ExtravDose Discussion Bonus Content

Roland Benke, PhD, CHP

Director – Technologies Division
roland.benke@rcdsoftware.com

Disclaimer

This presentation is an independent product of RCD and does not communicate the views or positions of the U.S. Nuclear Regulatory Commission (NRC).

Training Progression for ExtravDose

Training on theory covers multiphysics mathematical models for fluid flow, activity concentrations, and dosimetry

Beginner training emphasizes Basic calculation

Intermediate training includes Advanced calculation features

ExtravDose discussions

You are here.

Bonus Content

Bonus Content

Calculate maximum extravasation doses without fluid volume & gradually introduce fluid volume to obtain more realistic results

Diagnostic radionuclide ^{99m}Tc extravasation doses for a range of parameter values

Maximum theoretical ^{99m}Tc extravasation dose based on tissue area & biological half-life

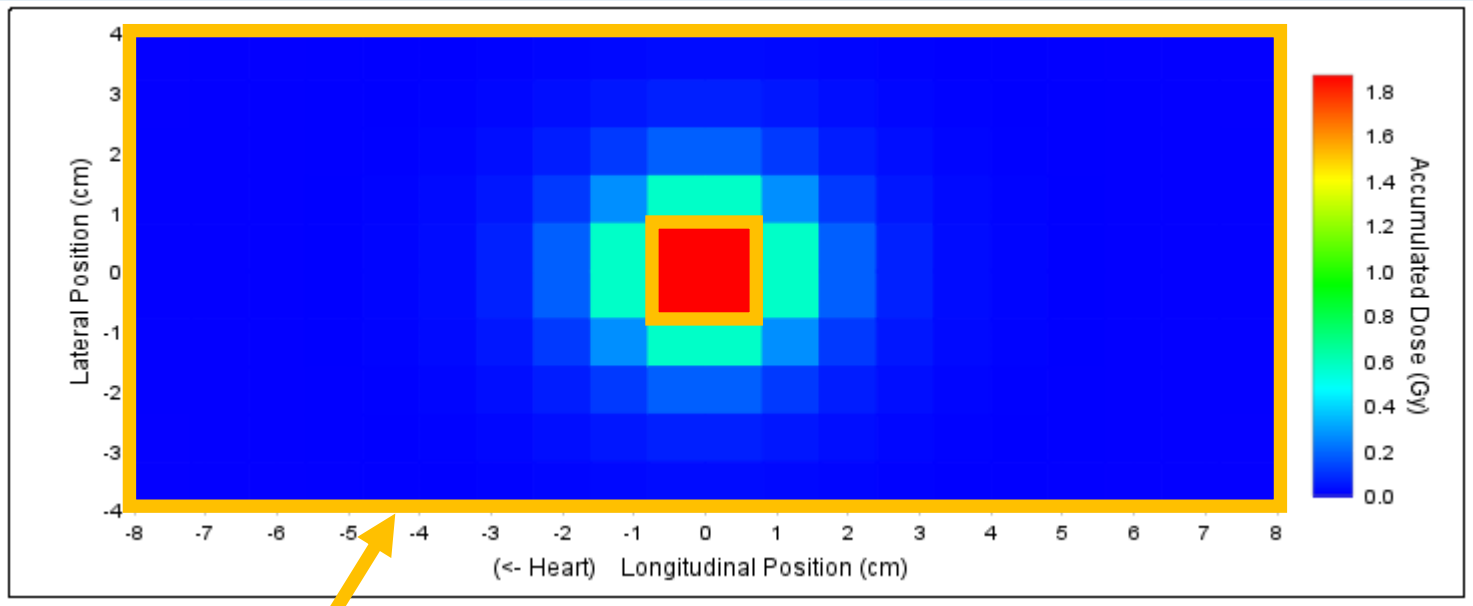
Part I – Calculate maximum doses without fluid volume

- **Smallest flow rate allowed (0.1 mL/min) minimizes fluid volume**
- **Effectively becomes "no fluid" volume calculation because only activity enters the system (with minimal fluid volume effects)**
- **Solely modeling extravasated activity while minimizing extravasated fluid volume overestimates tissue dose**

Good Practice

Start by determining effective half-life for the simulation inputs using a long-lived radionuclide, then repeat simulation with radionuclide in the radiopharmaceutical

Quick refresher on Tissue ROI



Tissue ROI is the full region of interest, representing all voxels

Half-life relationships

$$\frac{1}{T_e} = \frac{1}{T_r} + \frac{1}{T_b}$$

$$T_e = \frac{T_r \cdot T_b}{T_r + T_b} \qquad T_b = \frac{T_r \cdot T_e}{T_r - T_e}$$

T_e	effective half-life [min]
T_r	radiological half-life [min]
T_b	biological clearance half-time [min]

SPECIAL USE CASE for biological clearance from ROI

For a long-lived radionuclide, radioactive decay becomes negligible so that solving for effective half-life yields biological half-life.

$$\frac{1}{T_e} = \frac{1}{T_r}^{0} + \frac{1}{T_b}$$

$$T_e \approx T_b$$

- Set up your extravasation calculation
- Replace extravasation radionuclide with long-lived radionuclide (e.g., ^{14}C)
- Calculate effective half-life from ExtravDose results for *Accumulated ROI Dose* & *Maximum ROI Dose Rate*

$$T_b \approx T_e = \ln 2 \left(\frac{D_{\mathrm{ROI}}}{\dot{D}_{\mathrm{ROI}}} \right)$$

Assumption: Change in Tissue ROI dose rate over time is approximated by single exponential (i.e., effective half-life).

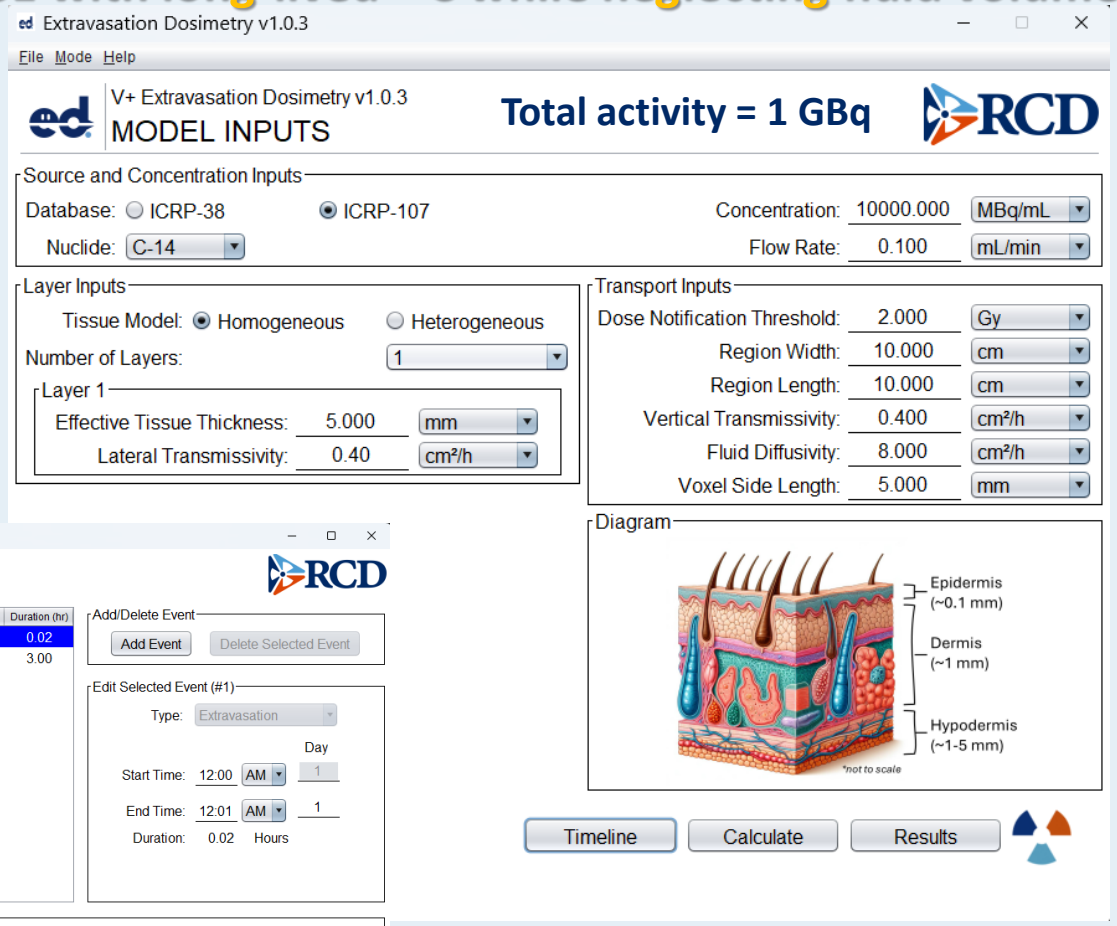
Establish clearance with Diffusivity & minimal Fluid Volume for Maximum Doses

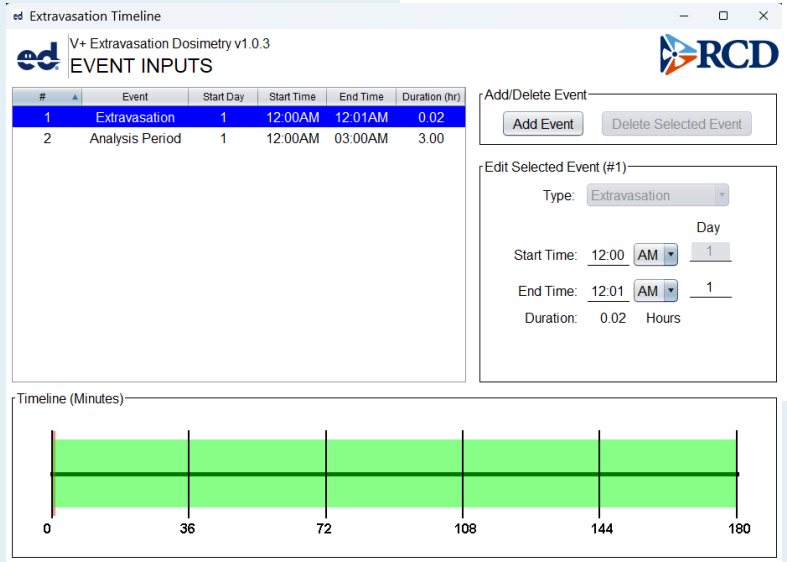
Lower Flow Rate, Extrav. Duration, & Transmissivities to control clearance rate with Diffusivity

