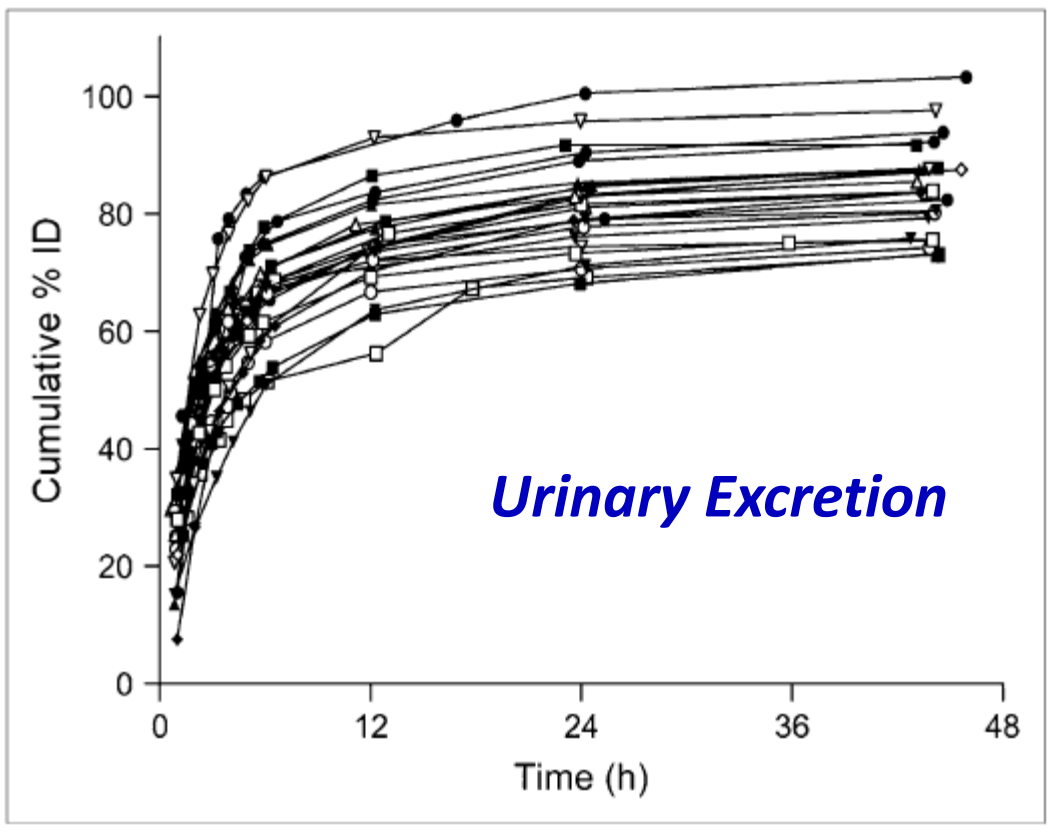
Most biokinetic models do not take into account disease states, functional organ impairment, the influence of other medications, or other influences that can substantially alter biokinetics. The literature includes a few examples where this is considered .

(e.g., the 1975 report by Cloutier et al. on the dosimetry of ^{198}Au colloid in various states of liver disease).

1. Biokinetic Parameters

Individual Patient Variations



^{166}Ho-DOTMP radiation-absorbed dose estimation for skeletal targeted radiotherapy. J Nucl Med. 2006;47:534–542.

1. Biokinetic Parameters

Individual Patient Variations

TABLE 5. Biologic (Decay-Corrected) Data for ^{111}In-Ibritumomab Tiuxetan

Site	Fraction initial uptake (±SD)	Retention half-time (h ± SD)	Residence time (h ± SD)
Heart contents	0.0640 ± 0.0212	48.1 ± 15.8	1.18 ± 0.557
Kidneys	0.0262 ± 0.00780	106 ± 45.7	1.40 ± 0.351
Liver	0.145 ± 0.0253	141 ± 76.0	12.9 ± 4.92
Lungs	0.0394 ± 0.0126	46.6 ± 11.7	1.41 ± 0.904
Red marrow	0.146 ± 0.0283	286 ± 347	11.7 ± 4.52
Spleen	0.0417 ± 0.0143	106 ± 56.5	1.63 ± 0.814
Testes	0.00192 ± 0.00133	67.4 ± 6.86	0.163 ± 0.0650
Whole body	1.0	380 ± 162	
Remainder of whole body	0.535 ± 0.0995	>400 (long)	51.8 ± 16.2

MIRD Dose Estimate Report No. 20: Radiation Absorbed-Dose Estimates for ^{111}In- and ^{90}Y-Ibritumomab Tiuxetan

Darrell R. Fisher[1], Sui Shen[2], and Ruby F. Meredith[2]

[1]Radioisotopes Program, Pacific Northwest National Laboratory, Richland, Washington; and [2]Department of Radiation Oncology, University of Alabama at Birmingham, Birmingham, Alabama

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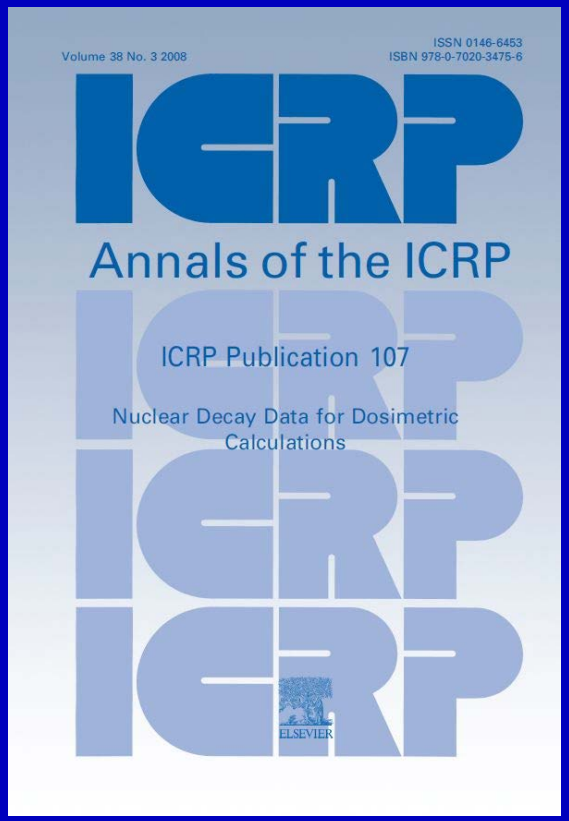
Red marrow fractional uptake COV ~19%

Red marrow residence time COV ~39%

2. Physics Parameters

By Keith F. Eckerman and Akira Endo
2008, 671 pp., Hardcover
ISBN: 0-932004-80-6

MIRD Decay Scheme Monograph (2008)



ICRP Publication 107 (2008)

3. Anatomic Parameters

The ICRP dose coefficients are based upon standardized anatomical models of "reference" persons – those at 50% height and weight, and with "average" organ masses.

