

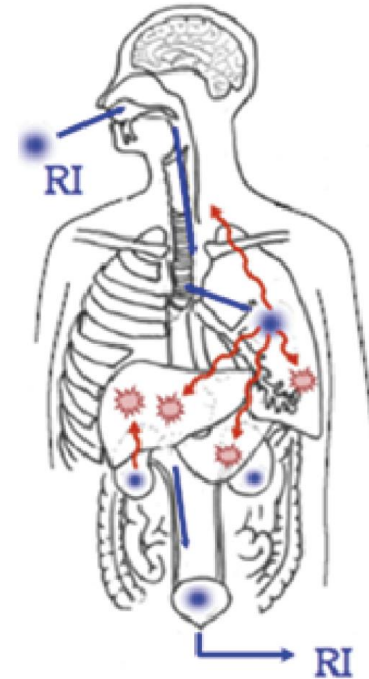
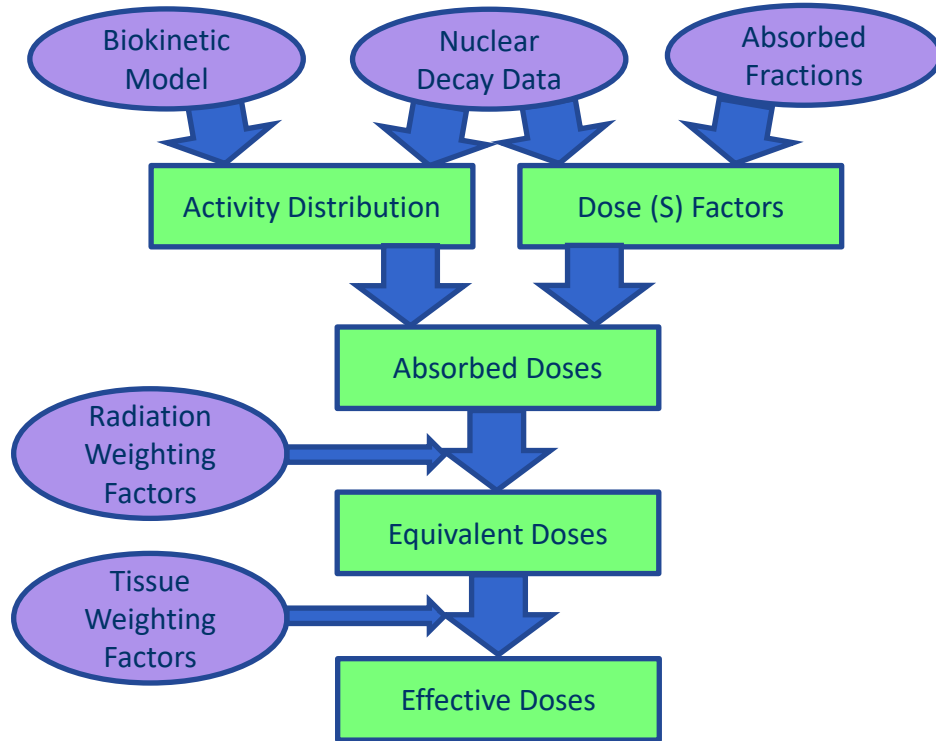
Old and New: Internal Dosimetry Calculations with the OpenDose Calculator