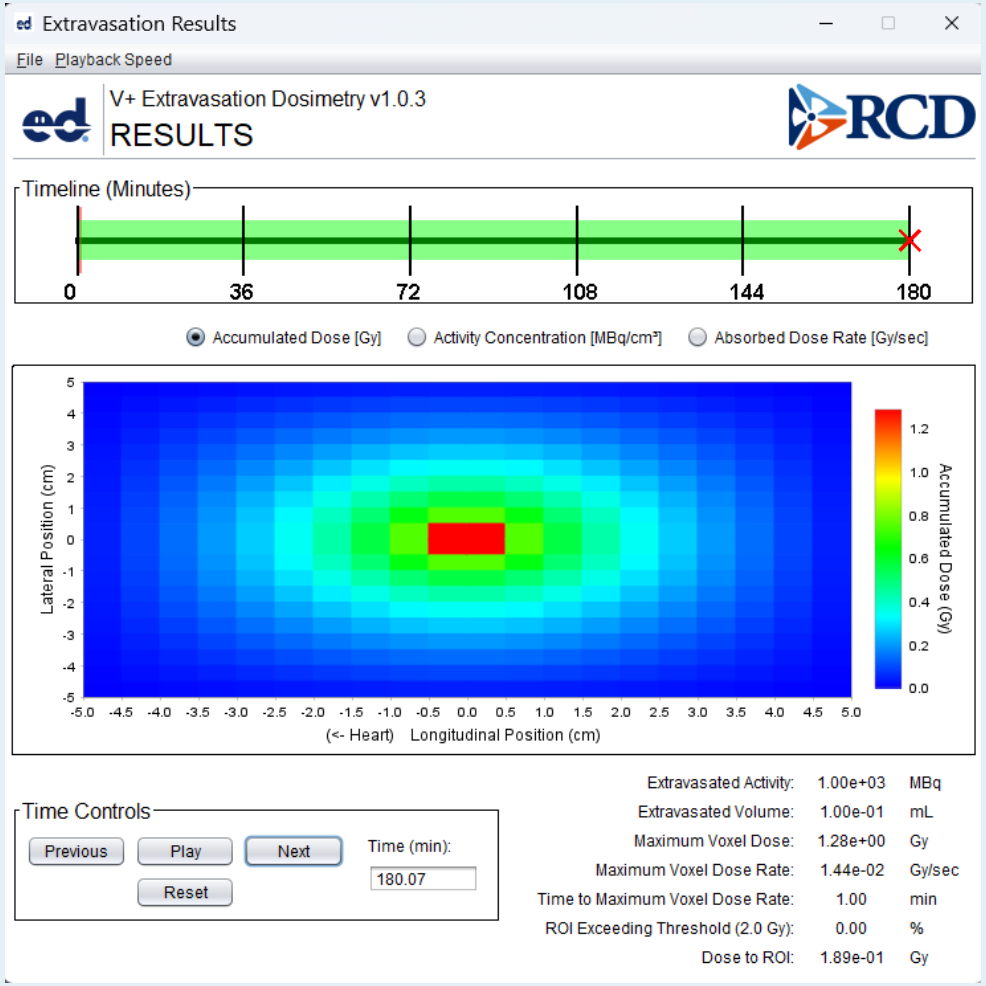
SPECIAL USE CASE with long-lived ^{14}C while neglecting fluid volume

ROI dimensions 10 cm × 10 cm × 0.5 cm

5-mm effective tissue thickness for this example

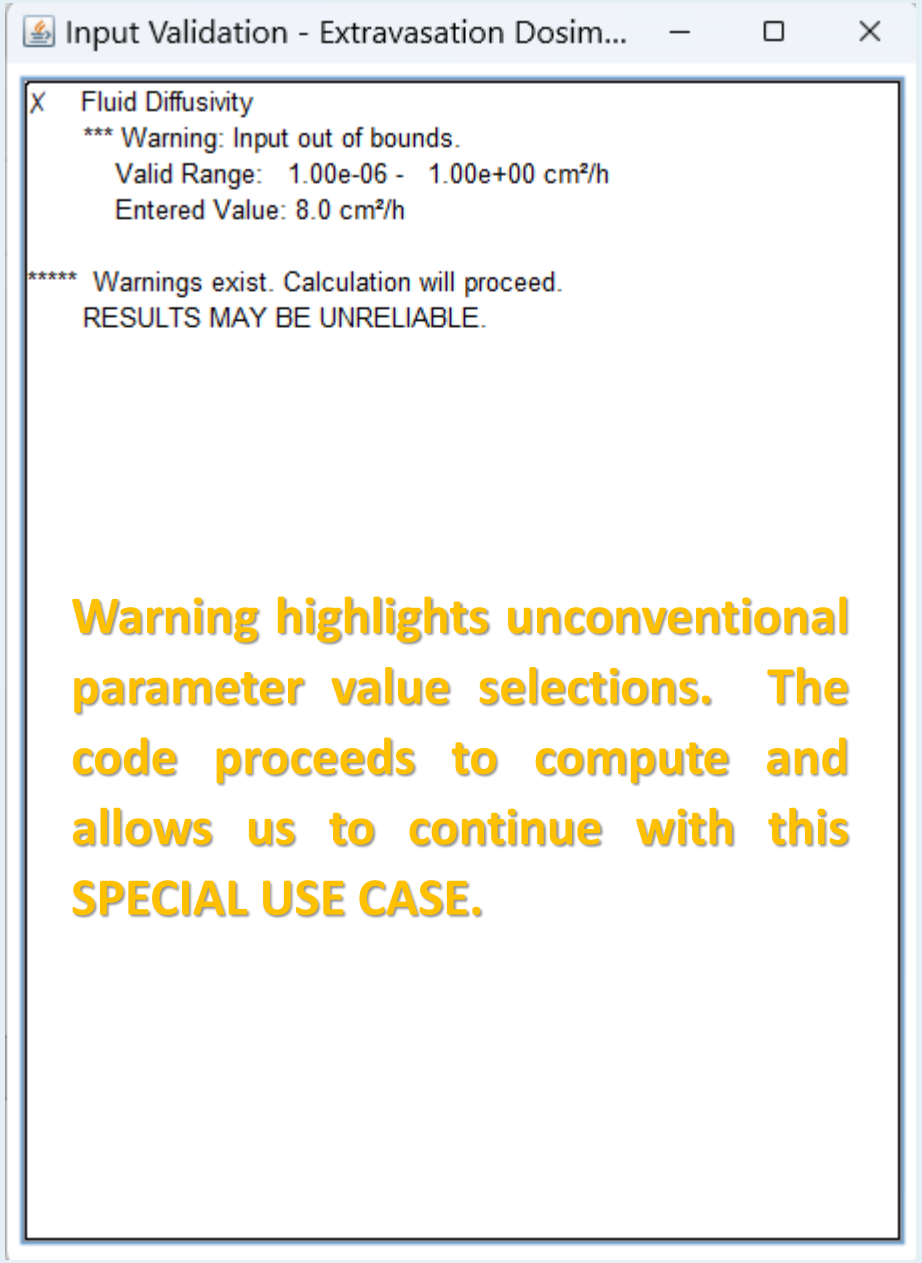






V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

Input Warning Received

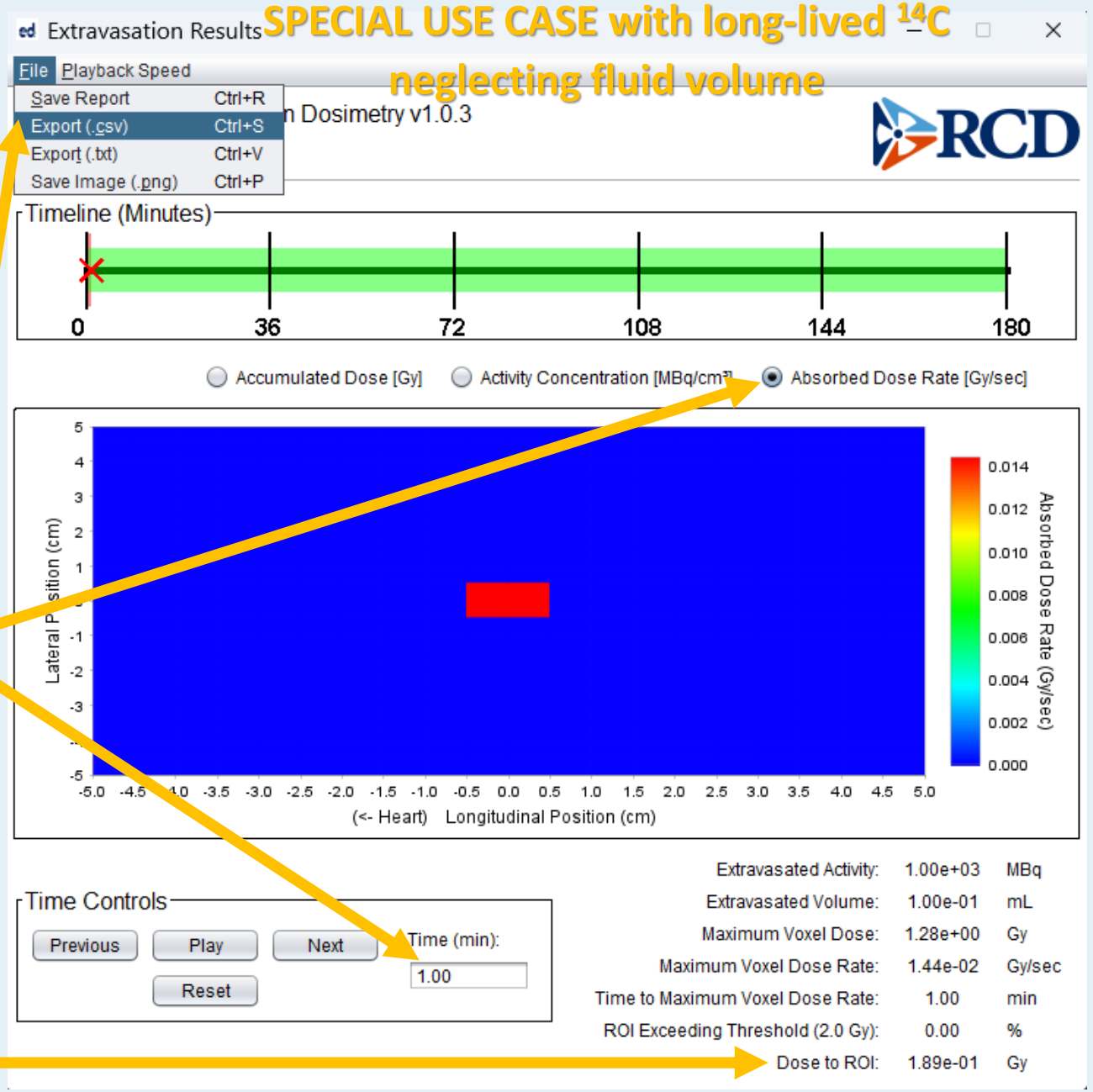


Outputs for Tissue ROI clearance

Obtain two ExtravDose outputs

- **Maximum Dose Rate to ROI [Gy/s] occurs at end of Extravasation Event, not analysis**
  1. Requires user to export .csv file of Absorbed Dose Rates at the correct time (e.g., 1 min)
  2. Compute average Absorbed Dose Rate for all voxels in ROI
- **Accumulated Dose to ROI [Gy]**

