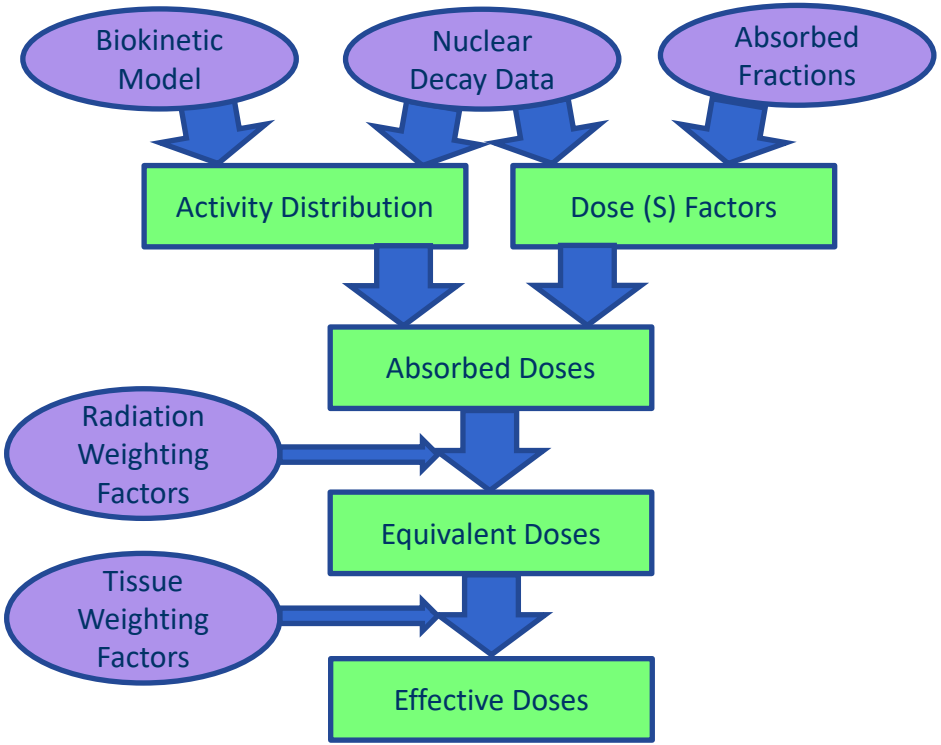
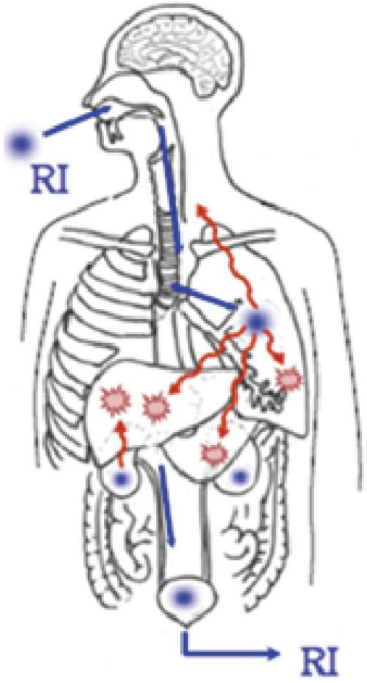
Old and New: Internal Dosimetry Calculations with the OpenDose Calculator

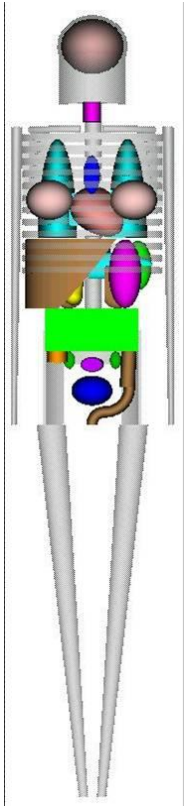
Erin McKay
Radiation Safety Officer
St. George Hospital