Table 2.9. Reference values for height, mass, and surface area of the total body (Sections 4.2.1 and 4.2.2)

	Height (cm)		Mass (kg)		Surface area (m^2)	
Age	Male	Female	Male	Female	Male	Female
Newborn	51	51	3.5	3.5	0.24	0.24
1 year	76	76	10	10	0.48	0.48
5 years	109	109	19	19	0.78	0.78
10 years	138	138	32	32	1.12	1.12
15 years	167	161	56	53	1.62	1.55
Adult	176	163	73	60	1.90	1.66

ICRP Publication 89 (2002)

3. Anatomic Parameters

Reported Variability of Organ Mass for Several Organs in Men, According to Subject Height

Organ	144<H<165	165<H<175	176<H<190
Heart	344 ± 75	360 ± 75	381 ± 56
Right lung	616 ± 20	625 ± 207	741 ± 274
Left lung	523 ± 190	551 ± 178	658 ± 257
Liver	1,455 ± 370	1,637 ± 369	1,831 ± 384
Spleen	120 ± 51	150 ± 88	180 ± 90
Pancreas	138 ± 35	143 ± 39	147 ± 39
Right kidney	150 ± 49	157 ± 36	170 ± 37
Left kidney	155 ± 53	164 ± 38	175 ± 38
Thyroid	25 ± 7	25 ± 13	25 ± 9

H = height (cm).

Liver mass → COV of 21 to 25%

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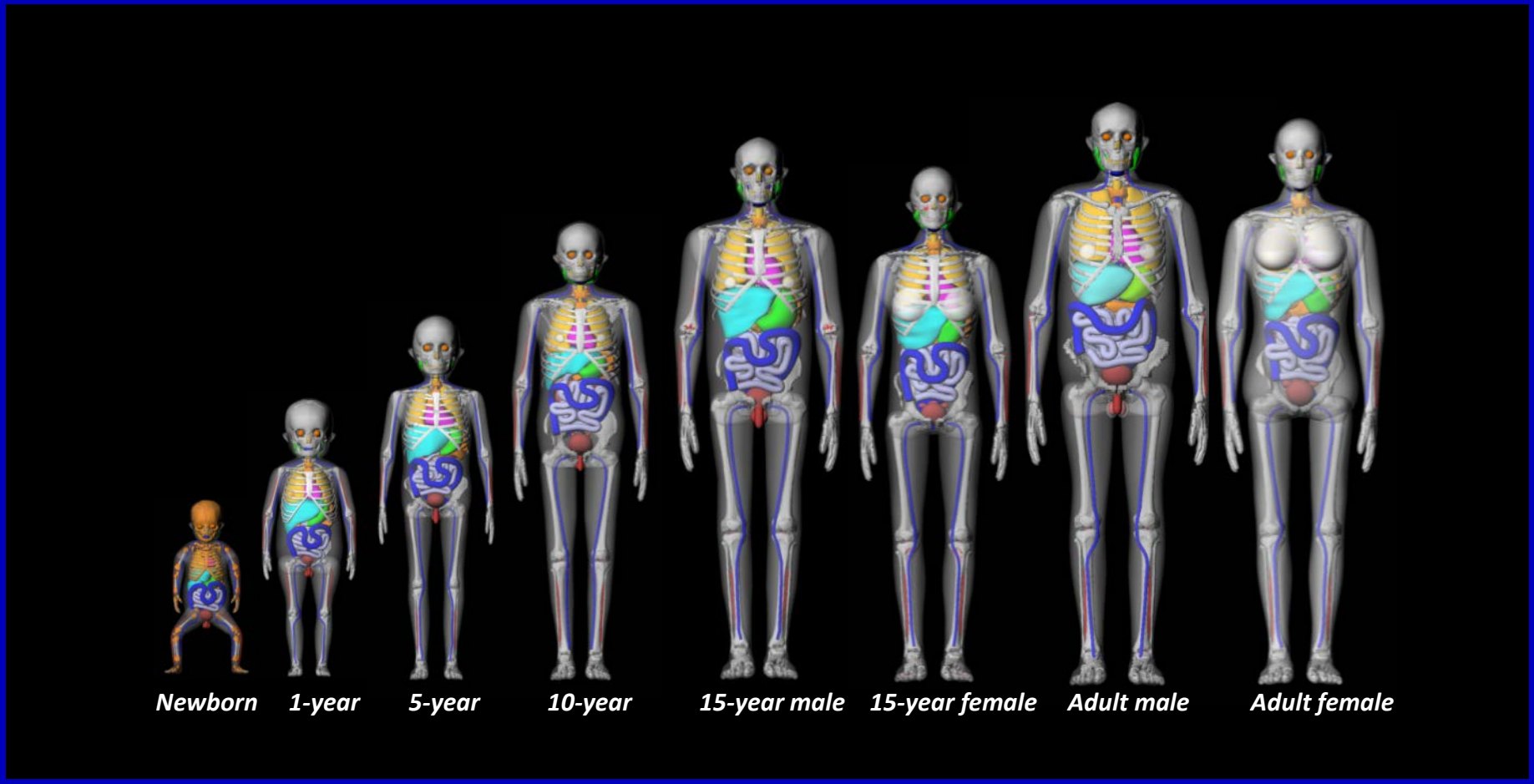
Computational Anatomic Phantoms

Phantom Types and Categories

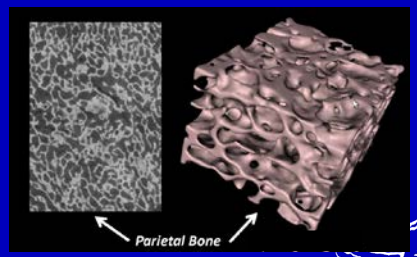
- **Phantom Format Types**
  - ⇨ Stylized (or mathematical) phantoms
  - ⇨ Voxel (or tomographic) phantoms
  - ⇨ Hybrid (or NURBS/PM) phantoms

- **Phantom Morphometric Categories**
  - ⇨ Reference (50^{th} percentile individual, patient matching by age only)
  - ⇨ Patient-dependent (patient matched by nearest height / weight)
  - ⇨ Patient-sculpted (patient matched to height, weight, and body contour)
  - ⇨ Patient-specific (phantom uniquely matching patient morphometry)

UF Series of Reference Hybrid Phantoms



Key Feature: ***MicroCT image-based models of active marrow and endosteum dosimetry for both internal electron sources and whole-body photon sources***