SPECIAL USE CASE with long-lived ^{14}C neglecting fluid volume



Export Absorbed Dose Rates at 1 min (End of Extravasation Event)

4.25E-09	4.73E-09	5.24E-09	5.80E-09	6.38E-09	6.96E-09	7.50E-09	7.97E-09	8.32E-09	8.50E-09	8.50E-09	8.32E-09	7.97E-09	7.50E-09	6.96E-09	6.38E-09	5.80E-09	5.24E-09	4.73E-09	4.25E-09
4.73E-09	5.32E-09	5.98E-09	6.71E-09	7.50E-09	8.32E-09	9.11E-09	9.81E-09	1.03E-08	1.06E-08	1.06E-08	1.03E-08	9.81E-09	9.11E-09	8.32E-09	7.50E-09	6.71E-09	5.98E-09	5.32E-09	4.73E-09
5.24E-09	5.98E-09	6.83E-09	7.81E-09	8.90E-09	1.01E-08	1.13E-08	1.23E-08	1.32E-08	1.37E-08	1.37E-08	1.32E-08	1.23E-08	1.13E-08	1.01E-08	8.90E-09	7.81E-09	6.83E-09	5.98E-09	5.24E-09
5.80E-09	6.71E-09	7.81E-09	9.11E-09	1.06E-08	1.23E-08	1.42E-08	1.59E-08	1.74E-08	1.82E-08	1.82E-08	1.74E-08	1.59E-08	1.42E-08	1.23E-08	1.06E-08	9.11E-09	7.81E-09	6.71E-09	5.80E-09
6.38E-09	7.50E-09	8.90E-09	1.06E-08	1.28E-08	1.53E-08	1.82E-08	2.13E-08	2.39E-08	2.55E-08	2.55E-08	2.39E-08	2.13E-08	1.82E-08	1.53E-08	1.28E-08	1.06E-08	8.90E-09	7.50E-09	6.38E-09
6.96E-09	8.32E-09	1.01E-08	1.23E-08	1.53E-08	1.91E-08	2.39E-08	2.94E-08	3.48E-08	3.82E-08	3.82E-08	3.48E-08	2.94E-08	2.39E-08	1.91E-08	1.53E-08	1.23E-08	1.01E-08	8.32E-09	6.96E-09
7.50E-09	9.11E-09	1.13E-08	1.42E-08	1.82E-08	2.39E-08	3.19E-08	4.26E-08	5.47E-08	6.36E-08	6.36E-08	5.47E-08	4.26E-08	3.19E-08	2.39E-08	1.82E-08	1.42E-08	1.13E-08	9.11E-09	7.50E-09
7.97E-09	9.81E-09	1.23E-08	1.59E-08	2.13E-08	2.94E-08	4.26E-08	6.40E-08	9.60E-08	1.27E-07	1.27E-07	9.60E-08	6.40E-08	4.26E-08	2.94E-08	2.13E-08	1.59E-08	1.23E-08	9.81E-09	7.97E-09
8.32E-09	1.03E-08	1.32E-08	1.74E-08	2.39E-08	3.48E-08	5.47E-08	9.60E-08	1.96E-07	3.73E-07	3.73E-07	1.96E-07	9.60E-08	5.47E-08	3.48E-08	2.39E-08	1.74E-08	1.32E-08	1.03E-08	8.32E-09
8.50E-09	1.06E-08	1.37E-08	1.82E-08	2.55E-08	3.82E-08	6.36E-08	1.27E-07	3.73E-07	1.44E-02	1.44E-02	3.73E-07	1.27E-07	6.36E-08	3.82E-08	2.55E-08	1.82E-08	1.37E-08	1.06E-08	8.50E-09
8.50E-09	1.06E-08	1.37E-08	1.82E-08	2.55E-08	3.82E-08	6.36E-08	1.27E-07	3.73E-07	1.44E-02	1.44E-02	3.73E-07	1.27E-07	6.36E-08	3.82E-08	2.55E-08	1.82E-08	1.37E-08	1.06E-08	8.50E-09
8.32E-09	1.03E-08	1.32E-08	1.74E-08	2.39E-08	3.48E-08	5.47E-08	9.60E-08	1.96E-07	3.73E-07	3.73E-07	1.96E-07	9.60E-08	5.47E-08	3.48E-08	2.39E-08	1.74E-08	1.32E-08	1.03E-08	8.32E-09
7.97E-09	9.81E-09	1.23E-08	1.59E-08	2.13E-08	2.94E-08	4.26E-08	6.40E-08	9.60E-08	1.27E-07	1.27E-07	9.60E-08	6.40E-08	4.26E-08	2.94E-08	2.13E-08	1.59E-08	1.23E-08	9.81E-09	7.97E-09
7.50E-09	9.11E-09	1.13E-08	1.42E-08	1.82E-08	2.39E-08	3.19E-08	4.26E-08	5.47E-08	6.36E-08	6.36E-08	5.47E-08	4.26E-08	3.19E-08	2.39E-08	1.82E-08	1.42E-08	1.13E-08	9.11E-09	7.50E-09
6.96E-09	8.32E-09	1.01E-08	1.23E-08	1.53E-08	1.91E-08	2.39E-08	2.94E-08	3.48E-08	3.82E-08	3.82E-08	3.48E-08	2.94E-08	2.39E-08	1.91E-08	1.53E-08	1.23E-08	1.01E-08	8.32E-09	6.96E-09
6.38E-09	7.50E-09	8.90E-09	1.06E-08	1.28E-08	1.53E-08	1.82E-08	2.13E-08	2.39E-08	2.55E-08	2.55E-08	2.39E-08	2.13E-08	1.82E-08	1.53E-08	1.28E-08	1.06E-08	8.90E-09	7.50E-09	6.38E-09
5.80E-09	6.71E-09	7.81E-09	9.11E-09	1.06E-08	1.23E-08	1.42E-08	1.59E-08	1.74E-08	1.82E-08	1.82E-08	1.74E-08	1.59E-08	1.42E-08	1.23E-08	1.06E-08	9.11E-09	7.81E-09	6.71E-09	5.80E-09
5.24E-09	5.98E-09	6.83E-09	7.81E-09	8.90E-09	1.01E-08	1.13E-08	1.23E-08	1.32E-08	1.37E-08	1.37E-08	1.32E-08	1.23E-08	1.13E-08	1.01E-08	8.90E-09	7.81E-09	6.83E-09	5.98E-09	5.24E-09
4.73E-09	5.32E-09	5.98E-09	6.71E-09	7.50E-09	8.32E-09	9.11E-09	9.81E-09	1.03E-08	1.06E-08	1.06E-08	1.03E-08	9.81E-09	9.11E-09	8.32E-09	7.50E-09	6.71E-09	5.98E-09	5.32E-09	4.73E-09
4.25E-09	4.73E-09	5.24E-09	5.80E-09	6.38E-09	6.96E-09	7.50E-09	7.97E-09	8.32E-09	8.50E-09	8.50E-09	8.32E-09	7.97E-09	7.50E-09	6.96E-09	6.38E-09	5.80E-09	5.24E-09	4.73E-09	4.25E-09

Average absorbed dose rate for all voxels $\dot{D}_{\mathrm{ROI}} = 0.000144\ Gy\ s^{-1}$

SPECIAL USE CASE with long-lived ^{14}C neglecting fluid volume

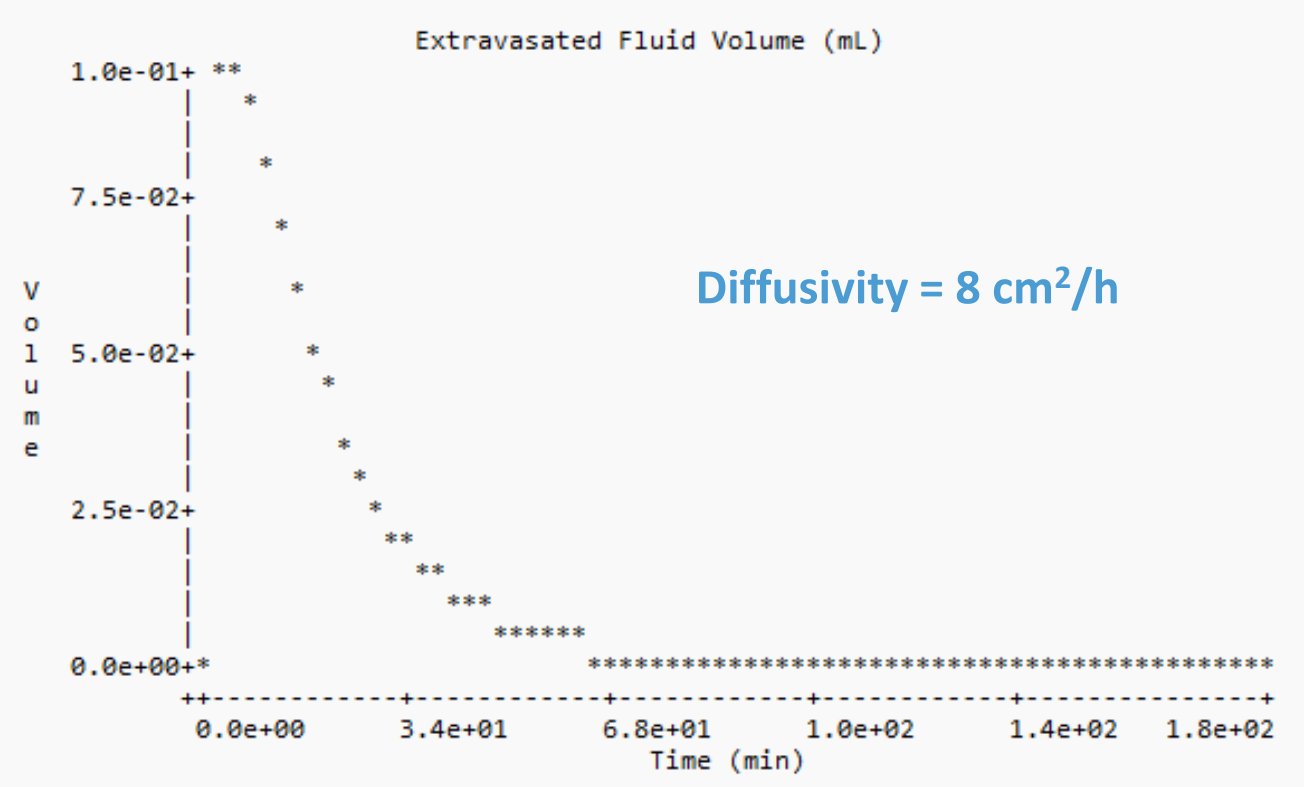
V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