Erin McKay

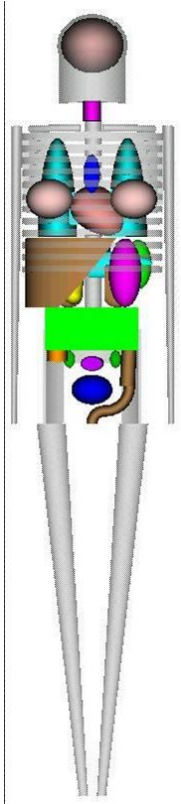
Radiation Safety Officer

St. George Hospital

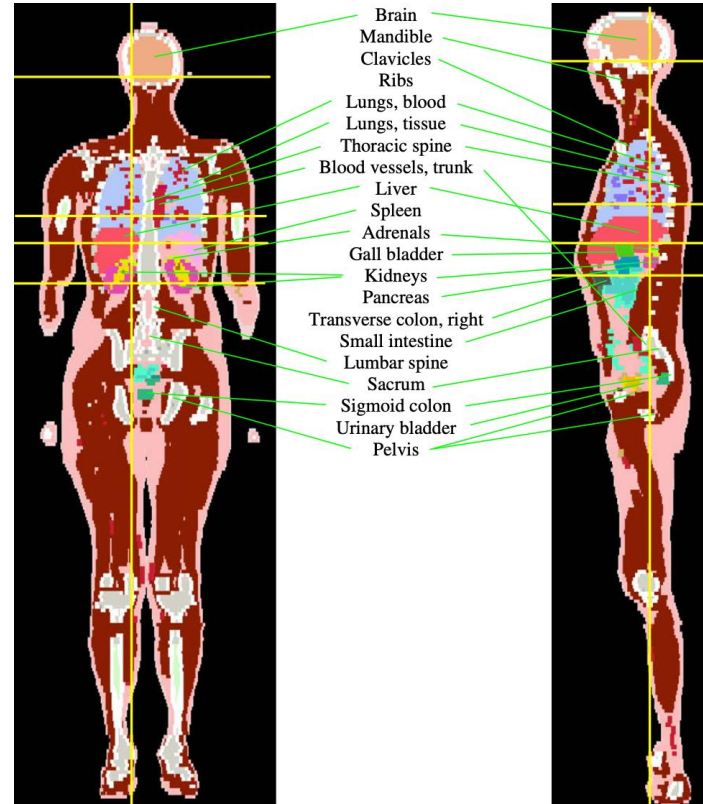
Internal Dosimetry Calculations



RADAR vs ICRP 89, 110, 133

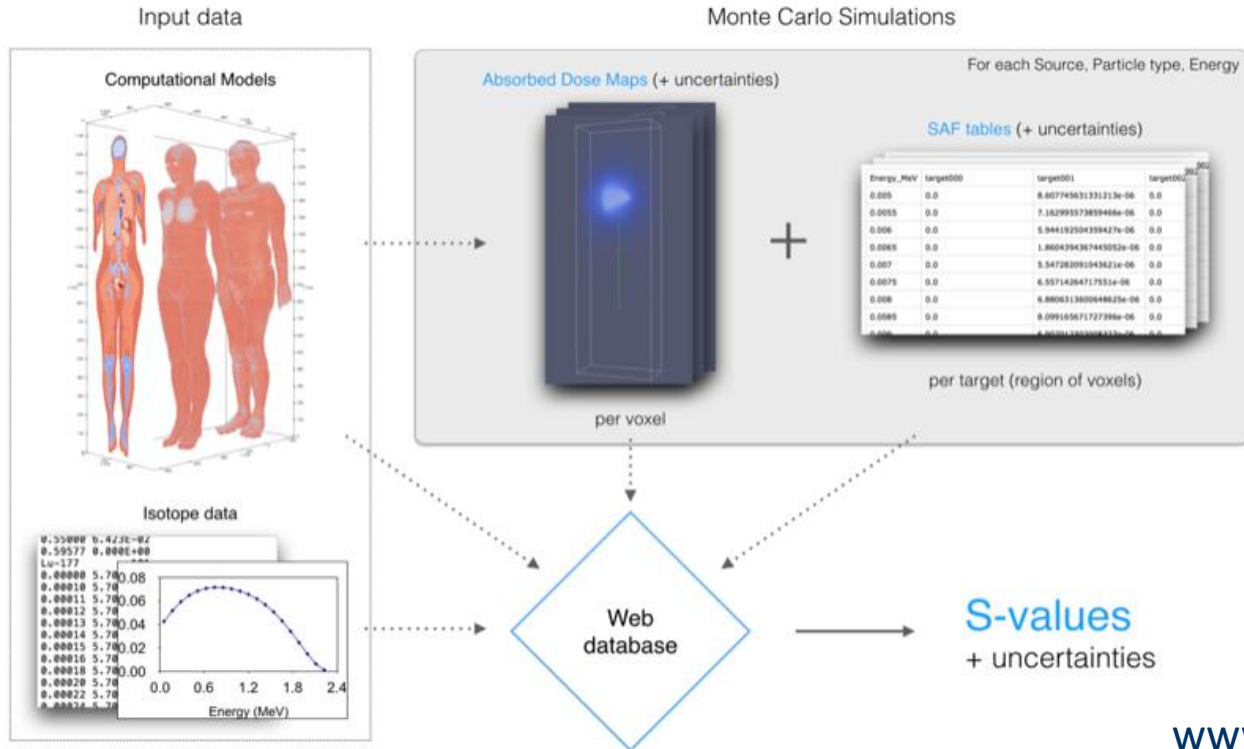


Cristy & Eckerman 1987



ICRP 110, 2007

The OpenDose Collaboration



Aim

- Develop a platform for radiopharmaceutical dosimetry reporting using arbitrary collections of absorbed fractions and spectra.
- Assess reports based on absorbed fractions from the RADAR web-site and from ICRP 133 and radiation spectra from ICRP 107.



OpenDose

Internal Dosimetry Calculator

Version 0.50.2 2021-07-04
erin@computerhead.com.au

Spectrum

I-122
I-123
I-124
I-125
I-126
I-128
I-129
I-130
I-130m
I-131

Phantom

ICRP AF
ICRP AM
OpenDose AF
OpenDose AM
RADAR Adult
RADAR Child01
RADAR Child05
RADAR Child10
RADAR Child15
RADAR Female

Residence Times


Equivalent Doses

Residence Time in Source Regions

Adrenals	<input type="text" value=""/>	+/-	<input type="text" value="0.0E00"/>	h