Internal Dosimetry Calculations

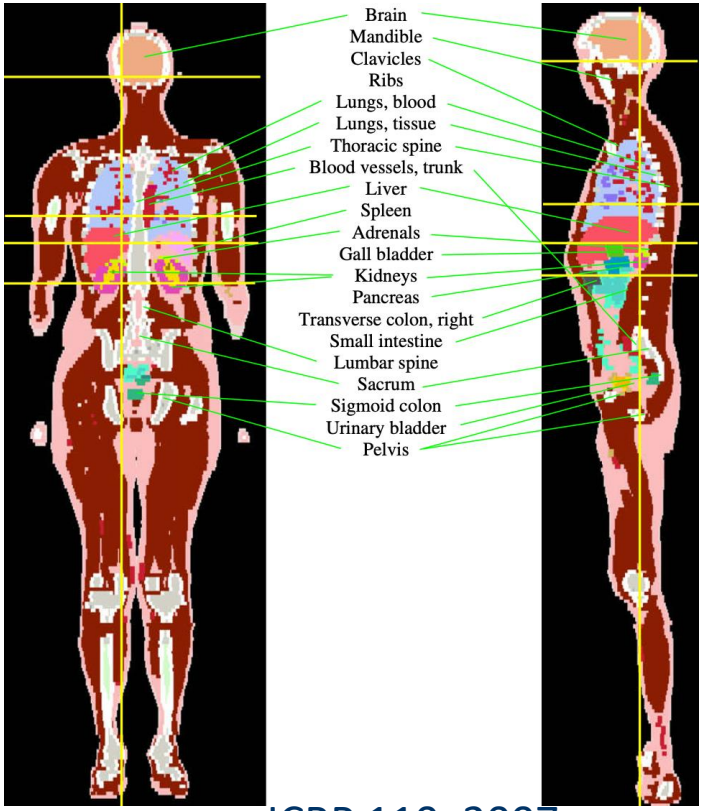




RADAR vs ICRP 89, 110, 133

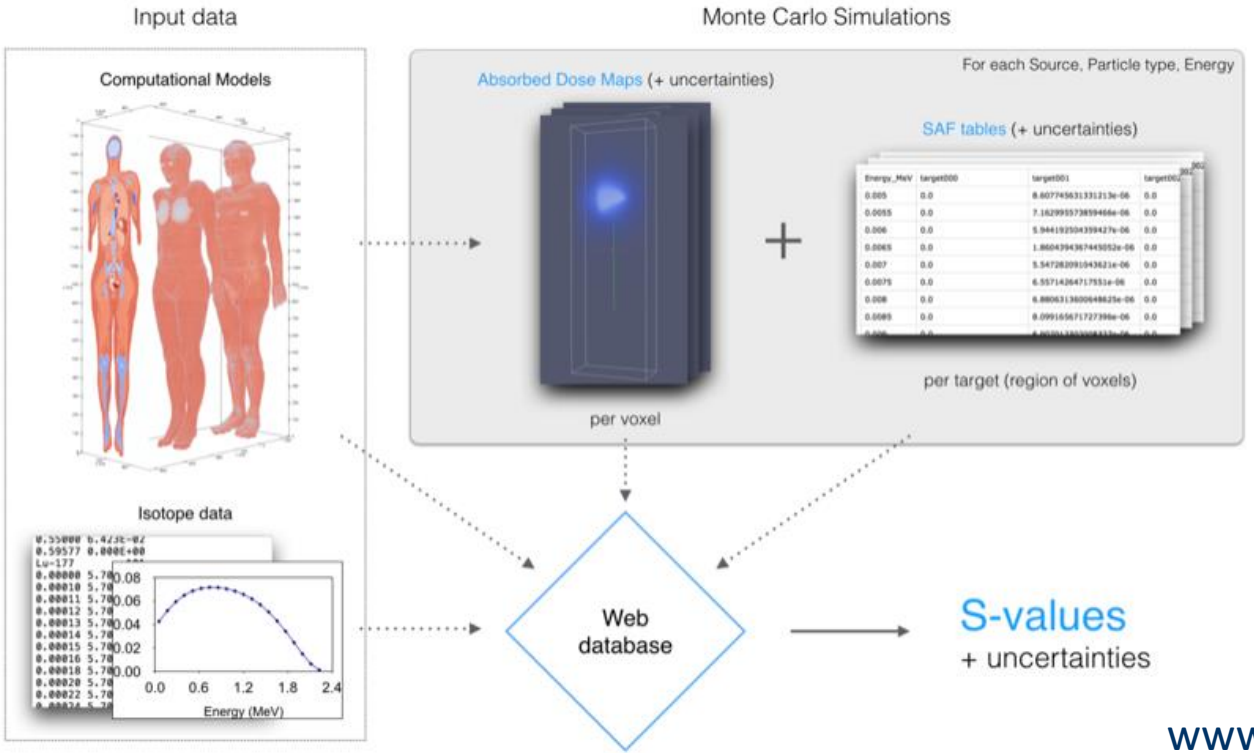


Cristy & Eckerman 1987



ICRP 110, 2007

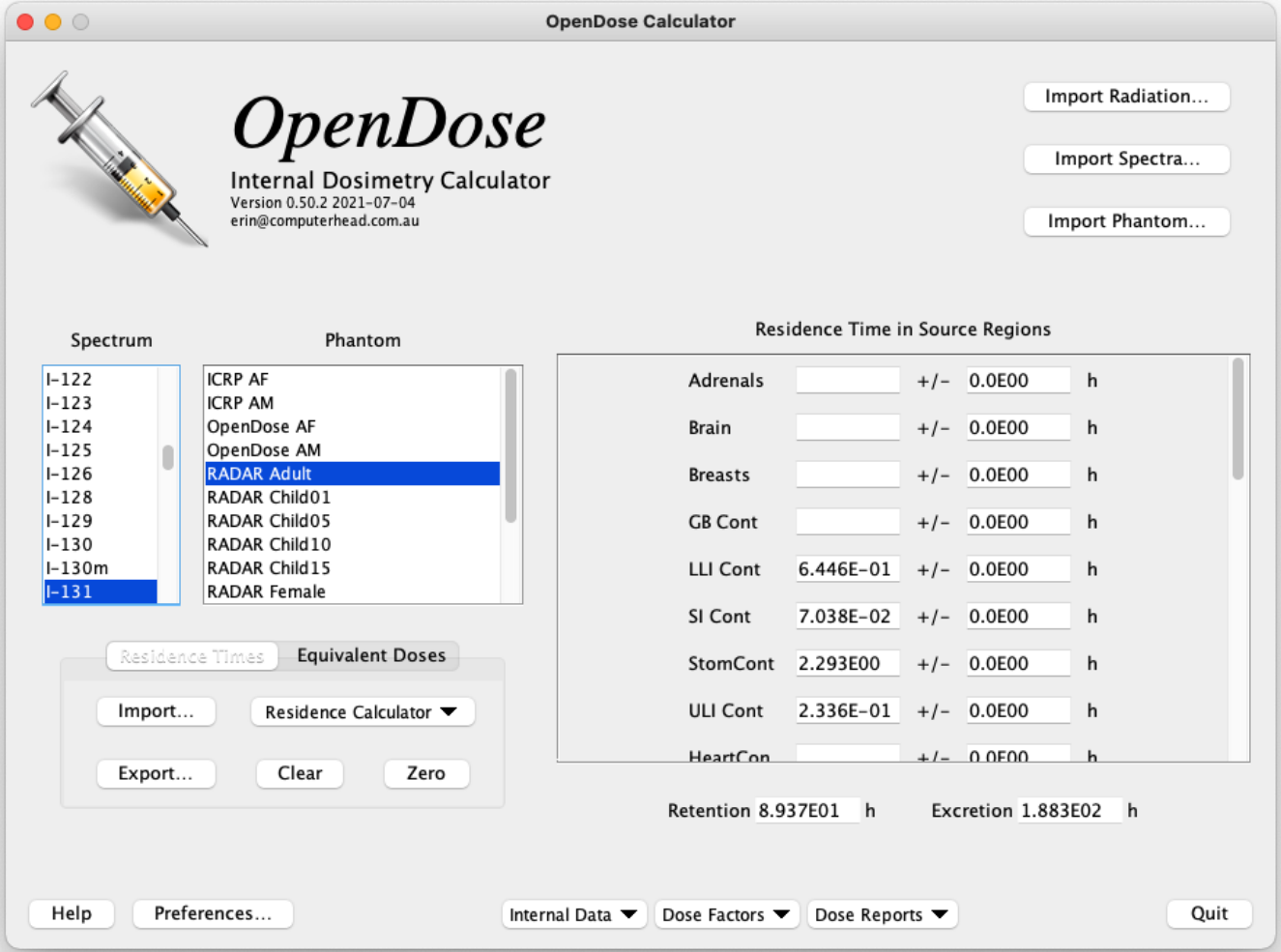
The OpenDose Collaboration

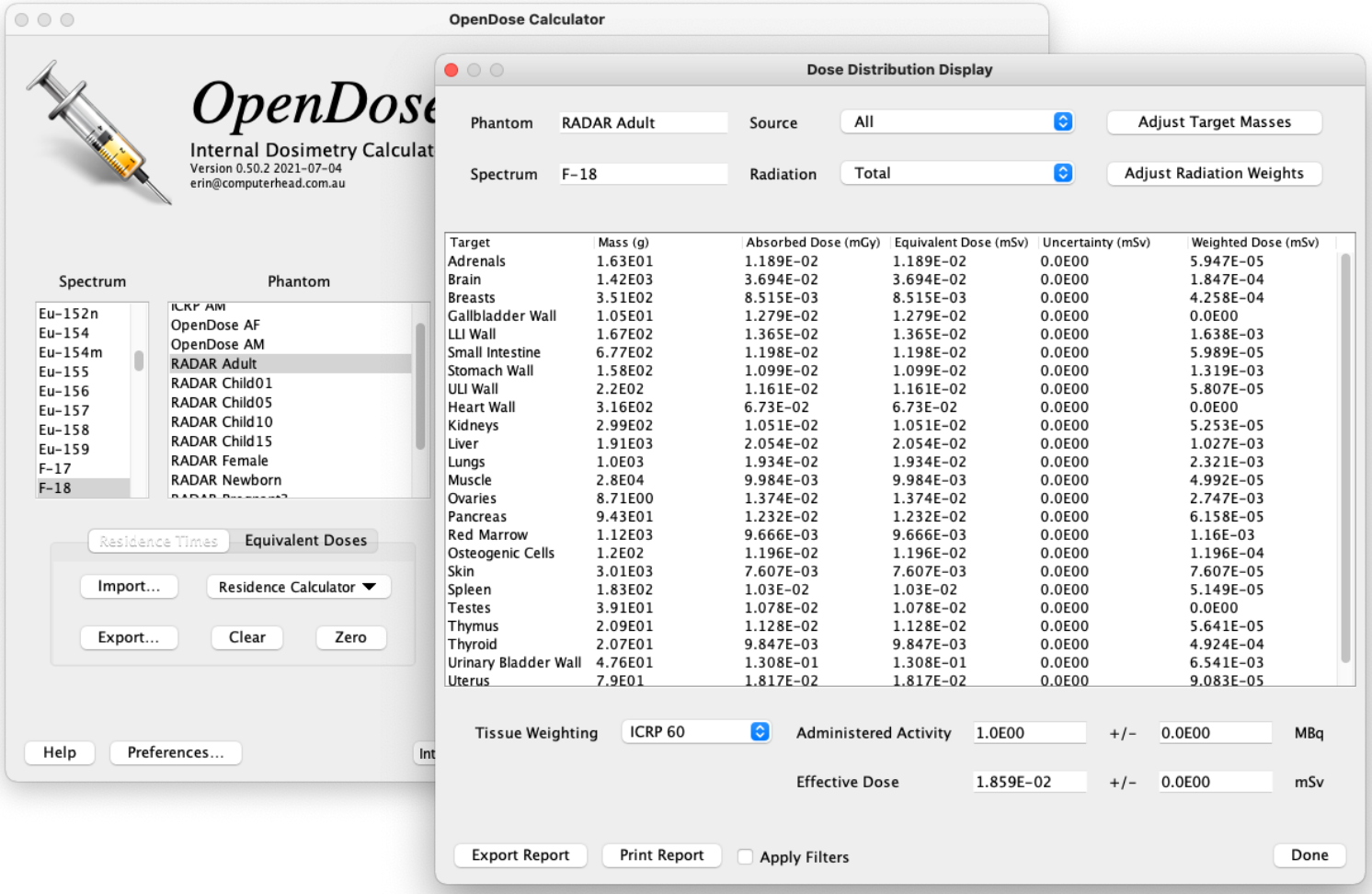


www.opendose.org

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 Calculator
OpenDose
Internal Dosimetry Calculator
Version 0.50.2 2021-07-04
erin@computerhead.com.au
Import Radiation...
Import Spectra...
Import Phantom...
Spectrum
Phantom
I-122
I-123
I-124
I-125
I-126
I-128
I-129
I-130
I-130m
I-131
ICRP AF
ICRP AM
OpenDose AF
OpenDose AM
RADAR Adult
RADAR Child01
RADAR Child05