Calculate clearance from ExtravDose results

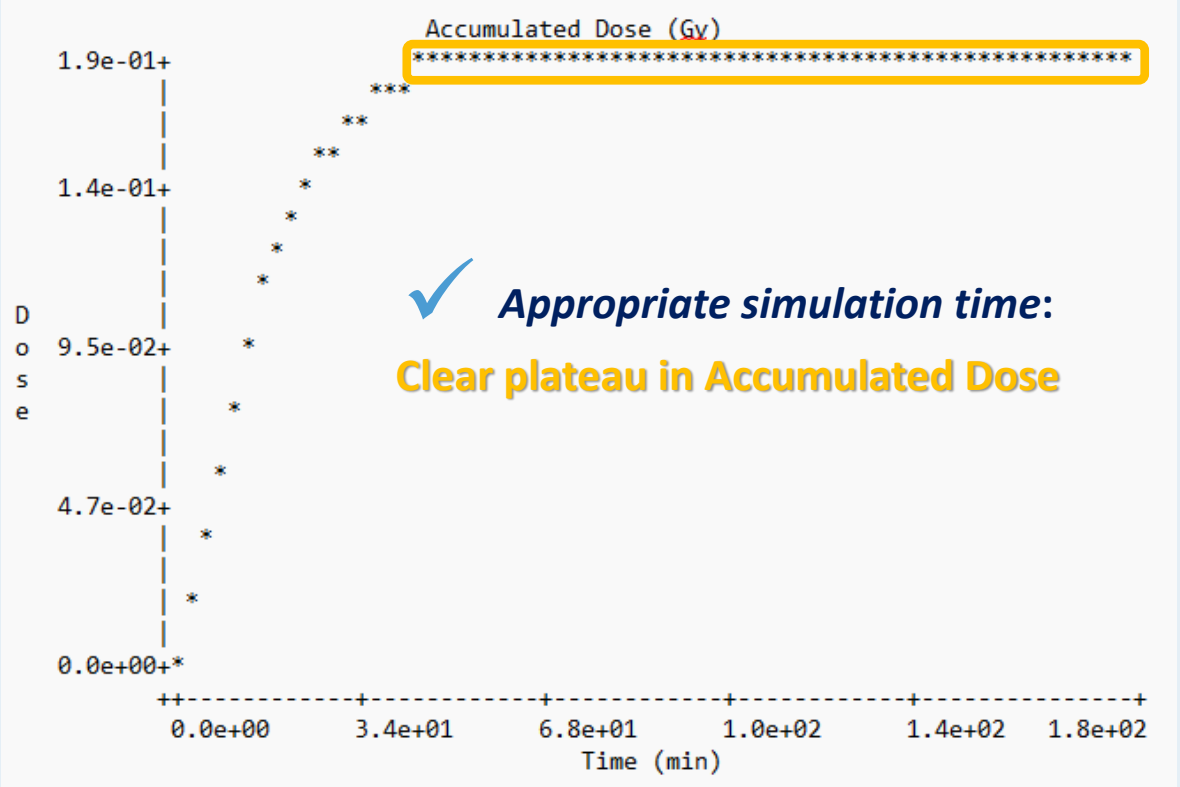
$$T_b \approx T_e = \left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{D_{\mathrm{ROI}}}{\dot{D}_{\mathrm{ROI}}}\right) = \left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{0.189\ Gy}{0.000144\ Gy\ s^{-1}}\right) = 0.25\ h$$

Clinical information should support T_b used in calculations

Modeling clearance with Diffusivity produced expected behavior (below), even for the minimal fluid volume in this special case



Diffusivity = 8 cm²/h

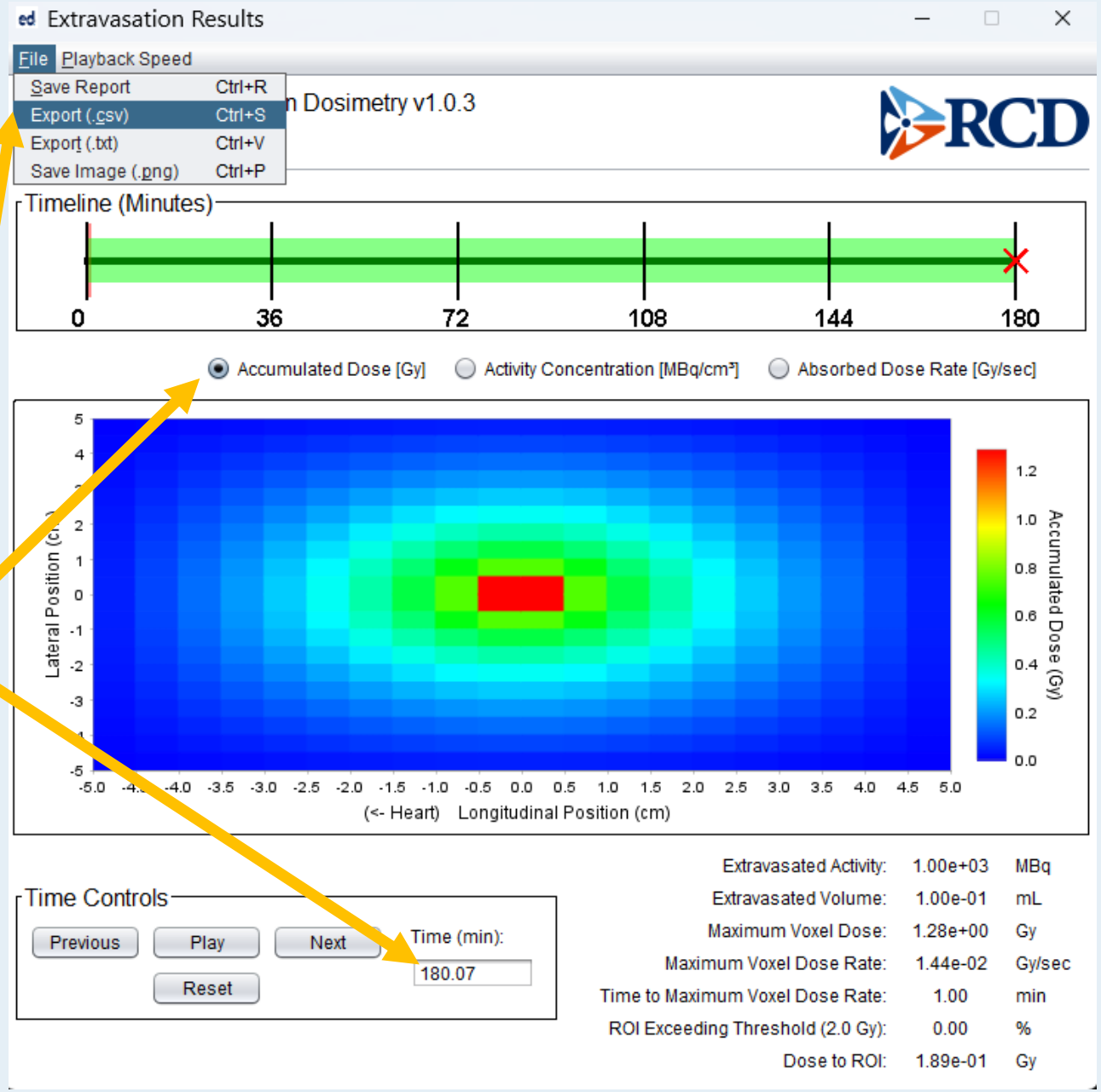


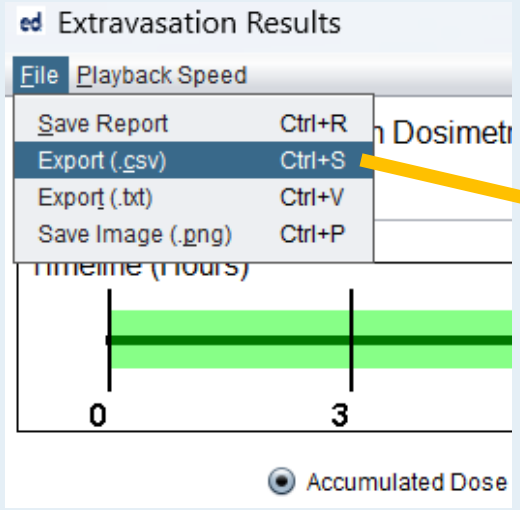
✓ ***Appropriate simulation time*:**

Clear plateau in Accumulated Dose

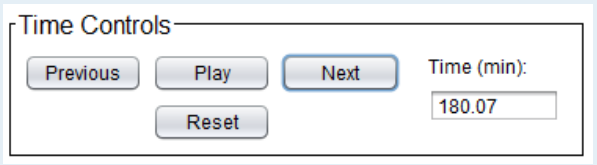
SPECIAL USE CASE with long-lived ^{14}C neglecting fluid volume