Brain	<input type="text" value=""/>	+/-	<input type="text" value="0.0E00"/>	h
Breasts	<input type="text" value=""/>	+/-	<input type="text" value="0.0E00"/>	h
GB Cont	<input type="text" value=""/>	+/-	<input type="text" value="0.0E00"/>	h
LLI Cont	<input type="text" value="6.446E-01"/>	+/-	<input type="text" value="0.0E00"/>	h
SI Cont	<input type="text" value="7.038E-02"/>	+/-	<input type="text" value="0.0E00"/>	h
StomCont	<input type="text" value="2.293E00"/>	+/-	<input type="text" value="0.0E00"/>	h
ULI Cont	<input type="text" value="2.336E-01"/>	+/-	<input type="text" value="0.0E00"/>	h
HeartCon	<input type="text" value=""/>	+/-	<input type="text" value="0.0E00"/>	h

Retention h

Excretion h



OpenDose

Internal Dosimetry Calculator
Version 0.50.2 2021-07-04
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Spectrum | **Phantom**

Eu-152n
Eu-154
Eu-154m
Eu-155
Eu-156
Eu-157
Eu-158
Eu-159
F-17
F-18

ICRP AM
OpenDose AF
OpenDose AM
RADAR Adult
RADAR Child01
RADAR Child05
RADAR Child10
RADAR Child15
RADAR Female
RADAR Newborn
RADAR Reference