RADAR Child10
RADAR Child15
RADAR Female
Residence Times
Equivalent Doses
Import...
Residence Calculator
Export...
Clear
Zero
Residence Time in Source Regions
Adrenals +/- 0.0E00 h
Brain +/- 0.0E00 h
Breasts +/- 0.0E00 h
GB Cont +/- 0.0E00 h
LLI Cont 6.446E-01 +/- 0.0E00 h
SI Cont 7.038E-02 +/- 0.0E00 h
StomCont 2.293E00 +/- 0.0E00 h
ULI Cont 2.336E-01 +/- 0.0E00 h
HeartCon +/- 0.0E00 h
Retention 8.937E01 h
Excretion 1.883E02 h
Help
Preferences...
Internal Data
Dose Factors
Dose Reports
Quit


OpenDose Calculator
OpenDose
Internal Dosimetry Calculat
Version 0.50.2 2021-07-04
erin@computerhead.com.au
Spectrum
Phantom
Eu-152n
Eu-154
Eu-154m
Eu-155
Eu-156
Eu-157
Eu-158
Eu-159
F-17
F-18
OpenDose AF
OpenDose AM
RADAR Adult
RADAR Child01
RADAR Child05
RADAR Child10
RADAR Child15
RADAR Female
RADAR Newborn
Residence Times
Equivalent Doses
Import...
Residence Calculator
Export...
Clear
Zero
Help
Preferences...
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

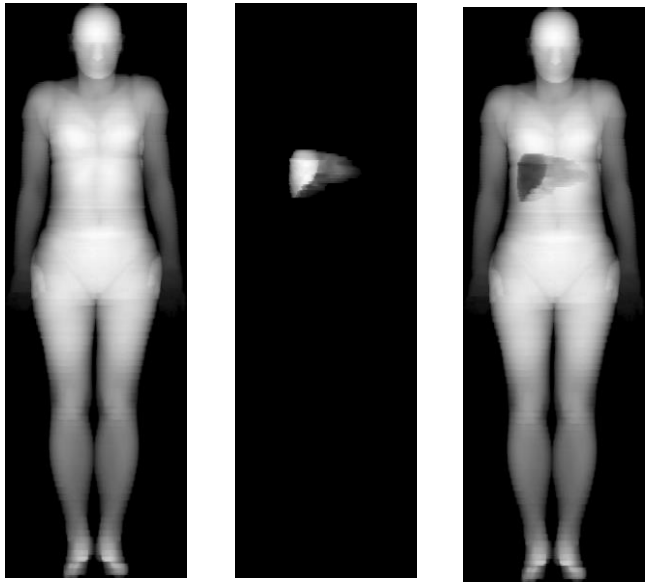
- Construct Phantoms
- Evaluate Biokinetic Models
- Calculate Effective Dose

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:

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

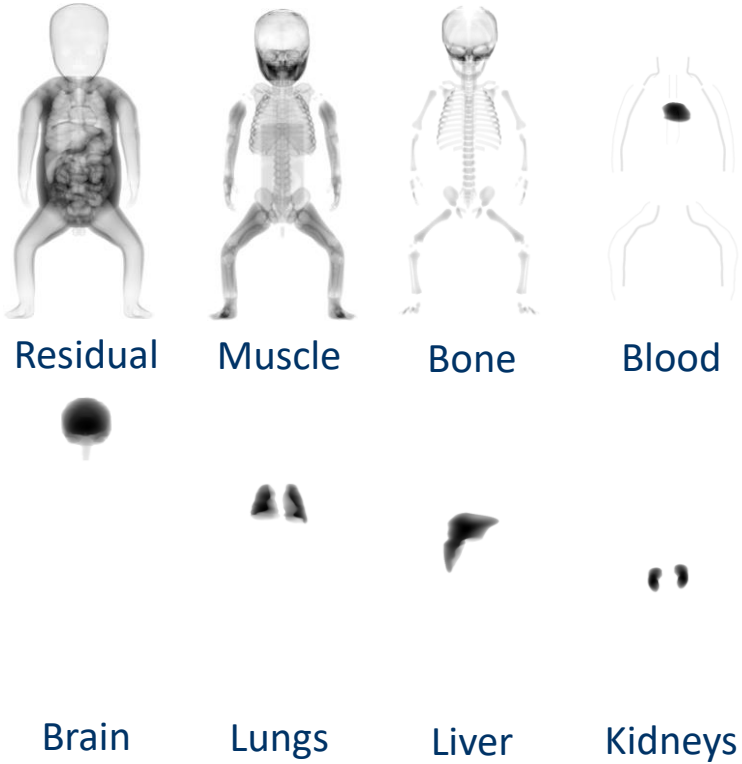
Rearranging:

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

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.