Export Accumulated Doses at Analysis End Time for All Voxels





Export Accumulated Doses at Analysis End Time



0.006	0.011	0.017	0.022	0.027	0.032	0.036	0.040	0.043	0.044	0.044	0.043	0.040	0.036	0.032	0.027	0.022	0.017	0.011	0.006
0.011	0.022	0.033	0.045	0.055	0.066	0.075	0.083	0.089	0.092	0.092	0.089	0.083	0.075	0.066	0.055	0.045	0.033	0.022	0.011
0.017	0.033	0.050	0.067	0.084	0.100	0.115	0.128	0.137	0.142	0.142	0.137	0.128	0.115	0.100	0.084	0.067	0.050	0.033	0.017
0.022	0.045	0.067	0.091	0.114	0.137	0.158	0.177	0.191	0.198	0.198	0.191	0.177	0.158	0.137	0.114	0.091	0.067	0.045	0.022
0.027	0.055	0.084	0.114	0.144	0.175	0.204	0.230	0.251	0.263	0.263	0.251	0.230	0.204	0.175	0.144	0.114	0.084	0.055	0.027
0.032	0.066	0.100	0.137	0.175	0.21	0.25	0.29	0.32	0.34	0.34	0.32	0.29	0.25	0.21	0.175	0.137	0.100	0.066	0.032
0.036	0.075	0.115	0.158	0.204	0.25	0.30	0.36	0.40	0.43	0.43	0.40	0.36	0.30	0.25	0.204	0.158	0.115	0.075	0.036
0.040	0.083	0.128	0.177	0.230	0.29	0.36	0.43	0.50	0.56	0.56	0.50	0.43	0.36	0.29	0.230	0.177	0.128	0.083	0.040
0.043	0.089	0.137	0.191	0.251	0.32	0.40	0.50	0.62	0.75	0.75	0.62	0.50	0.40	0.32	0.251	0.191	0.137	0.089	0.043
0.044	0.092	0.142	0.198	0.263	0.34	0.43	0.56	0.75	1.28	1.28	0.75	0.56	0.43	0.34	0.263	0.198	0.142	0.092	0.044
0.044	0.092	0.142	0.198	0.263	0.34	0.43	0.56	0.75	1.28	1.28	0.75	0.56	0.43	0.34	0.263	0.198	0.142	0.092	0.044
0.043	0.089	0.137	0.191	0.251	0.32	0.40	0.50	0.62	0.75	0.75	0.62	0.50	0.40	0.32	0.251	0.191	0.137	0.089	0.043
0.040	0.083	0.128	0.177	0.230	0.29	0.36	0.43	0.50	0.56	0.56	0.50	0.43	0.36	0.29	0.230	0.177	0.128	0.083	0.040
0.036	0.075	0.115	0.158	0.204	0.25	0.30	0.36	0.40	0.43	0.43	0.40	0.36	0.30	0.25	0.204	0.158	0.115	0.075	0.036
0.032	0.066	0.100	0.137	0.175	0.21	0.25	0.29	0.32	0.34	0.34	0.32	0.29	0.25	0.21	0.175	0.137	0.100	0.066	0.032
0.027	0.055	0.084	0.114	0.144	0.175	0.204	0.230	0.251	0.263	0.263	0.251	0.230	0.204	0.175	0.144	0.114	0.084	0.055	0.027
0.022	0.045	0.067	0.091	0.114	0.137	0.158	0.177	0.191	0.198	0.198	0.191	0.177	0.158	0.137	0.114	0.091	0.067	0.045	0.022
		0.050	0.067	0.084	0.100	0.115	0.128	0.137	0.142	0.142	0.137	0.128	0.115	0.100	0.084	0.067	0.050	0.033	0.017
		0.033	0.045	0.055	0.066	0.075	0.083	0.089	0.092	0.092	0.089	0.083	0.075	0.066	0.055	0.045	0.033	0.022	0.011
		0.017	0.022	0.027	0.032	0.036	0.040	0.043	0.044	0.044	0.043	0.040	0.036	0.032	0.027	0.022	0.017	0.011	0.006

ROI Area (cm^2)		Dose to ROI (Gy per GBq extravasated)
1	**Max Voxels**	1.28
9		0.66
25		0.45
100	**Full ROI**	0.189

Voxel data allow dose tabulations for other subregions.

SPECIAL USE CASE with long-lived ^{14}C neglecting fluid volume

V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

Repeat simulation for 750 MBq ^{82}Rb (example extravasation).

Begin with minimal fluid volume, then gradually add realism.

Clinical information should support T_b used in calculations.

Recalculate doses for ^{82}Rb infusion with 50% extravasation

- Enter administered concentration (strontium impurities not included)
- Enter 50% of total infusion flow rate for extravasation

```
********************************************************************************
User Inputs
********************************************************************************

--------------------------------------------------------------------------------
Source and Concentration Information
--------------------------------------------------------------------------------
                              Database:      ICRP107
                               Nuclide:        Rb-82
          Administration Concentration:         30.0      MBq/mL
              Administration Flow Rate:         25.0      mL/min
             Total Extravasated Volume:         25.0          mL
           Total Extravasated Activity:        750.0         MBq

--------------------------------------------------------------------------------
Layer Inputs
--------------------------------------------------------------------------------
                         Tissue Model:   Homogenous
                     Number of Layers:            1

                   Break Down by Layer

          Effective Tissue Thickness 1:          5.0          mm
              Lateral Transmissivity 1:          0.4       cm²/h
```

```
--------------------------------------------------------------------------------
Transport Inputs
--------------------------------------------------------------------------------
   Radiation Dose Notification Threshold:          2.0          Gy
                           Region Width:         10.0          cm
                          Region Length:         10.0          cm
                  Vertical Transmissivity:          0.4       cm²/h
                       Fluid Diffusivity:          8.0       cm²/h
                  Cubic Voxel Side Length:          5.0          mm

--------------------------------------------------------------------------------
Event Inputs
--------------------------------------------------------------------------------
                              Event 1 - Extravasation
                        Event Start Day:            1
                       Event Start Time:        12:00         AM
                          Event End Day:            1
                         Event End Time:        12:01         AM
                         Event Duration:        0.017          h

                              Event 2 - Analysis Period
                        Event Start Day:            1
                       Event Start Time:        12:00         AM
                          Event End Day:            1
                         Event End Time:        03:00         AM
                         Event Duration:        3.000          h
```

Recalculate with ^{82}Rb Radionuclide & Extravasated Activity = 750 MBq

SPECIAL USE CASE neglecting fluid volume

ROI dimensions 10 cm × 10 cm × 0.5 cm

Extravasation Dosimetry v1.0.3

File Mode Help

V+ Extravasation Dosimetry v1.0.3

MODEL INPUTS

Total activity = 750 MBq

Source and Concentration Inputs

Database: ICRP-38 ICRP-107

Nuclide: Rb-82

Concentration: 7500.000 MBq/mL

Flow Rate: 0.100 mL/min

Layer Inputs

Tissue Model: Homogeneous Heterogeneous

Number of Layers: 1

Layer 1

Effective Tissue Thickness: 5.000 mm

Lateral Transmissivity: 0.40 cm²/h

Transport Inputs

Dose Notification Threshold: 2.000 Gy

Region Width: 10.000 cm

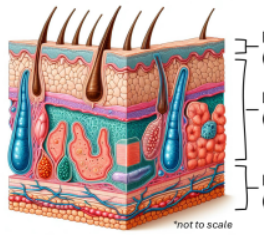
Region Length: 10.000 cm

Vertical Transmissivity: 0.400 cm²/h

Fluid Diffusivity: 8.000 cm²/h

Voxel Side Length: 5.000 mm

Diagram



Timeline | Calculate | Results

Extravasation Timeline

V+ Extravasation Dosimetry v1.0.3

EVENT INPUTS

#	Event	Start Day	Start Time	End Time	Duration (hr)
1	Extravasation	1	12:00AM	12:01AM	0.02
2	Analysis Period	1	12:00AM	03:00AM	3.00

Add/Delete Event

Add Event | Delete Selected Event

Edit Selected Event (#1)

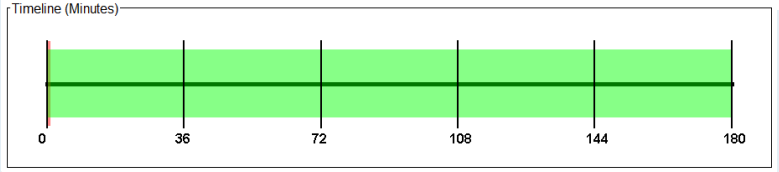
Type: Extravasation

Start Time: 12:00 AM Day 1

End Time: 12:01 AM 1

Duration: 0.02 Hours

Timeline (Minutes)



Extravasation Results

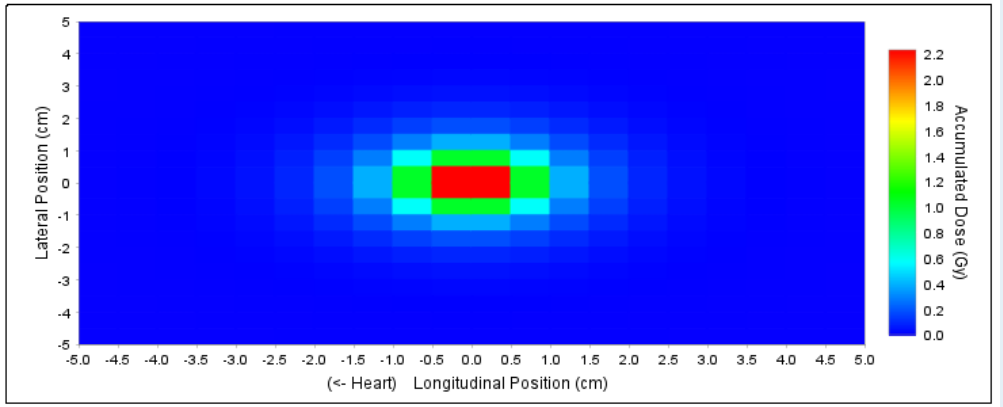
File Playback Speed

V+ Extravasation Dosimetry v1.0.3

RESULTS

Timeline (Minutes)

Accumulated Dose [Gy] Activity Concentration [MBq/cm³] Absorbed Dose Rate [Gy/sec]