Residence Times | Equivalent Doses

Import... | Residence Calculator ▾

Export... | Clear | Zero

Help | Preferences... | Int

Dose Distribution Display

Phantom: RADAR Adult | Source: All | Adjust Target Masses

Spectrum: F-18 | Radiation: Total | Adjust Radiation Weights

Target	Mass (g)	Absorbed Dose (mGy)	Equivalent Dose (mSv)	Uncertainty (mSv)	Weighted Dose (mSv)
Adrenals	1.63E01	1.189E-02	1.189E-02	0.0E00	5.947E-05
Brain	1.42E03	3.694E-02	3.694E-02	0.0E00	1.847E-04
Breasts	3.51E02	8.515E-03	8.515E-03	0.0E00	4.258E-04
Gallbladder Wall	1.05E01	1.279E-02	1.279E-02	0.0E00	0.0E00
LLI Wall	1.67E02	1.365E-02	1.365E-02	0.0E00	1.638E-03
Small Intestine	6.77E02	1.198E-02	1.198E-02	0.0E00	5.989E-05
Stomach Wall	1.58E02	1.099E-02	1.099E-02	0.0E00	1.319E-03
ULI Wall	2.2E02	1.161E-02	1.161E-02	0.0E00	5.807E-05
Heart Wall	3.16E02	6.73E-02	6.73E-02	0.0E00	0.0E00
Kidneys	2.99E02	1.051E-02	1.051E-02	0.0E00	5.253E-05
Liver	1.91E03	2.054E-02	2.054E-02	0.0E00	1.027E-03
Lungs	1.0E03	1.934E-02	1.934E-02	0.0E00	2.321E-03
Muscle	2.8E04	9.984E-03	9.984E-03	0.0E00	4.992E-05
Ovaries	8.71E00	1.374E-02	1.374E-02	0.0E00	2.747E-03
Pancreas	9.43E01	1.232E-02	1.232E-02	0.0E00	6.158E-05
Red Marrow	1.12E03	9.666E-03	9.666E-03	0.0E00	1.16E-03
Osteogenic Cells	1.2E02	1.196E-02	1.196E-02	0.0E00	1.196E-04
Skin	3.01E03	7.607E-03	7.607E-03	0.0E00	7.607E-05
Spleen	1.83E02	1.03E-02	1.03E-02	0.0E00	5.149E-05
Testes	3.91E01	1.078E-02	1.078E-02	0.0E00	0.0E00
Thymus	2.09E01	1.128E-02	1.128E-02	0.0E00	5.641E-05
Thyroid	2.07E01	9.847E-03	9.847E-03	0.0E00	4.924E-04
Urinary Bladder Wall	4.76E01	1.308E-01	1.308E-01	0.0E00	6.541E-03
Uterus	7.9E01	1.817E-02	1.817E-02	0.0E00	9.083E-05

Tissue Weighting: ICRP 60 | Administered Activity: 1.0E00 +/- 0.0E00 MBq

Effective Dose: 1.859E-02 +/- 0.0E00 mSv

Export Report | Print Report | Apply Filters | Done

Generation of Dose Reports

- Construct Phantoms
- Evaluate Biokinetic Models
- Calculate Effective Dose

Phantom Construction

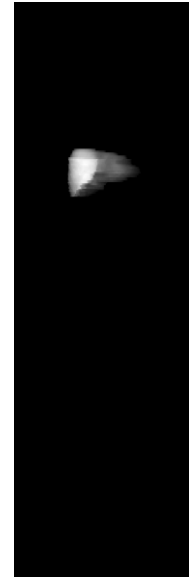
- Based on collections of (specific) absorbed fractions (AFs or SAFs)
- Described by a manifest file (JSON format)
- Can include post-composition adjustments:
 - Default radiation weighting factors (OLINDA/EXM)
 - Default target mass changes (ICRP 110/133)
 - Replacement of particular fractions (OpenDose marrow)

Subtractive Model

- Used by RADAR, OLINDA/EXM (v1)
- Generate SAFs for source organs and total body irradiating target organs.
- Combine with emission spectra to form dose factors (DFs or S-values)
- Calculate DFs for organs irradiated by remainder of body by subtracting mass-weighted fractions of the source organ DFs from the total body DFs



Total



Liver



Remainder

Remainder of Body Source

For the total body source the cumulated activity in each tissue is simply proportional to its mass:

$$m_{TB}S_{lung\leftarrow TB} = m_{liver}S_{lung\leftarrow liver} + m_{RB}S_{lung\leftarrow RB}$$