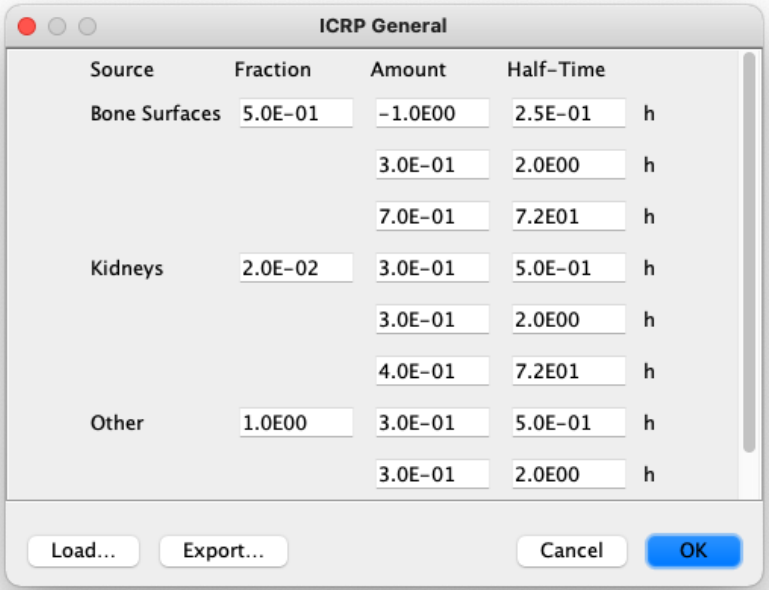
Kinetic Model Evaluation

- 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)

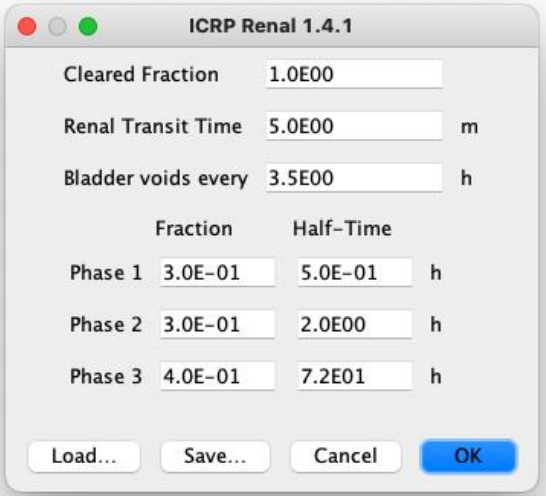
```
"icrp_general":{
   "compartments":[
      ["Bone Surfaces",0.5,[
         [-1.0,0.25,"h"],
         [0.3,2.0,"h"],
         [0.7,72.0,"h"]
      ]],
      ["Kidneys",0.02,[
         [0.3,0.5,"h"],
         [0.3,2.0,"h"],
         [0.4,72.0,"h"]
      ]],
      ["Other",1.0,[
         [0.3,0.5,"h"],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



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

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"]
}
```