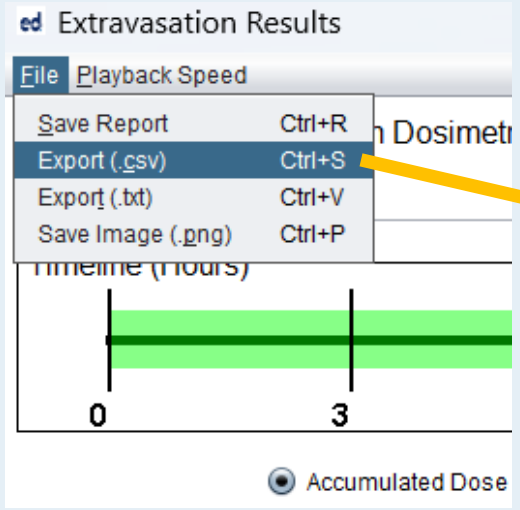
Time Controls

Previous | Play | Next | Reset

Time (min): 180.07

Extravasated Activity:	7.50e+02	MBq
Extravasated Volume:	1.00e-01	mL
Maximum Voxel Dose:	2.23e+00	Gy
Maximum Voxel Dose Rate:	5.10e-02	Gy/sec
Time to Maximum Voxel Dose Rate:	1.00	min
ROI Exceeding Threshold (2.0 Gy):	1.00	%
Dose to ROI:	8.52e-02	Gy

V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/



750-MBq ^{82}Rb extravasation with minimal fluid

SPECIAL USE CASE neglecting fluid volume

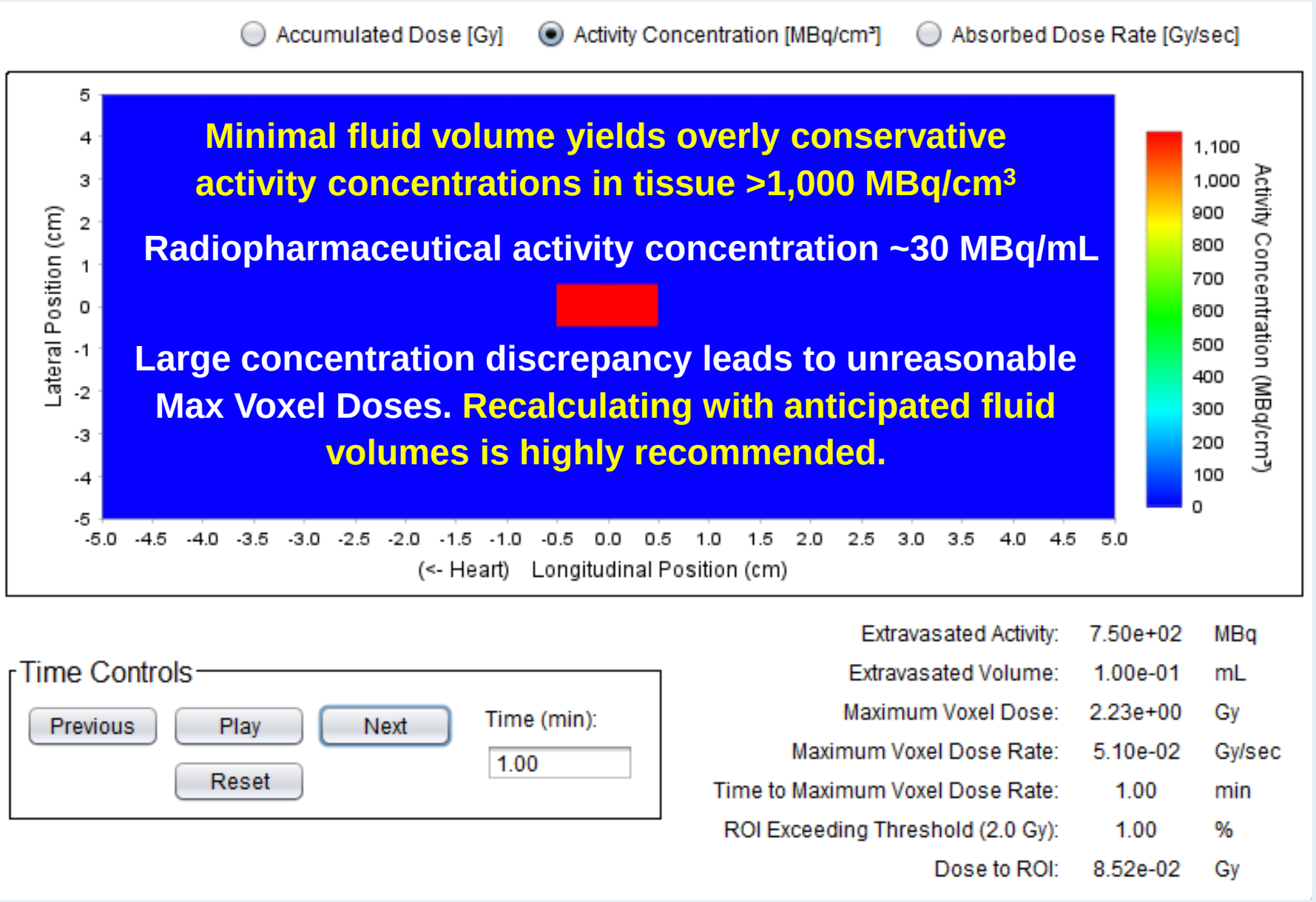
0.0004	0.0005	0.0007	0.0009	0.0012	0.0015	0.0018	0.0022	0.0024	0.0026	0.0026	0.0024	0.0022	0.0018	0.0015	0.0012	0.0009	0.0007	0.0005	0.0004
0.0005	0.0008	0.0011	0.0016	0.0022	0.0030	0.0038	0.0047	0.0055	0.0060	0.0060	0.0055	0.0047	0.0038	0.0030	0.0022	0.0016	0.0011	0.0008	0.0005
0.0007	0.0011	0.0017	0.0026	0.0038	0.0053	0.0071	0.0091	0.0109	0.0119	0.0119	0.0109	0.0091	0.0071	0.0053	0.0038	0.0026	0.0017	0.0011	0.0007
0.0009	0.0016	0.0026	0.0040	0.0061	0.0090	0.0126	0.0168	0.0207	0.0232	0.0232	0.0207	0.0168	0.0126	0.0090	0.0061	0.0040	0.0026	0.0016	0.0009
0.0012	0.0022	0.0038	0.0061	0.0097	0.0149	0.0221	0.0307	0.0394	0.0451	0.0451	0.0394	0.0307	0.0221	0.0149	0.0097	0.0061	0.0038	0.0022	0.0012
0.0015	0.0030	0.0053	0.0090	0.0149	0.024	0.038	0.056	0.075	0.089	0.089	0.075	0.056	0.038	0.024	0.0149	0.0090	0.0053	0.0030	0.0015
0.0018	0.0038	0.0071	0.0126	0.0221	0.038	0.063	0.100	0.145	0.181	0.181	0.145	0.100	0.063	0.038	0.0221	0.0126	0.0071	0.0038	0.0018
0.0022	0.0047	0.0091	0.0168	0.0307	0.056	0.100	0.17	0.28	0.39	0.39	0.28	0.17	0.100	0.056	0.0307	0.0168	0.0091	0.0047	0.0022
0.0024	0.0055	0.0109	0.0207	0.0394	0.075	0.145	0.28	0.58	1.03	1.03	0.58	0.28	0.145	0.075	0.0394	0.0207	0.0109	0.0055	0.0024
0.0026	0.0060	0.0119	0.0232	0.0451	0.089	0.181	0.39	1.03	2.23	2.23	1.03	0.39	0.181	0.089	0.0451	0.0232	0.0119	0.0060	0.0026
0.0026	0.0060	0.0119	0.0232	0.0451	0.089	0.181	0.39	1.03	2.23	2.23	1.03	0.39	0.181	0.089	0.0451	0.0232	0.0119	0.0060	0.0026
0.0024	0.0055	0.0109	0.0207	0.0394	0.075	0.145	0.28	0.58	1.03	1.03	0.58	0.28	0.145	0.075	0.0394	0.0207	0.0109	0.0055	0.0024
0.0022	0.0047	0.0091	0.0168	0.0307	0.056	0.100	0.17	0.28	0.39	0.39	0.28	0.17	0.100	0.056	0.0307	0.0168	0.0091	0.0047	0.0022
0.0018	0.0038	0.0071	0.0126	0.0221	0.038	0.063	0.100	0.145	0.181	0.181	0.145	0.100	0.063	0.038	0.0221	0.0126	0.0071	0.0038	0.0018
0.0015	0.0030	0.0053	0.0090	0.0149	0.024	0.038	0.056	0.075	0.089	0.089	0.075	0.056	0.038	0.024	0.0149	0.0090	0.0053	0.0030	0.0015
0.0012	0.0022	0.0038	0.0061	0.0097	0.0149	0.0221	0.0307	0.0394	0.0451	0.0451	0.0394	0.0307	0.0221	0.0149	0.0097	0.0061	0.0038	0.0022	0.0012
0.0009	0.0016	0.0026	0.0040	0.0061	0.0090	0.0126	0.0168	0.0207	0.0232	0.0232	0.0207	0.0168	0.0126	0.0090	0.0061	0.0040	0.0026	0.0016	0.0009
0.0007	0.0011	0.0017	0.0026	0.0038	0.0053	0.0071	0.0091	0.0109	0.0119	0.0119	0.0109	0.0091	0.0071	0.0053	0.0038	0.0026	0.0017	0.0011	0.0007
0.0005	0.0008	0.0011	0.0016	0.0022	0.0030	0.0038	0.0047	0.0055	0.0060	0.0060	0.0055	0.0047	0.0038	0.0030	0.0022	0.0016	0.0011	0.0008	0.0005
0.0004	0.0005	0.0007	0.0009	0.0012	0.0015	0.0018	0.0022	0.0024	0.0026	0.0026	0.0024	0.0022	0.0018	0.0015	0.0012	0.0009	0.0007	0.0005	0.0004

ROI Area (cm^2)		Dose to ROI (Gy per 750-MBq extravasation)
1	**Max Voxels**	2.23
9		0.71
25		0.31
100	**Full ROI**	0.085

- **Overestimations due to minimal fluid being modeled**
- **Results considered Maximum Doses for Activity & ROI inputs**