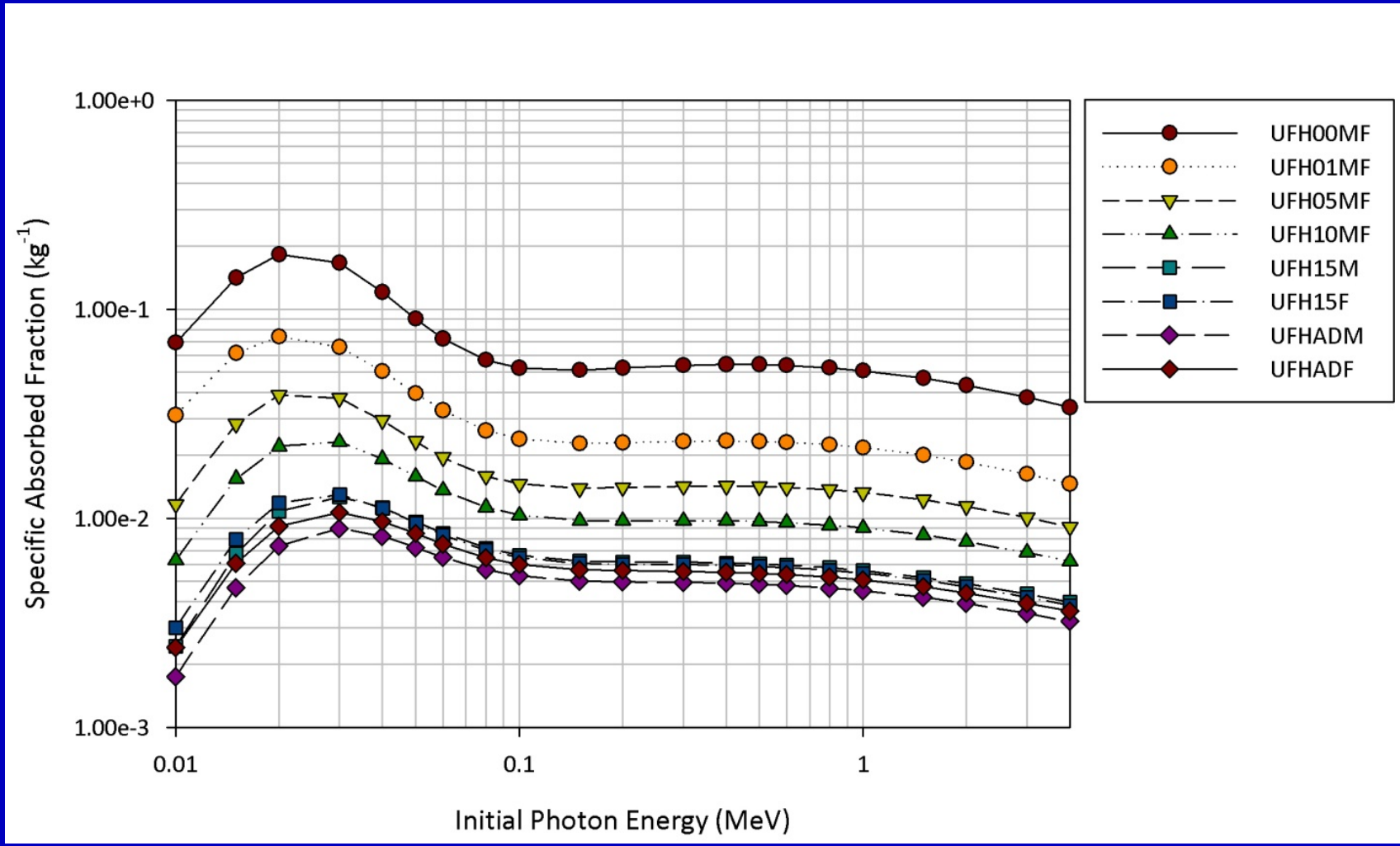
UF UNIVERSITY of FLORIDA

J. Crayton Pruitt Family Department of Biomedical Engineering
Medical Physics Program

GATOR Engineering

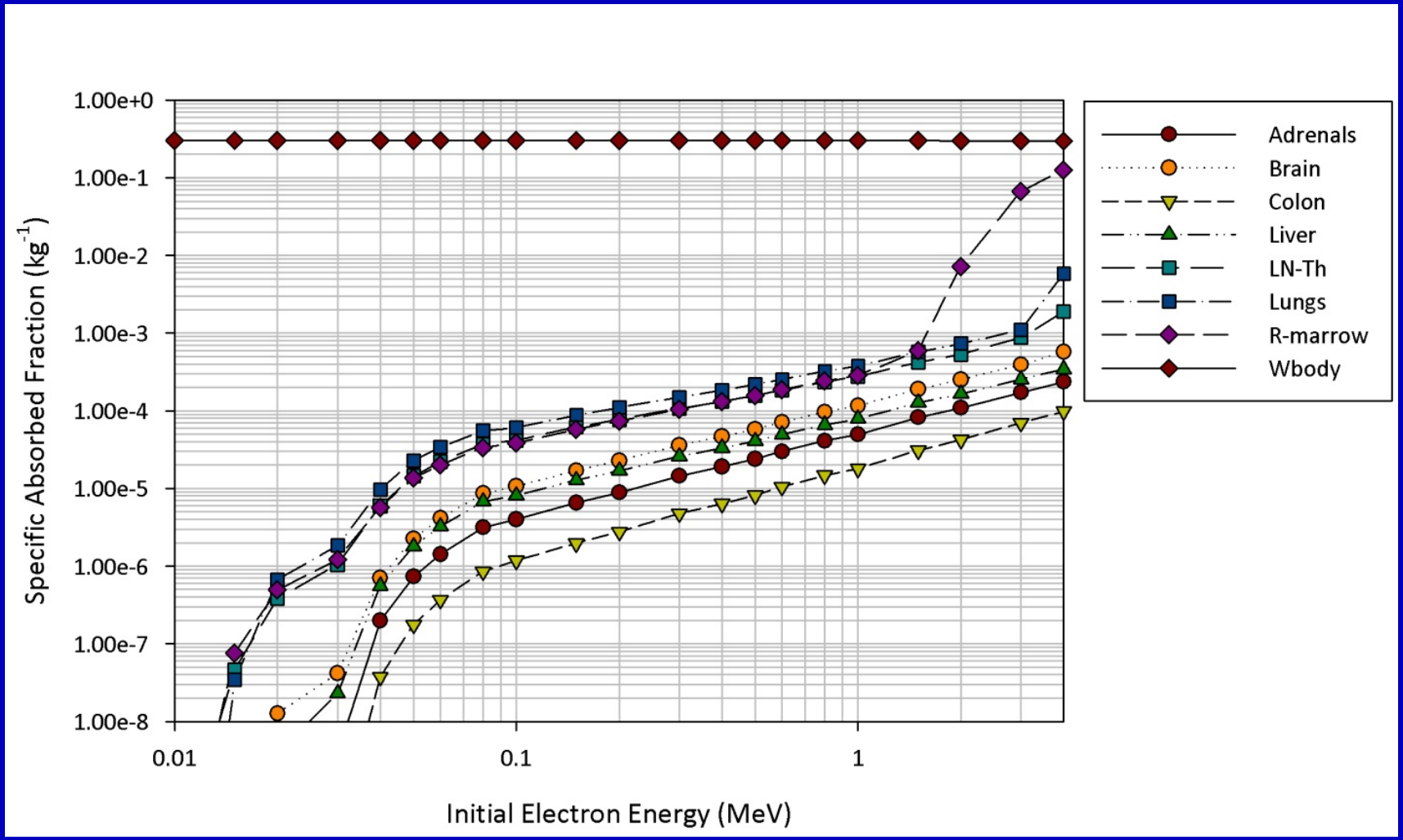
3. Anatomic Parameters – Reference Phantoms