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

Compartment Modeller

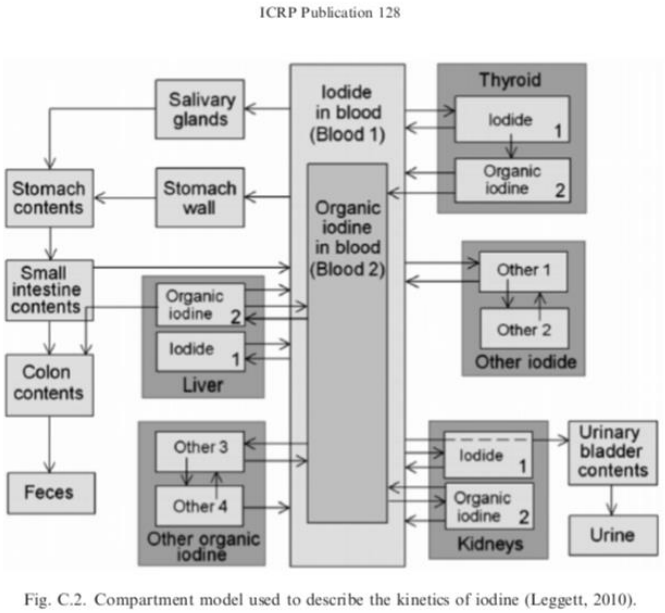
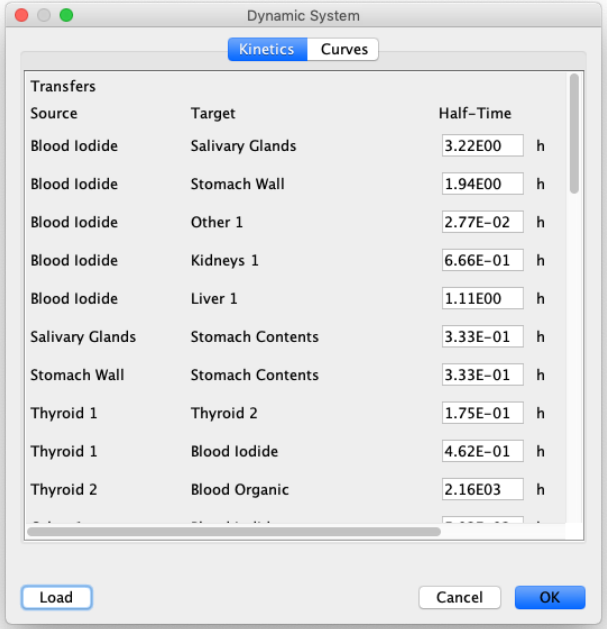
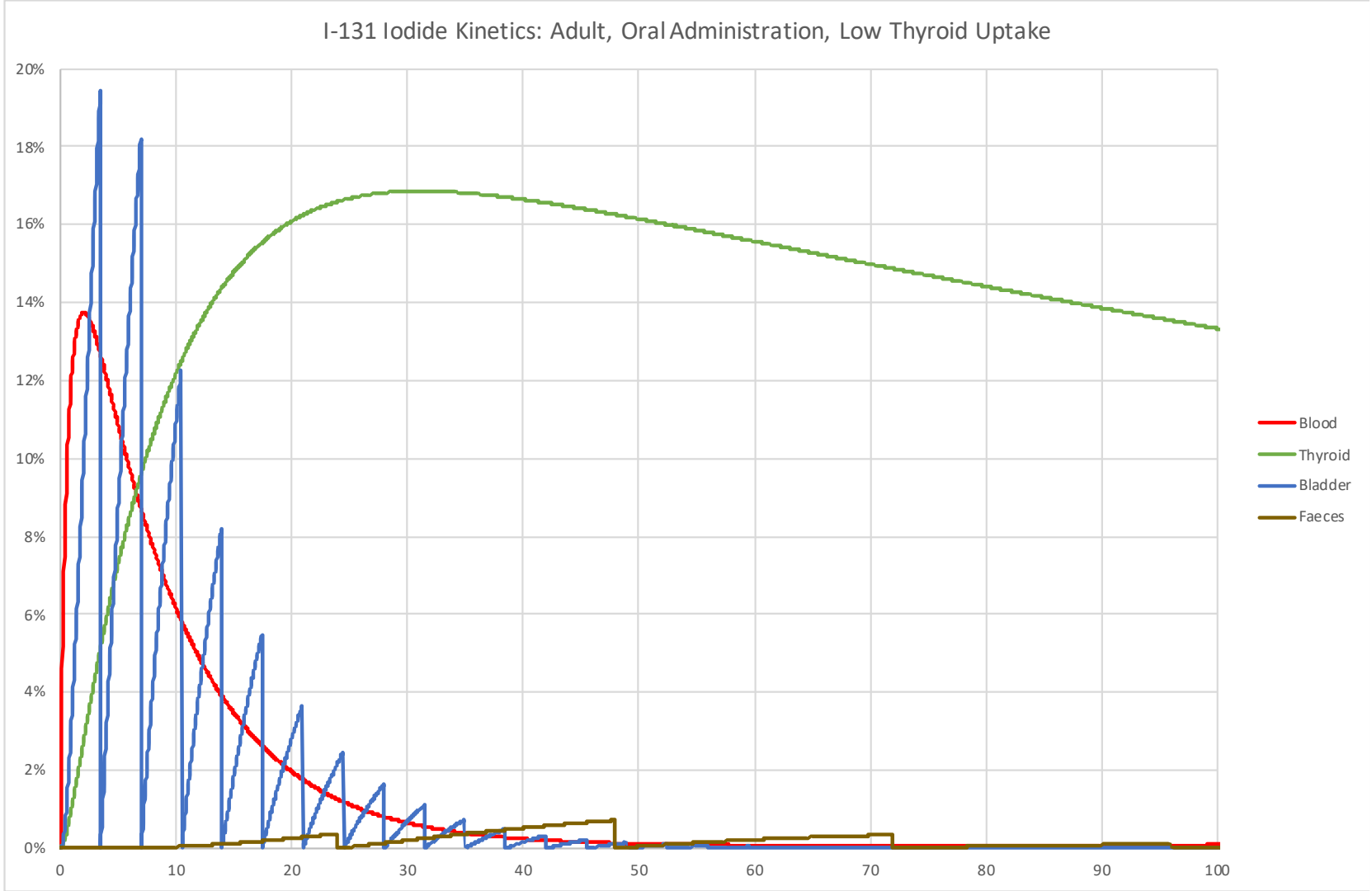


Fig. C.2. Compartment model used to describe the kinetics of iodine (Leggett, 2010).