V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

SPECIAL USE CASE neglecting fluid volume



750-MBq ^{82}Rb extravasation with minimal fluid volume

Part II – Gradually introduce fluid volume to obtain more realistic results

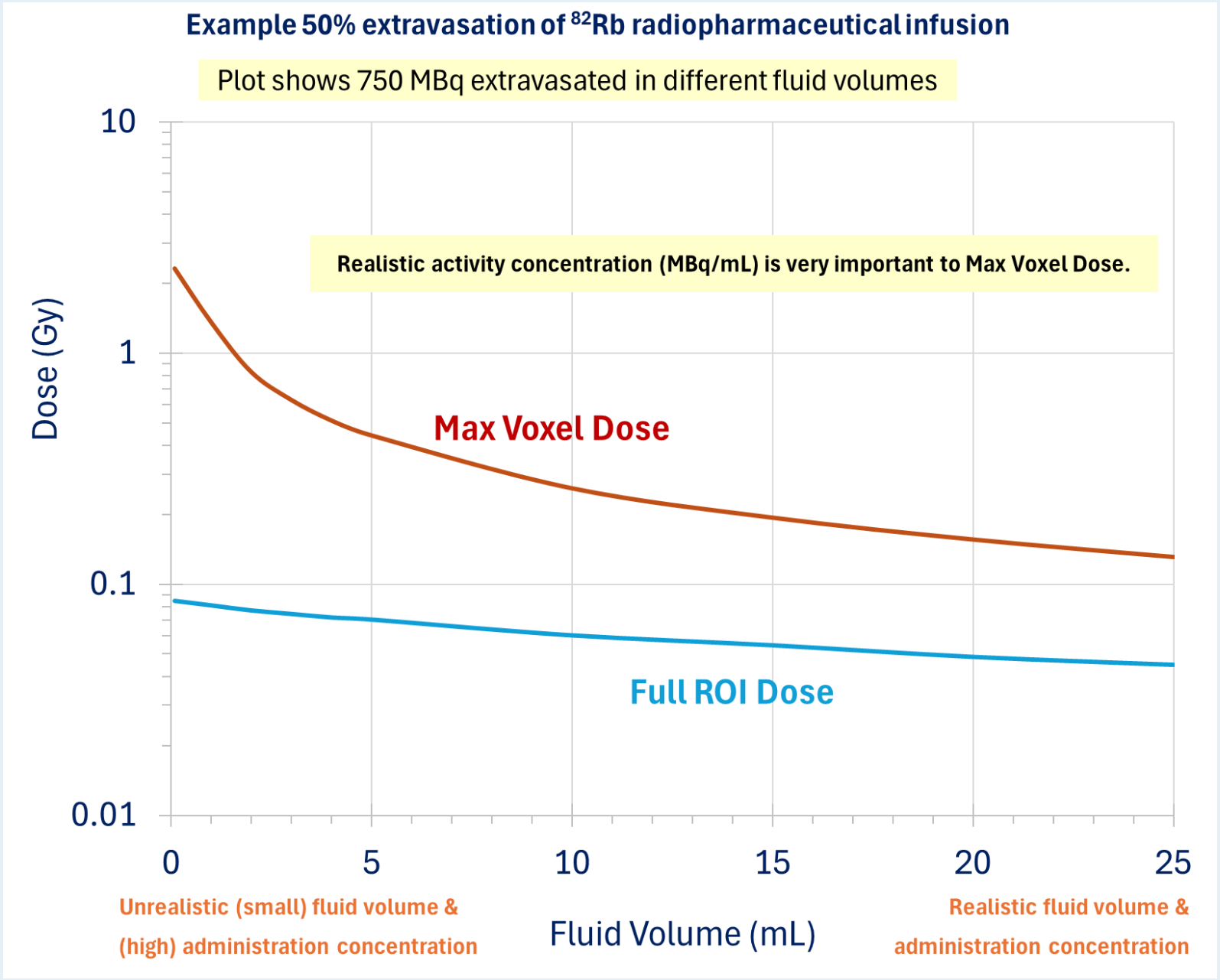
Compare results for same 750-MBq ^{82}Rb extravasation for different fluid volumes

Fluid volumes are controlled by changing concentration & flow rate inputs

Concentration:	7500.000	MBq/mL
Flow Rate:	0.100	mL/min

Concentration:	75.000	MBq/mL
Flow Rate:	10.000	mL/min

Concentration:	30.000	MBq/mL
Flow Rate:	25.000	mL/min



Max Voxel Dose & Full ROI Dose exhibit different sensitivity to Fluid Volume

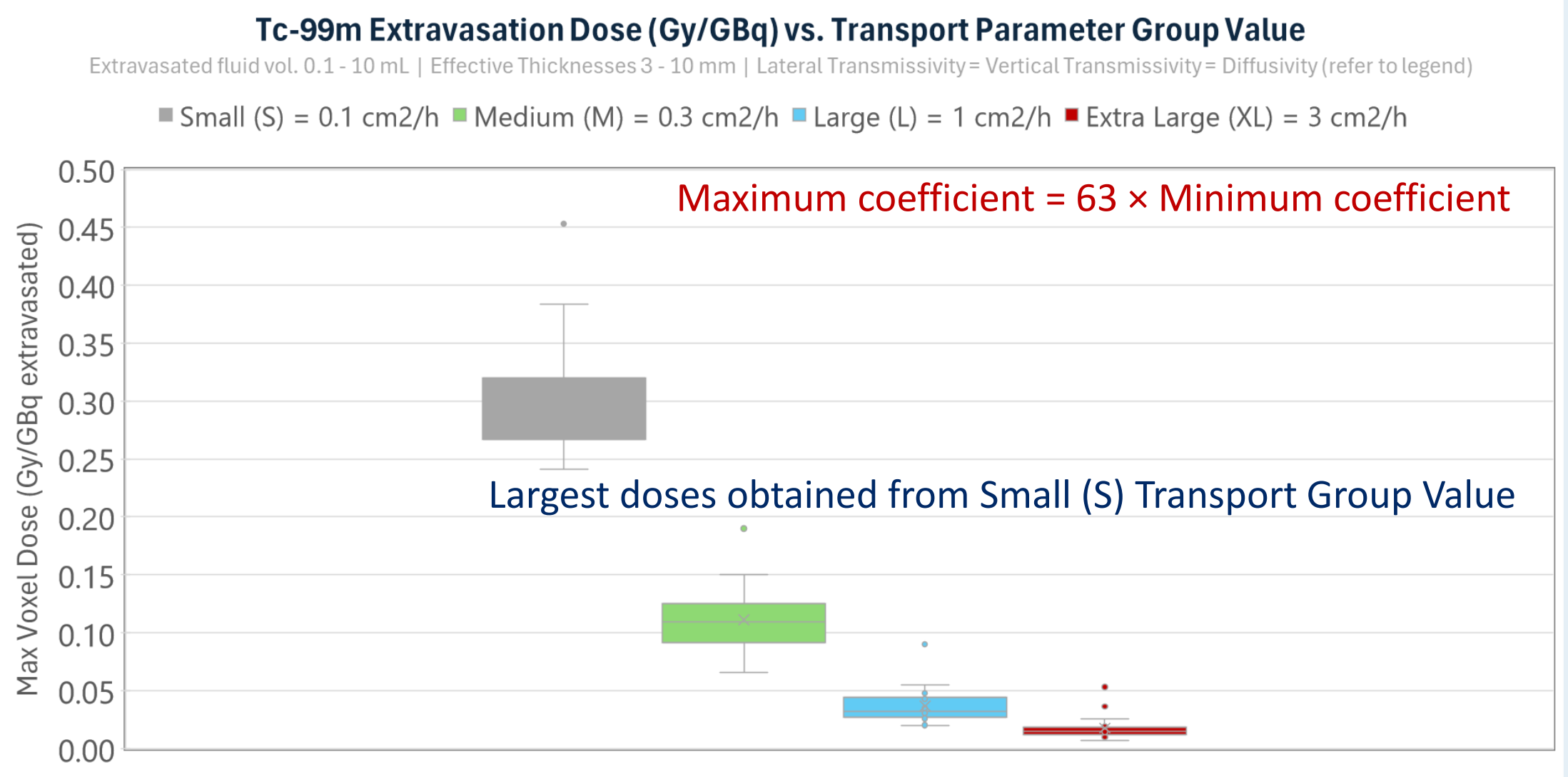
V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

Assess ^{99m}Tc extravasation doses for a range of parameter values

- **Assessment includes parameter consolidation**
  - $Effective\ Thickness = Voxel\ Side\ Length$ **(single layer only)**
  - $Lateral\ Transmissivity = Vertical\ Transmissivity = Diffusivity$
- **Evaluate local tissue doses for a range of parameter values**
  - $Fluid\ volumes \mid Infiltration\ thicknesses \mid Fluid\ transport$
- **Consider Max Voxels & 100-cm^2 ROI tissue area separately**