Photon Φ(muscle ← lungs) for all phantoms in the UF phantom family



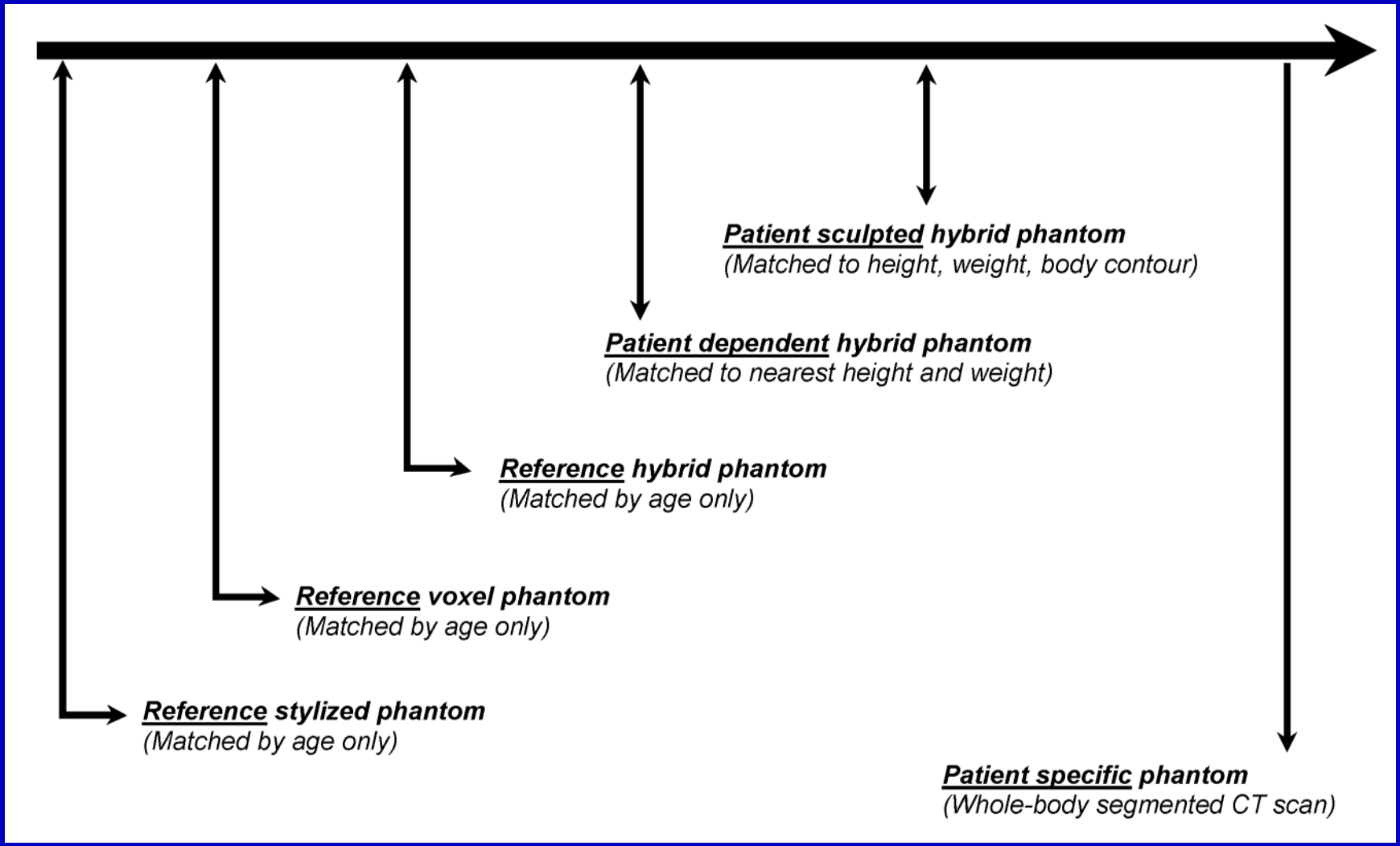
3. Anatomic Parameters – Reference Phantoms

A subset of the electron SAF curves for the thyroid source tissue in the newborn phantom