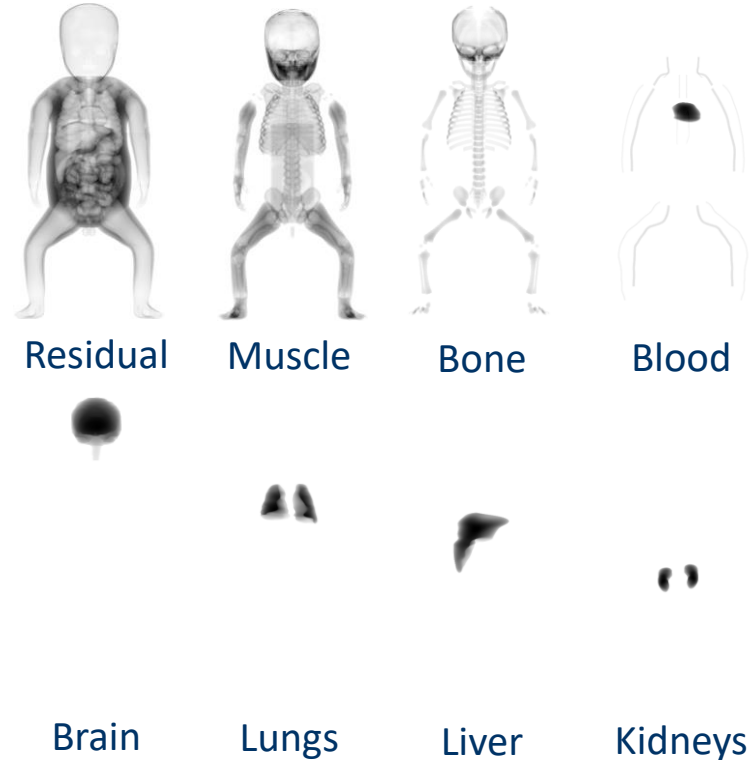
Rearranging:

$$S_{lung\leftarrow RB} = \frac{m_{TB}}{m_{RB}}S_{lung\leftarrow TB} - \frac{m_{liver}}{m_{RB}}S_{lung\leftarrow liver}$$

This is prone to truncation due to the low precision of rounded-off SAF values.

Additive Model

- Used by ICRP 133, IDAC (v2)
- Generate SAFs for all defined organ regions irradiating each other.
- Combine with emission spectra to form dose factors (DFs)
- Calculate DFs for the Remainder of Body by weighted sum of unused source DFs.



Remainder of Body Source

Starting with the same assumption of activity distributed in proportion to source region mass:

$$S_{lung \leftarrow RB} = \sum_{organ} \frac{m_{organ}}{m_{RB}} S_{lung \leftarrow organ} - \frac{m_{liver}}{m_{RB}} S_{lung \leftarrow liver}$$

This is more stable than the subtractive algorithm as the contribution from specified sources simply cancels out.

Kinetic Model Evaluation

- Each phantom supports zero or more plug-in residence time calculators
- This is determined by a section in the phantom manifest
- Each subsection maps calculator variables (LHS) onto one or more phantom source regions (RHS)
- Variables are identified by position, not name

```
"residence_time":[
  ["ICRP General",[
    ["Adrenals",["Adrenals",1.0]],
    ...
    ["Other",["TotBody",1.0]]
  ]],
  ["ICRP Gut",[
    ["Stomach",["StomCont",1.0]],
    ...
    ["Lower Lg. Int.",["LLI Cont",1.0]]
  ]],
  ["ICRP Renal",[
    ["Kidneys",["Kidneys",1.0]],
    ["Bladder",["UB Cont",1.0]]
  ]
]
```

ICRP General (ICRP 53)

```
"icrp_general":{
  "compartments":[
    ["Bone Surfaces",0.5,[
      [-1.0,0.25,"h"],
      [0.3,2.0,"h"],
      [0.7,72.0,"h"]
    ]],
    ["Kidneys",0.02,[
      [0.3,0.5,"h"],
      [0.3,2.0,"h"],
      [0.4,72.0,"h"]
    ]],
    ["Other",1.0,[
      [0.3,0.5,"h"],
      [0.3,2.0,"h"],
      [0.4,72.0,"h"]
    ]
  ]
}
```

The screenshot shows a dialog box titled "ICRP General" with a table of parameters for three compartments: Bone Surfaces, Kidneys, and Other. Each compartment has three rows of parameters: Fraction, Amount, and Half-Time, each with a text input field and a unit 'h'.