(ICRP 128)


I-131 Iodide Kinetics: Adult, Oral Administration, Low Thyroid Uptake
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
10
20
30
40
50
60
70
80
90
100
Blood
Thyroid
Bladder
Faeces

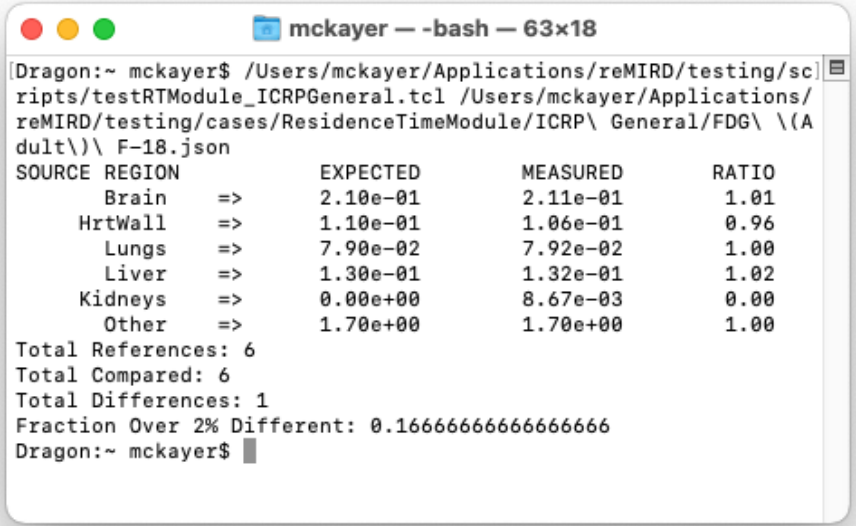
Effective Dose Calculation

- 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",[]]
   ]]
]
```

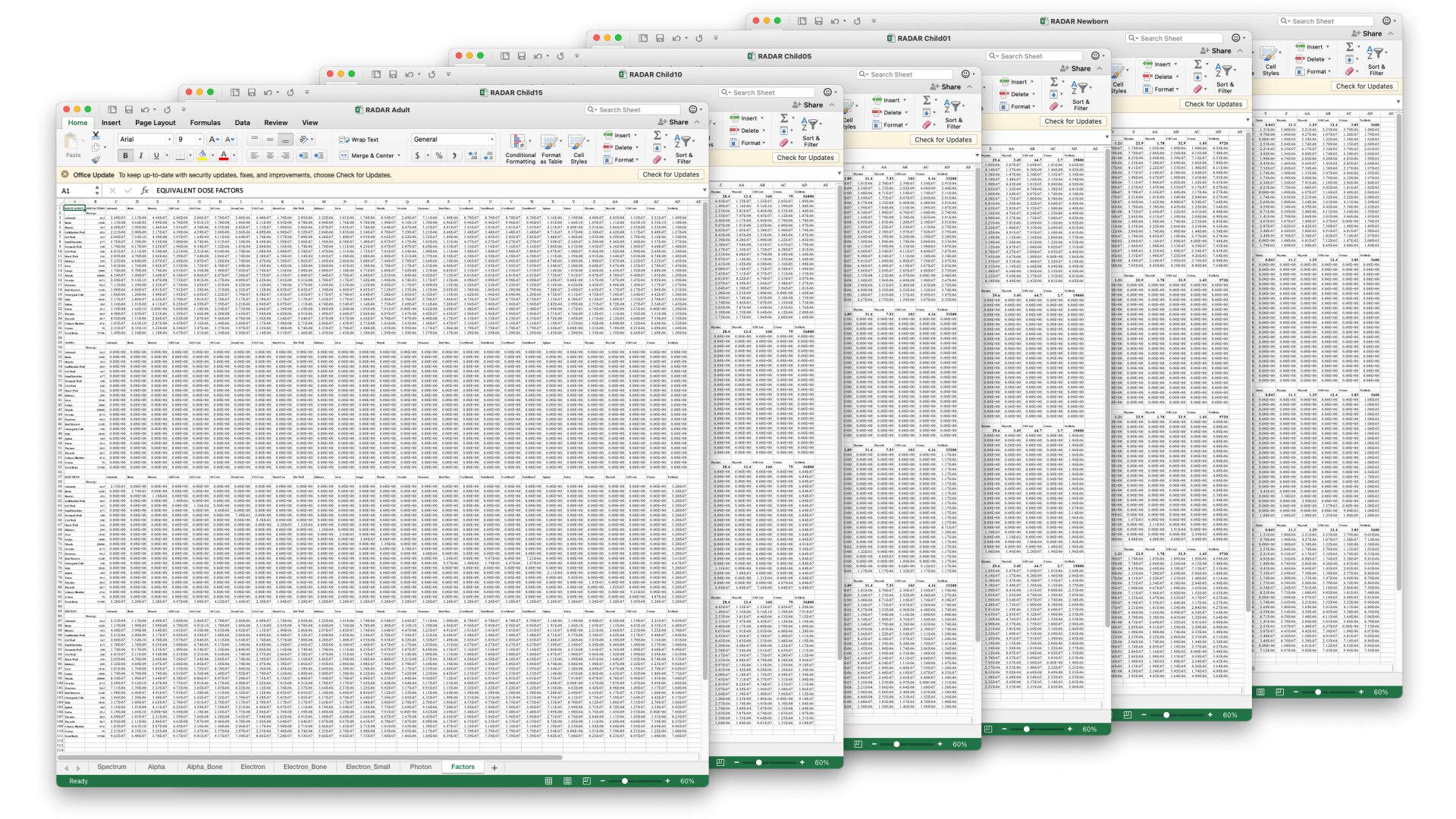
Validation Framework

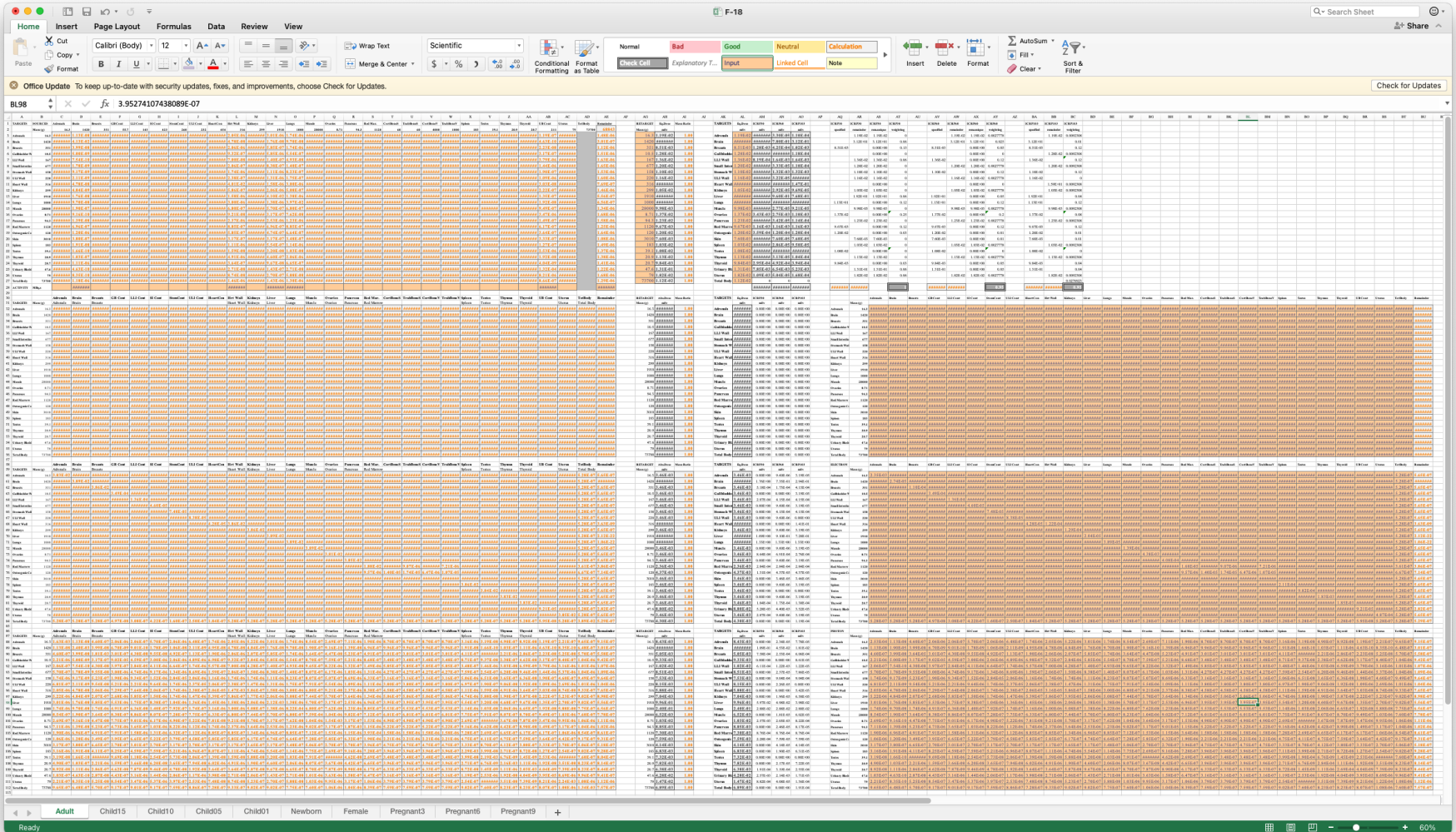
```
{"icrp_general":{
   "compartments":[
   ...
   ]
},
"validation":{
   "spectrum":F-18,
   "half_life":1.8295,
   "time_unit":"h",
   "tolerance":0.02,
   "residence_time":[
      ["Brain",0.21,"h"],
      ["HrtWall",0.11,"h"],
      ["Lungs",0.079,"h"],
      ["Liver",0.13,"h"],
      ["Other",1.7,"h"],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



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…


RADAR Newborn
RADAR Child01
RADAR Child05
RADAR Child10
RADAR Child15
RADAR Adult
Home
Insert
Page Layout
Formulas
Data
Review
View
Office Update To keep up-to-date with security updates, fixes, and improvements, choose Check for Updates.
Check for Updates
EQUIVALENT DOSE FACTORS
Spectrum
Alpha
Alpha_Bone
Electron
Electron_Bone
Electron_Small
Photon
Factors
Ready


F-18
Search Sheet
Share
Home
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Page Layout
Formulas
Data
Review
View
Paste
Cut
Copy
Format
Calibri (Body)
12
Wrap Text
Merge & Center
Scientific
Conditional Formatting
Format as Table
Normal
Bad
Good
Neutral
Calculation
Check Cell
Explanatory T...
Input
Linked Cell
Note
Insert
Delete
Format
AutoSum
Fill
Clear
Sort & Filter
Office Update
To keep up-to-date with security updates, fixes, and improvements, choose Check for Updates.
Check for Updates
BL98
3.952741074380896E-07
Adult
Child15
Child10
Child05
Child01
Newborn
Female
Pregnant3
Pregnant6
Pregnant9
Ready
60%

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