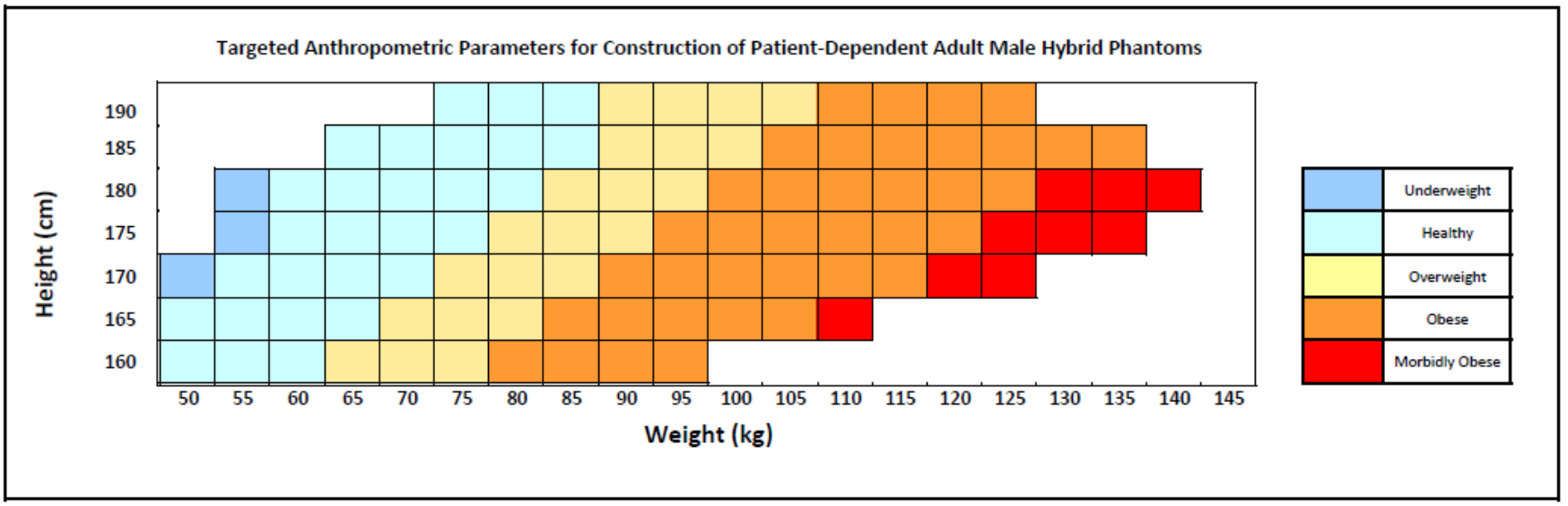


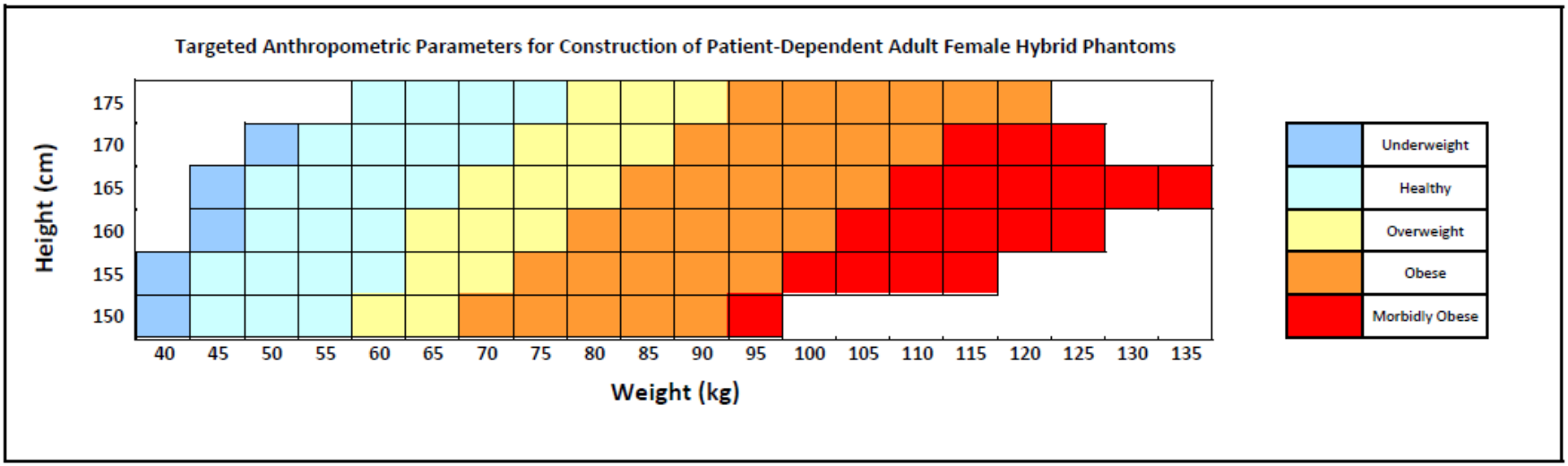
Continuum of Anatomic Specificity

Pre-computed dose library ← → ***Patient-specific dose calculation***