Source	Fraction	Amount	Half-Time	Unit
Bone Surfaces	5.0E-01	-1.0E00	2.5E-01	h
		3.0E-01	2.0E00	h
		7.0E-01	7.2E01	h
Kidneys	2.0E-02	3.0E-01	5.0E-01	h
		3.0E-01	2.0E00	h
		4.0E-01	7.2E01	h
Other	1.0E00	3.0E-01	5.0E-01	h
		3.0E-01	2.0E00	h

Buttons at the bottom: Load..., Export..., Cancel, OK

$$\frac{\tilde{A}_S}{A_0} = F_S \sum_{j=n+1}^{n+m} a_j \sum_{i=1}^n \left\{ a_i \frac{T_i}{T_i - T_j} \left[\exp\left(\frac{-\ln(2)}{T_{i,eff}} t\right) - \exp\left(\frac{-\ln(2)}{T_{j,eff}} t\right) \right] \right\}$$

ICRP Renal Model (ICRP 53)

```
"icrp_renal":{  
  "fraction":1.0,  
  "clearance":[  
    [null,0.3,0.5,"h"],  
    [null,0.3,2.0,"h"],  
    [null,0.4,72.0,"h"]  
  ],  
  "transit_time":[5.0,"m"],  
  "void_interval":[3.5,"h"]  
}
```

$$\tilde{A}_B = f_r \sum_{i=1}^n a_i \left[\frac{1 - \exp(-\lambda_p t_v)}{\lambda_p} - \frac{1 - \exp(-(\lambda_i + \lambda_p)t_v)}{\lambda_i + \lambda_p} \right] \\ \times \left[\frac{1}{1 - \exp(-(\lambda_i + \lambda_p)t_v)} \right]$$

The screenshot shows a window titled "ICRP Renal 1.4.1" with the following parameters and values:

Parameter	Value	Unit
Cleared Fraction	1.0E00	
Renal Transit Time	5.0E00	m
Bladder voids every	3.5E00	h
Phase Parameters		
Phase	Fraction	Half-Time
Phase 1	3.0E-01	5.0E-01 h
Phase 2	3.0E-01	2.0E00 h
Phase 3	4.0E-01	7.2E01 h

Buttons at the bottom: Load..., Save..., Cancel, OK

Compartment Modeller

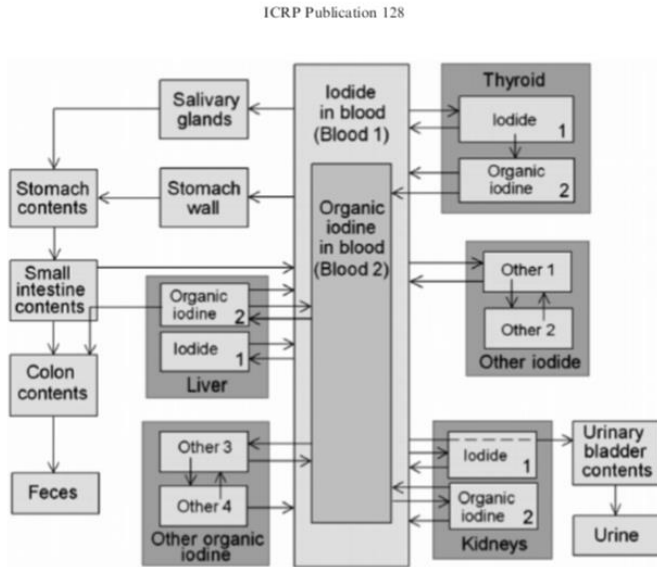


Fig. C.2. Compartment model used to describe the kinetics of iodine (Leggett, 2010).

(ICRP 128)