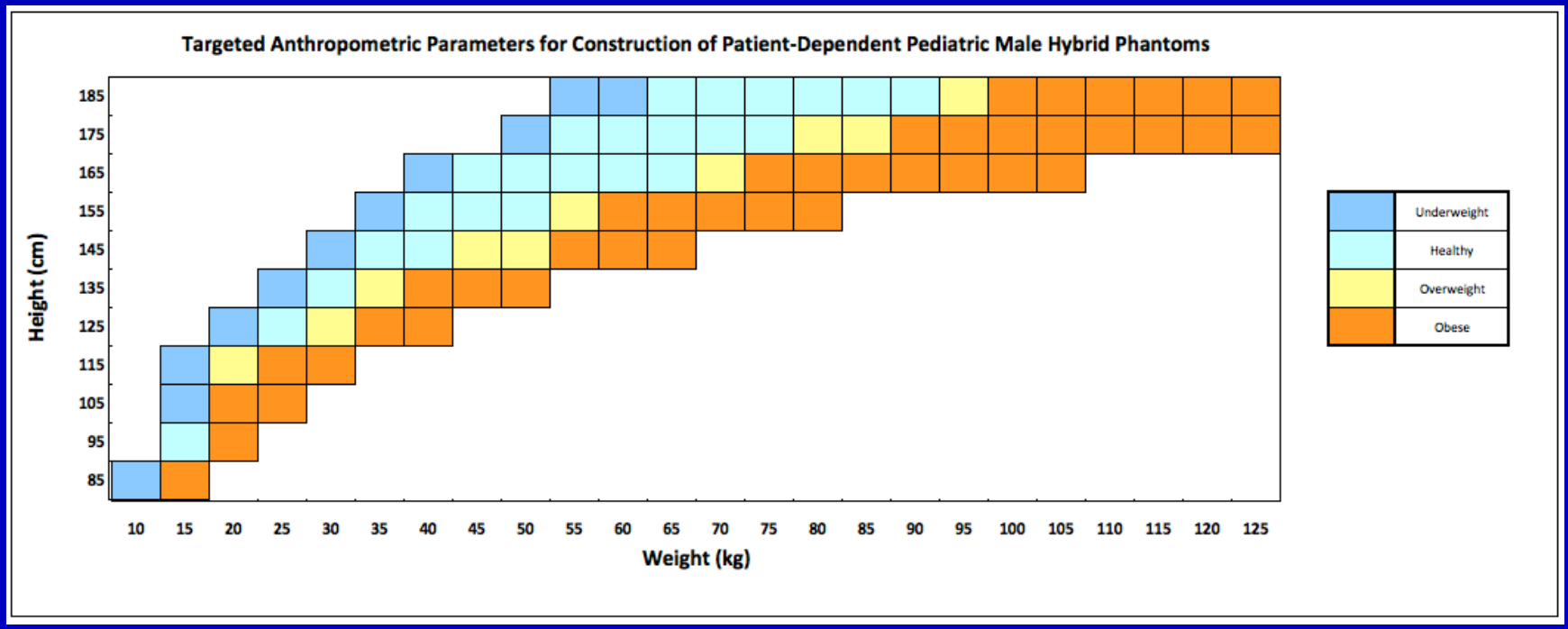


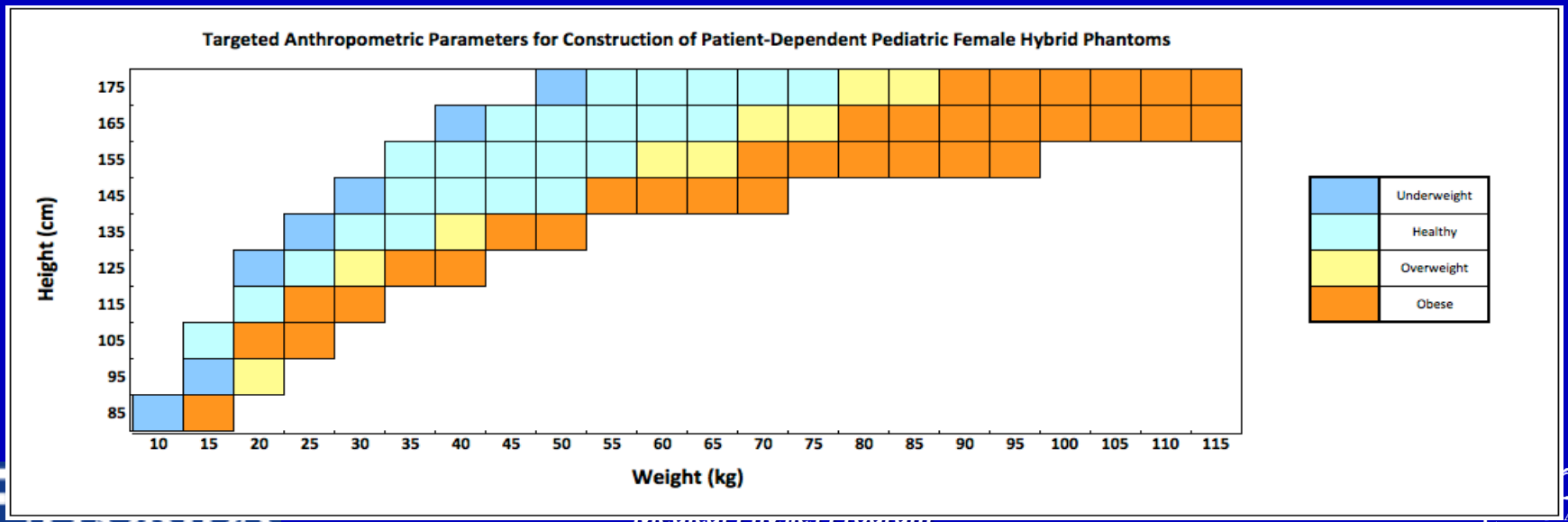
Patient-Dependent Phantoms – Adults



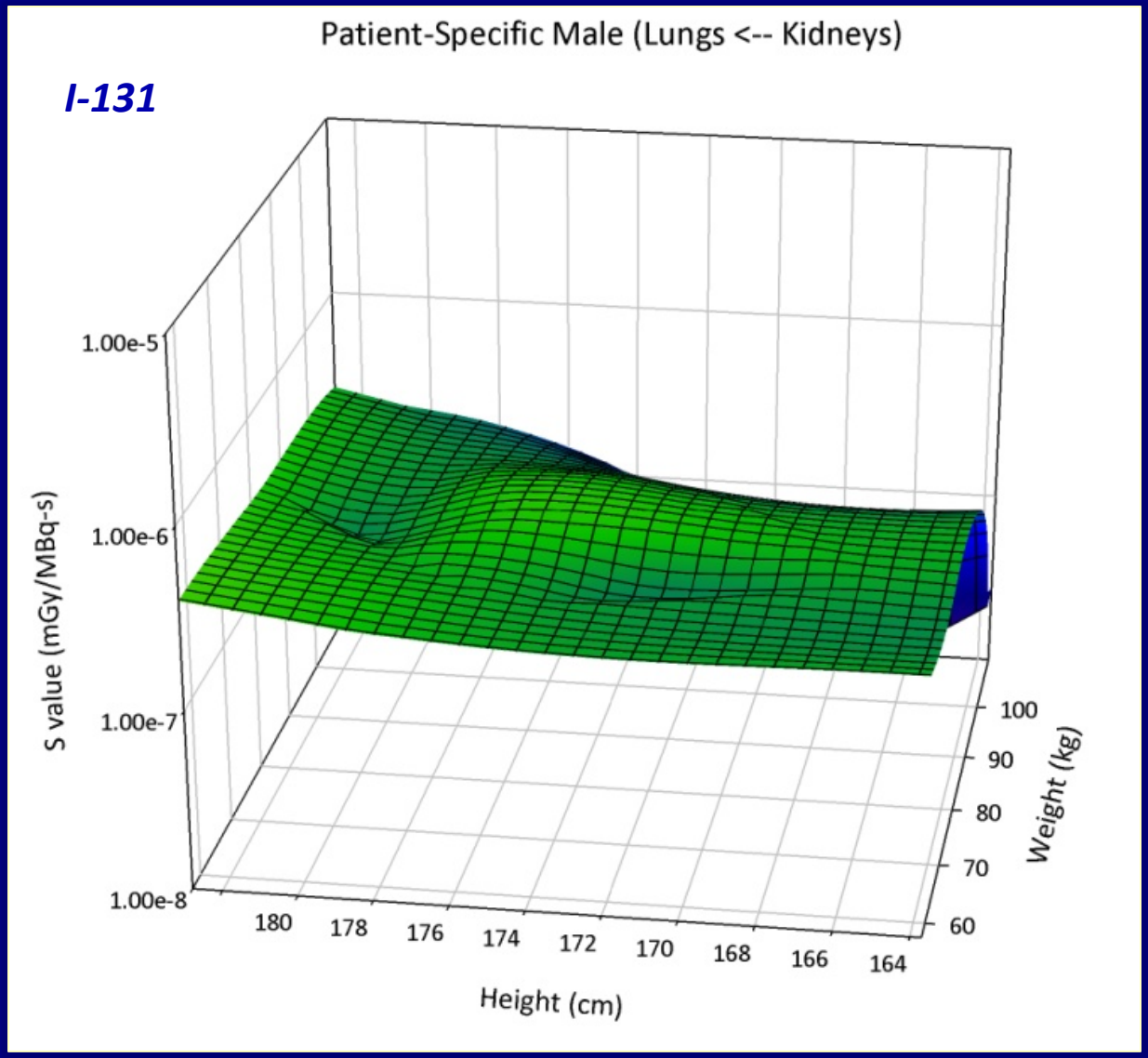


Patient-Dependent Phantoms – Children

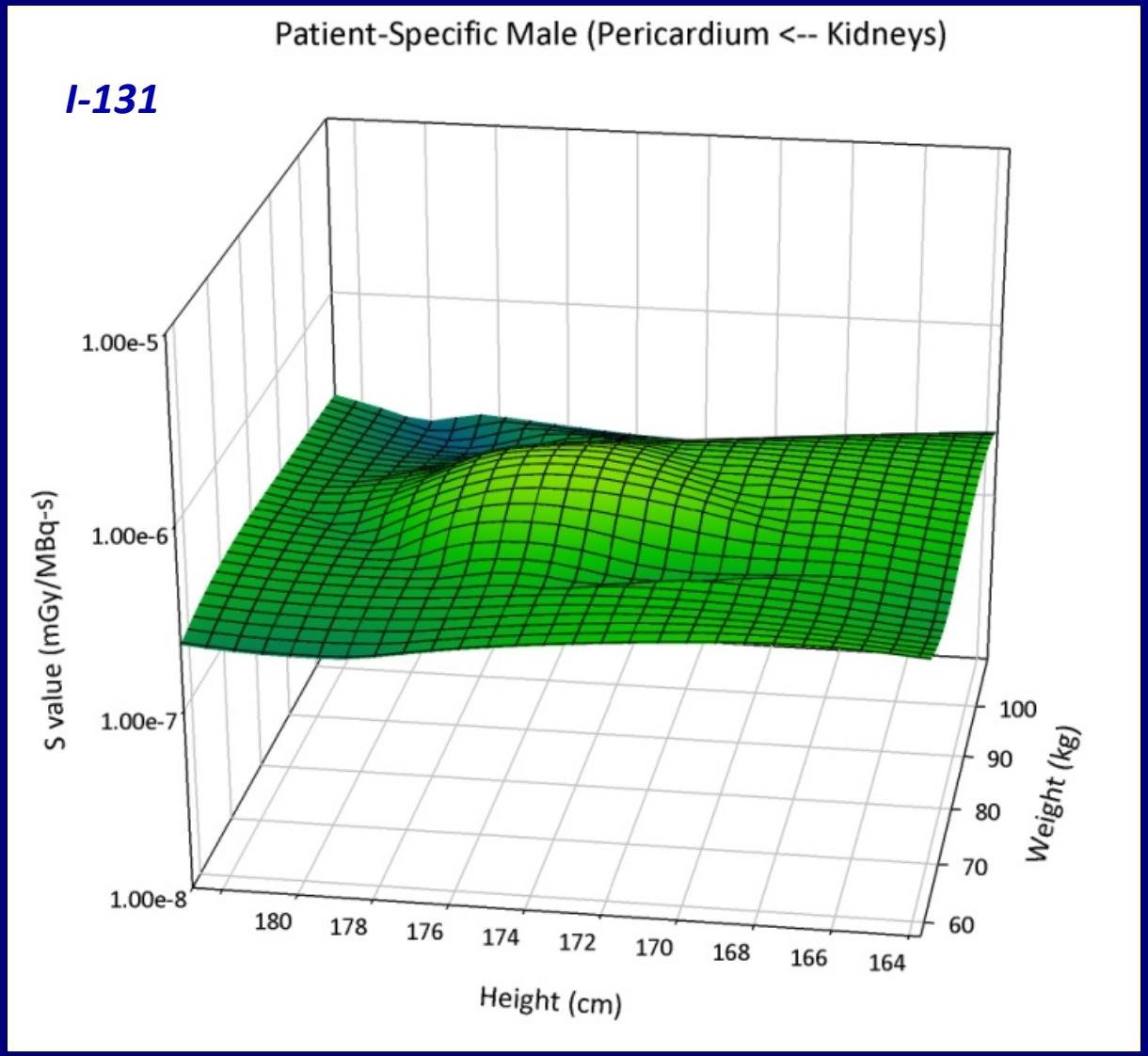




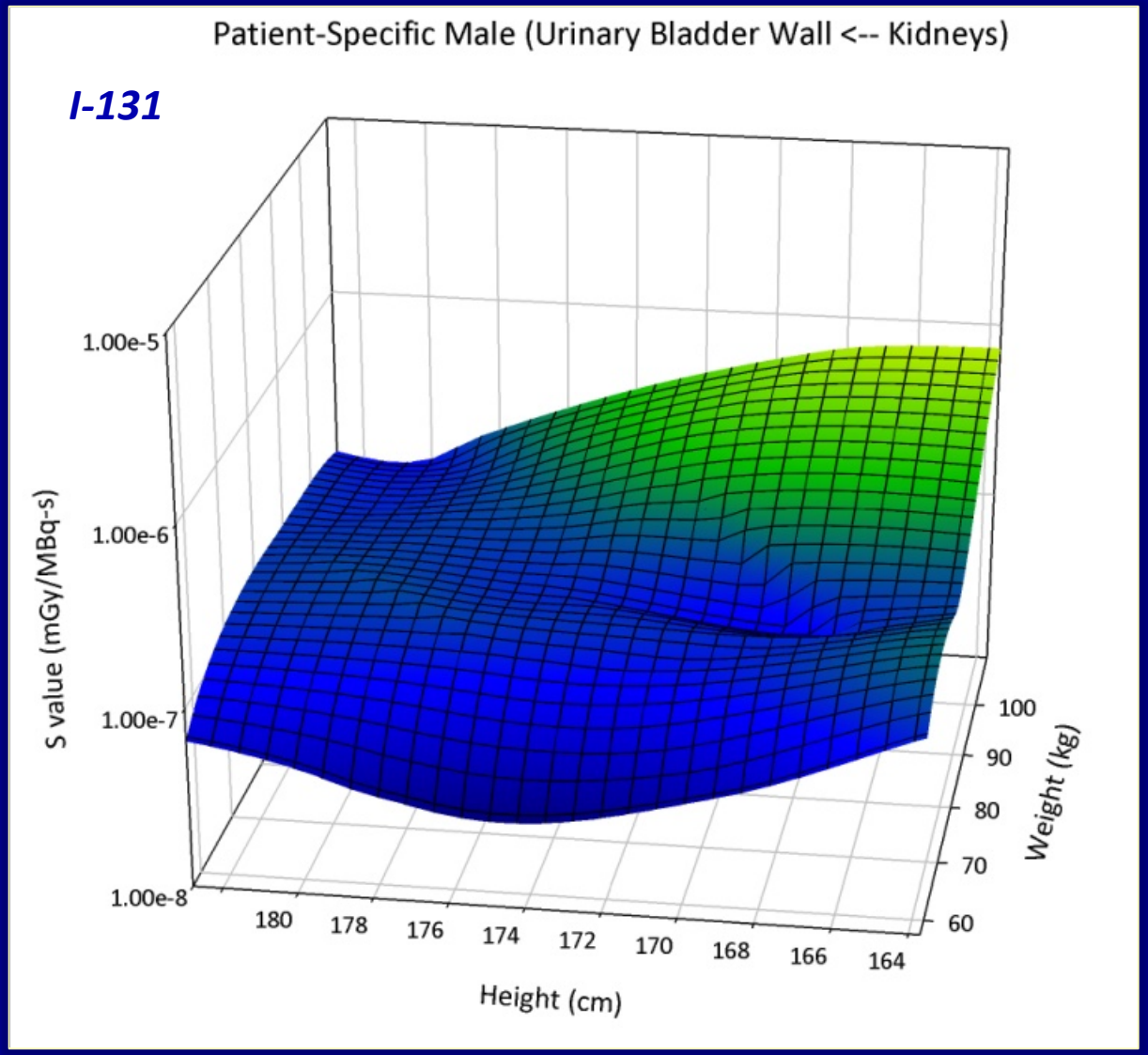
3. Anatomic Parameters – Patient Variations



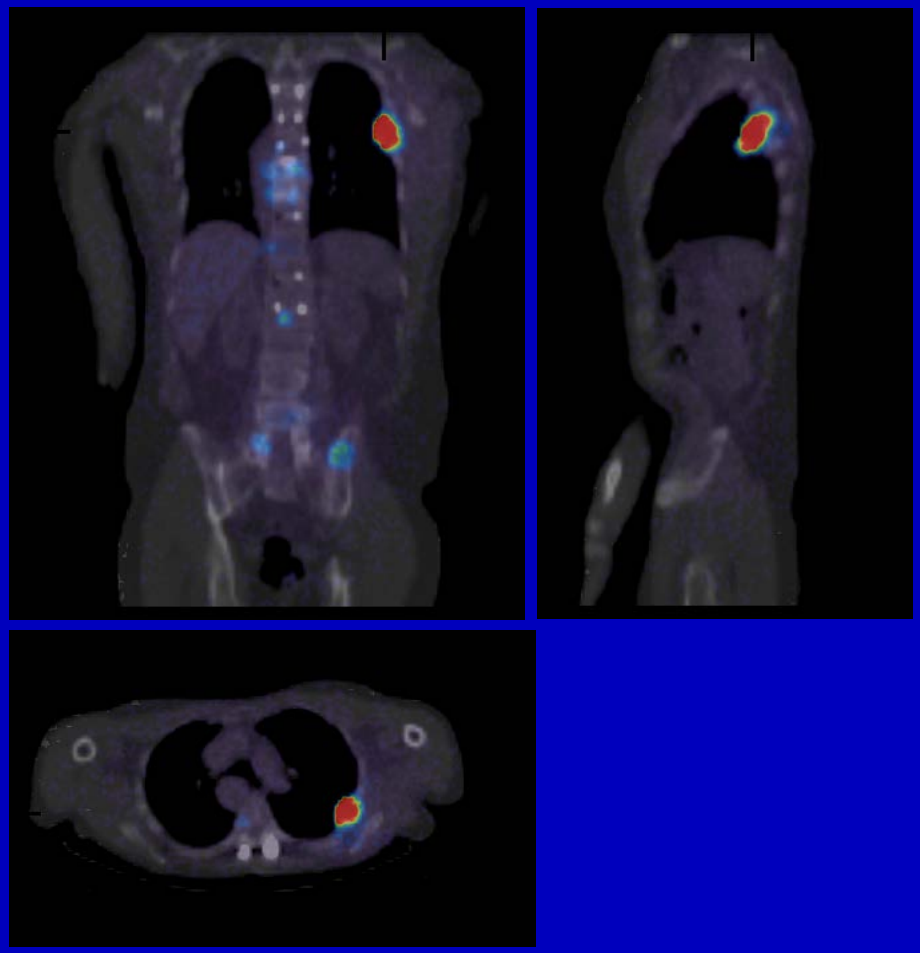
3. Anatomic Parameters – Patient Variations