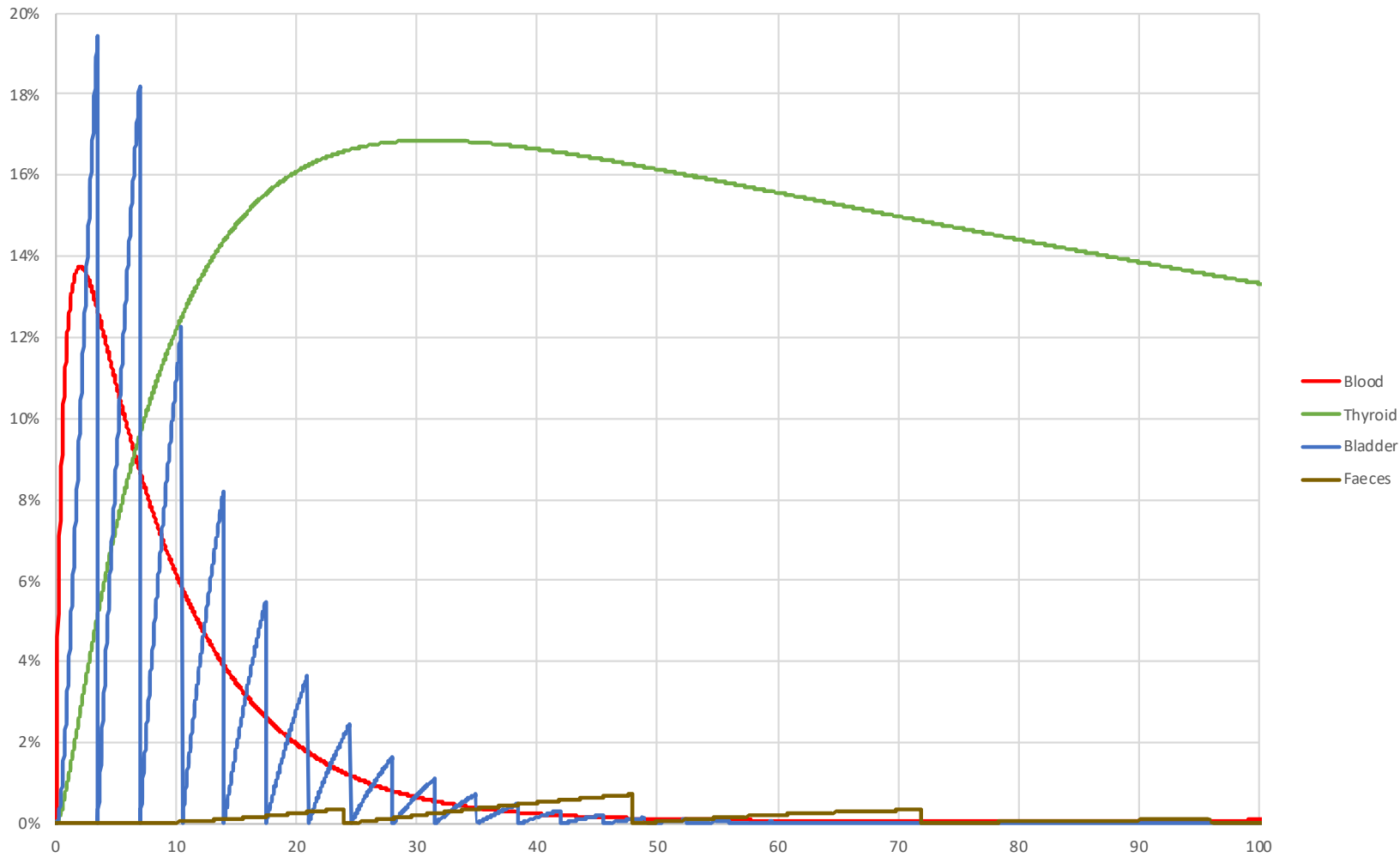
Dynamic System

Kinetics Curves

Source	Target	Half-Time
Blood Iodide	Salivary Glands	3.22E00 h
Blood Iodide	Stomach Wall	1.94E00 h
Blood Iodide	Other 1	2.77E-02 h
Blood Iodide	Kidneys 1	6.66E-01 h
Blood Iodide	Liver 1	1.11E00 h
Salivary Glands	Stomach Contents	3.33E-01 h
Stomach Wall	Stomach Contents	3.33E-01 h
Thyroid 1	Thyroid 2	1.75E-01 h
Thyroid 1	Blood Iodide	4.62E-01 h
Thyroid 2	Blood Organic	2.16E03 h

Load Cancel OK

I-131 Iodide Kinetics: Adult, Oral Administration, Low Thyroid Uptake



Effective Dose Calculation

- Each phantom supports zero or more plug-in effective dose calculators
- Again this is determined by a section in the phantom manifest
- Each subsection maps calculator variables (LHS) onto one or more phantom target regions (RHS)

```
"effective_dose":[  
  ["ICRP 60",[  
    ["Adrenals",["Adrenals",null]],  
    ...  
    ["Gonads",["Ovaries",null],["Testes",null]],  
    ...  
    ["Oesophagus",[]]  
  ]],  
  ["ICRP 103",[  
    ["Adrenals",["Adrenals",null]],  
    ...  
    ["Salivary Glands",[]]  
  ]]  
]
```