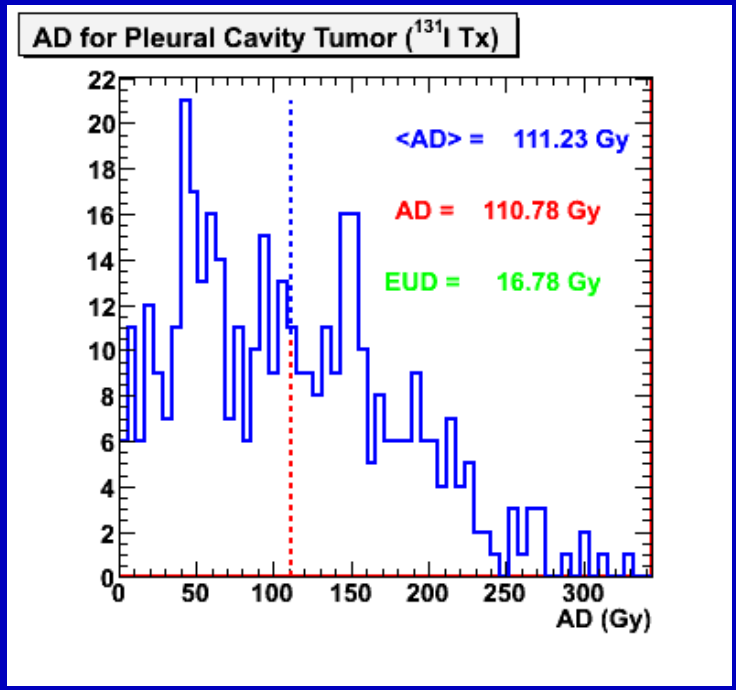
3. Anatomic Parameters – Patient Variations



3. Anatomic Parameters – State-of-the-Art



On-the-fly Monte Carlo simulation using Patient's CT and SPECT/PET images



Conclusions

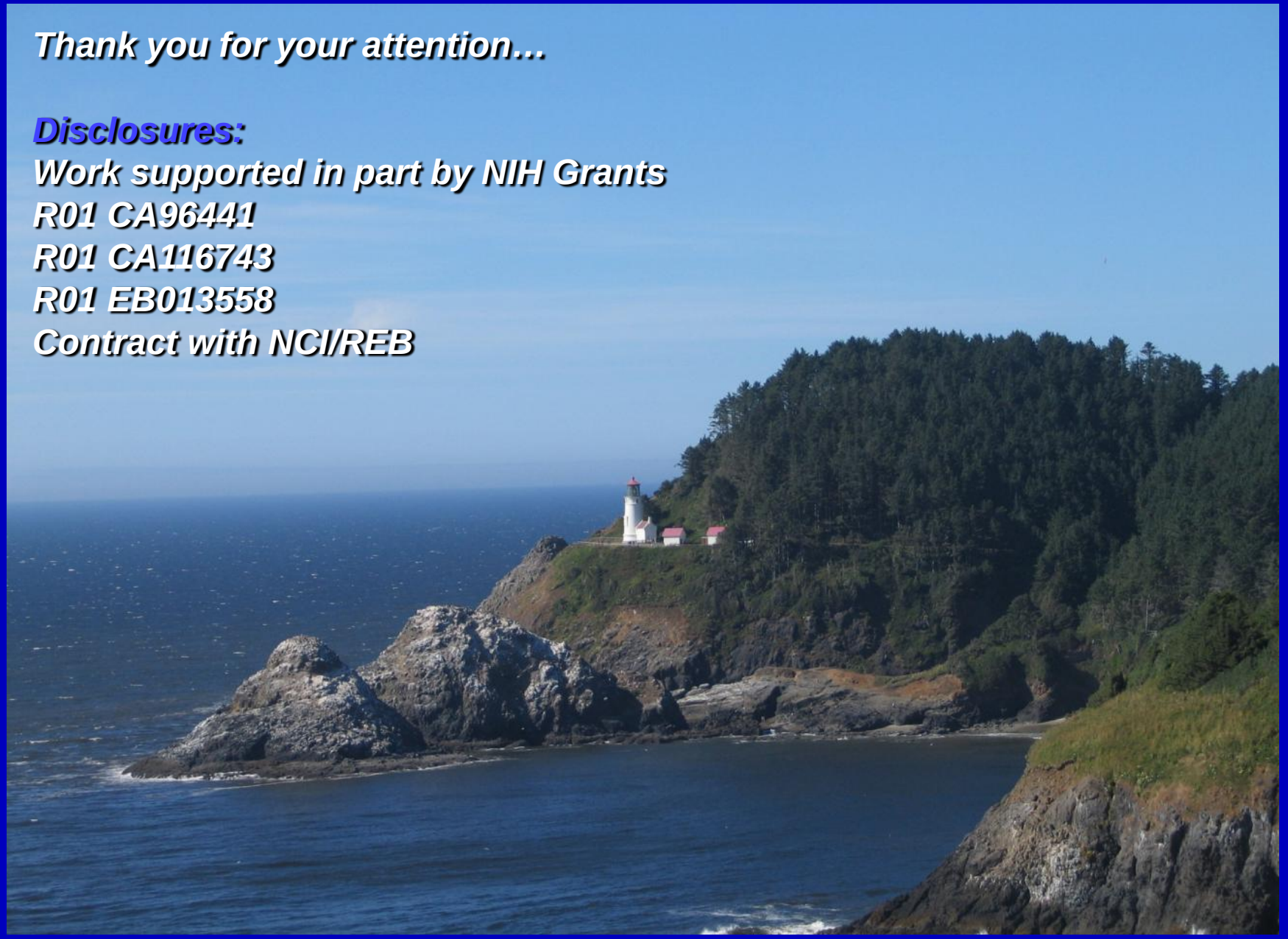
The only viable dose index for patient "dose tracking" in nuclear medicine would be injected activity.

However, to infer organ and effective dose, one would have to rely on reference models for both…

- *Radiopharmaceutical biokinetics*
- *Organ masses and values of absorbed fraction*

Future improvements may be made in expanding dose coefficients to include -

- *An expanded library of computational phantoms of varying age, height, and weight with associated radionuclide S values – work in progress*
- *Parameterized biokinetic models for different patient disease states and genetic makeup – logistically difficult and likely to be prohibitively costly*



Thank you for your attention…

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