Validation Framework

```
{ "icrp_general": {  
  "compartments": [  
    ...  
  ]  
},  
"validation": {  
  "spectrum": "F-18",  
  "half_life": 1.8295,  
  "time_unit": "h",  
  "tolerance": 0.02,  
  "residence_time": [  
    ["Brain", 0.21, "h"],  
    ["HrtWall", 0.11, "h"],  
    ["Lungs", 0.079, "h"],  
    ["Liver", 0.13, "h"],  
    ["Other", 1.7, "h"],  
    ["Bladder", 0.26, "h"]  
  ]  
}
```

```
mckayer -- bash -- 63x18  
Dragon:~ mckayer$ /Users/mckayer/Applications/reMIRD/testing/scripts/testRTModule_ICRPGGeneral.tcl /Users/mckayer/Applications/reMIRD/testing/cases/ResidenceTimeModule/ICRP\ General\FDG\ \ (Adult)\ F-18.json  
SOURCE REGION      EXPECTED      MEASURED      RATIO  
Brain =>          2.10e-01     2.11e-01     1.01  
HrtWall =>        1.10e-01     1.06e-01     0.96  
Lungs =>          7.90e-02     7.92e-02     1.00  
Liver =>          1.30e-01     1.32e-01     1.02  
Kidneys =>        0.00e+00     8.67e-03     0.00  
Other =>          1.70e+00     1.70e+00     1.00  
Total References: 6  
Total Compared: 6  
Total Differences: 1  
Fraction Over 2% Different: 0.16666666666666666  
Dragon:~ mckayer$
```

Data for Validation

- Validation of residence time calculation was based on ICRP published data
- Validation of effective dose calculation was based on an Excel spreadsheet
- Validation for dose factor and absorbed dose calculations were originally going to be based on OLINDA/EXM and IDAC but...

Office suite interface with multiple overlapping windows. The primary window is titled "RADAR Adult" and contains a spreadsheet with columns labeled A1 through AD1 and rows for "EQUIVALENT DOSE FACTORS". The spreadsheet includes a header row with "A1" through "AD1" and a main data area with columns "A" through "AD". The data area contains numerical values and text labels such as "Alpha", "Electron", "Photon", and "Factors". The interface includes a menu bar with options like "Home", "Insert", "Page Layout", "Formulas", "Data", "Review", and "View". A ribbon is visible with tabs for "General", "Conditional Formatting", "Format", "Cell Styles", "Insert", "Delete", "Sort & Filter", and "Check for Updates". The status bar at the bottom shows "Ready" and "60%". Other windows in the background are titled "RADAR Child01", "RADAR Child05", "RADAR Child10", "RADAR Child15", "RADAR Child20", and "RADAR Newborn". Each window displays a similar spreadsheet layout with search bars and navigation icons. The overall appearance is that of a professional data management or calculation software.

BL98 3.95274107438089E-07

Check for Updates

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Comparison of Dosimetry

Radiopharmaceutical	ICRP 128 (mSv/MBq)	OCD RADAR (mSv/MBq)		OCD ICRP 133 (mSv/MBq)	
	Adult	Adult	Female	AM	AF
Tc-99m HDP	4.96×10^{-3}	5.42×10^{-3}	7.23×10^{-3}	3.65×10^{-3}	5.71×10^{-3}
F-18 FDG	1.90×10^{-2}	1.86×10^{-2}	2.42×10^{-2}	1.59×10^{-2}	2.11×10^{-2}
I-131 Iodide	$2.20 \times 10^{+1}$	$2.17 \times 10^{+1}$	$2.63 \times 10^{+1}$	$1.87 \times 10^{+1}$	$2.24 \times 10^{+1}$

Table 1. Effective doses calculated for 5 different phantoms using tissue weighting factors from ICRP 60.

Discussion

A platform has been developed to support comparison of internal dosimetry results from different sources

- Designed to support end-user validation
- Could be used as part of a validation chain for qualifying commercial software

Conclusion

For a small sample of radiopharmaceuticals, RADAR and ICRP 133 phantoms produce similar estimates of Effective Dose