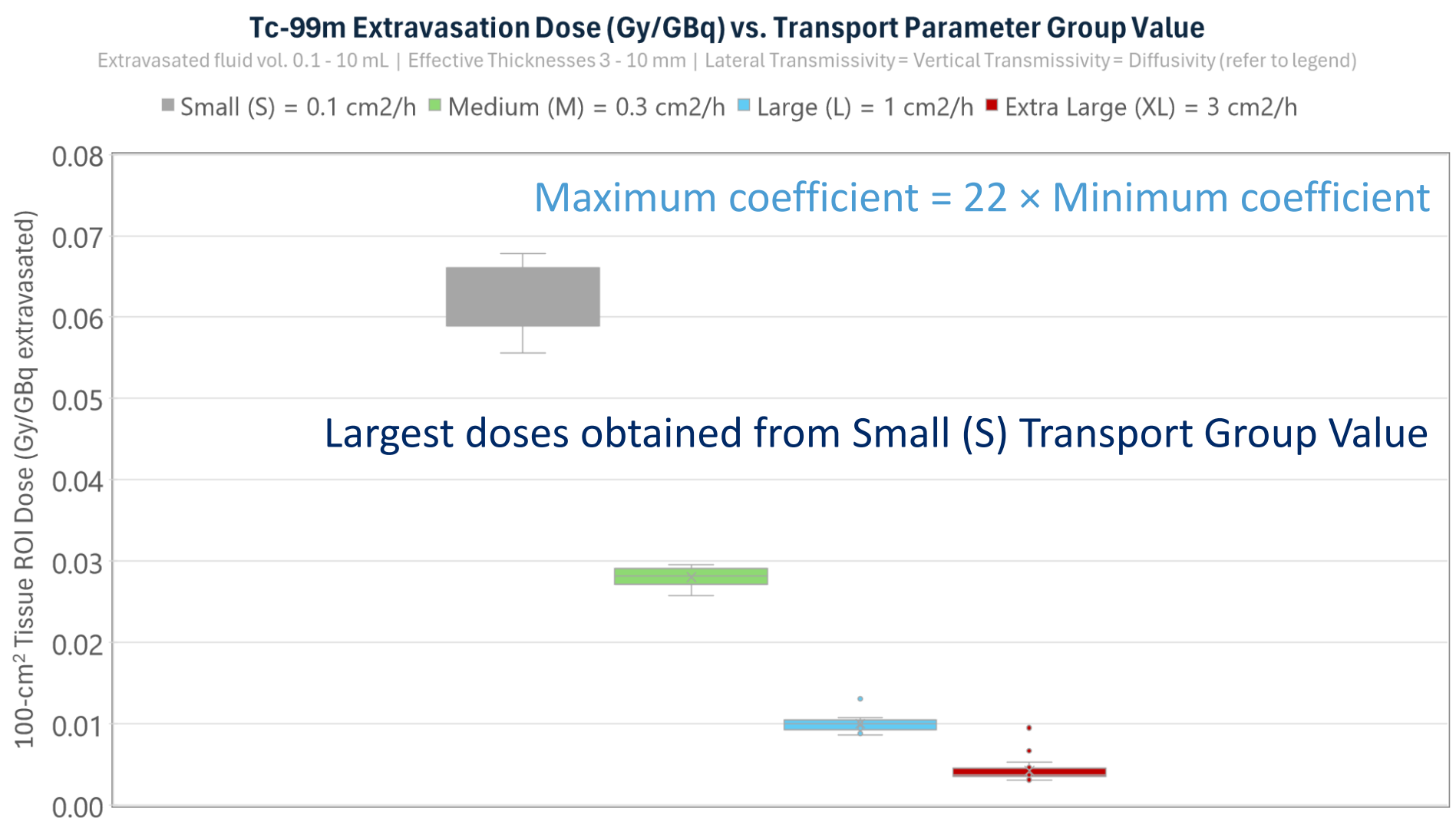
^{99m}Tc Extravasation Doses for Max Voxels

– Max voxel size depends on effective thickness {3, 5, 7, 10 mm}



^{99m}Tc Extravasation Dose Coefficient for Tissue ROI

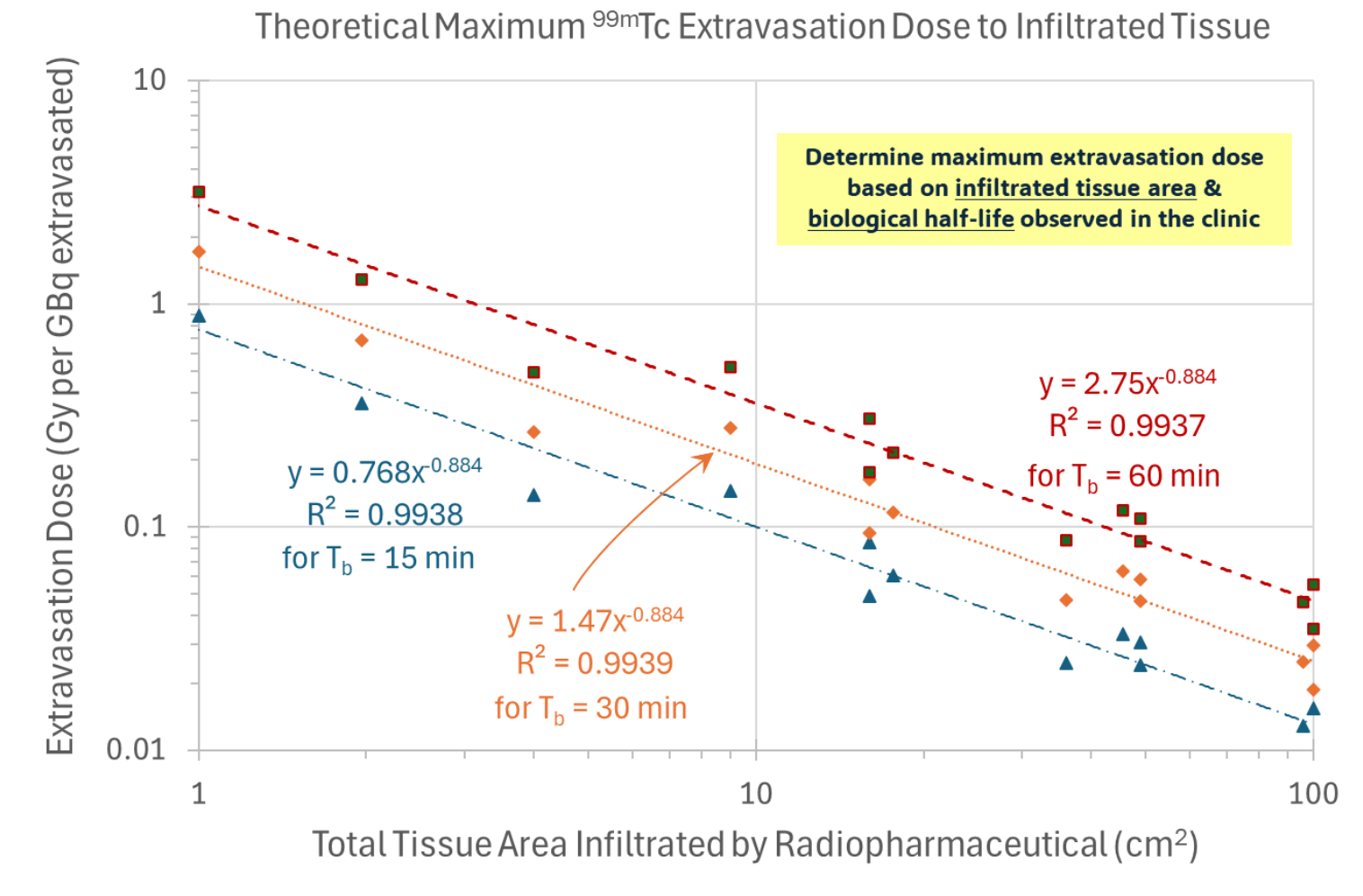
– Closest ROI area match {96, 100, 104 cm^2} for effective thickness



V+ software is available from U.S. NRC https://ramp.nrc-gateway.gov/

Maximum theoretical extravasation dose for ^{99m}Tc based on clinical observations of infiltration area & biological half-life

Theoretical maximum extravasation dose based on infiltrated tissue area & biological half-life



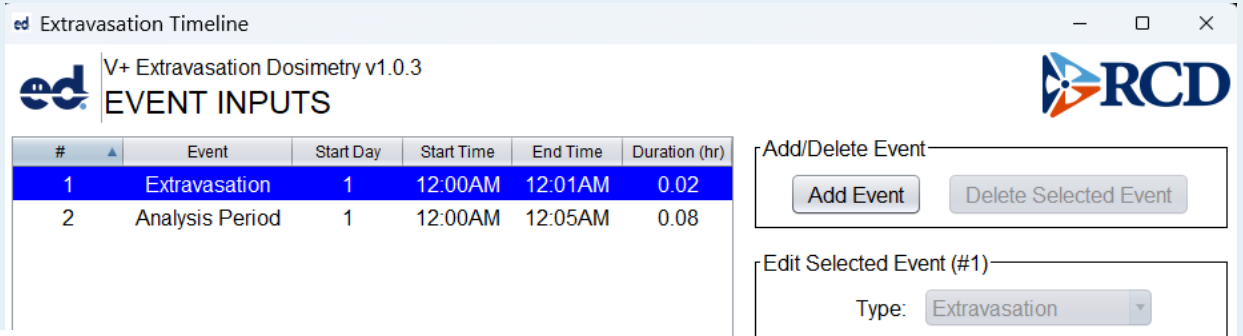
Normalized to 1 GBq extravasated

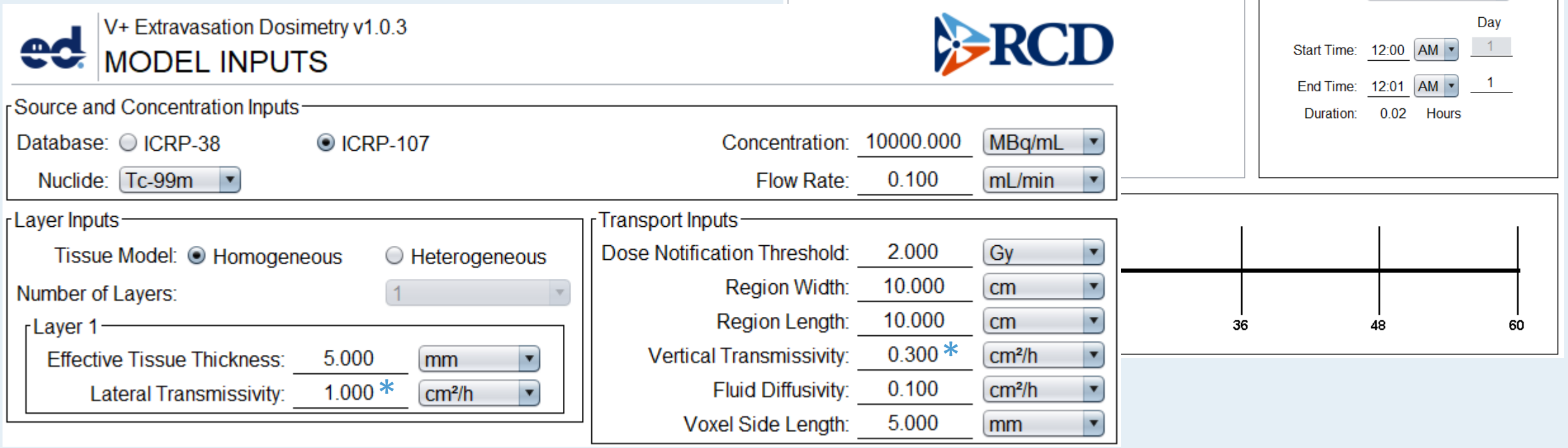
ExtravDose calculates maximum dose rate for activity infiltration into various tissue thicknesses {3, 5, 7, 10 mm}

Time dependency manually applied to obtain accumulated dose (next slide)

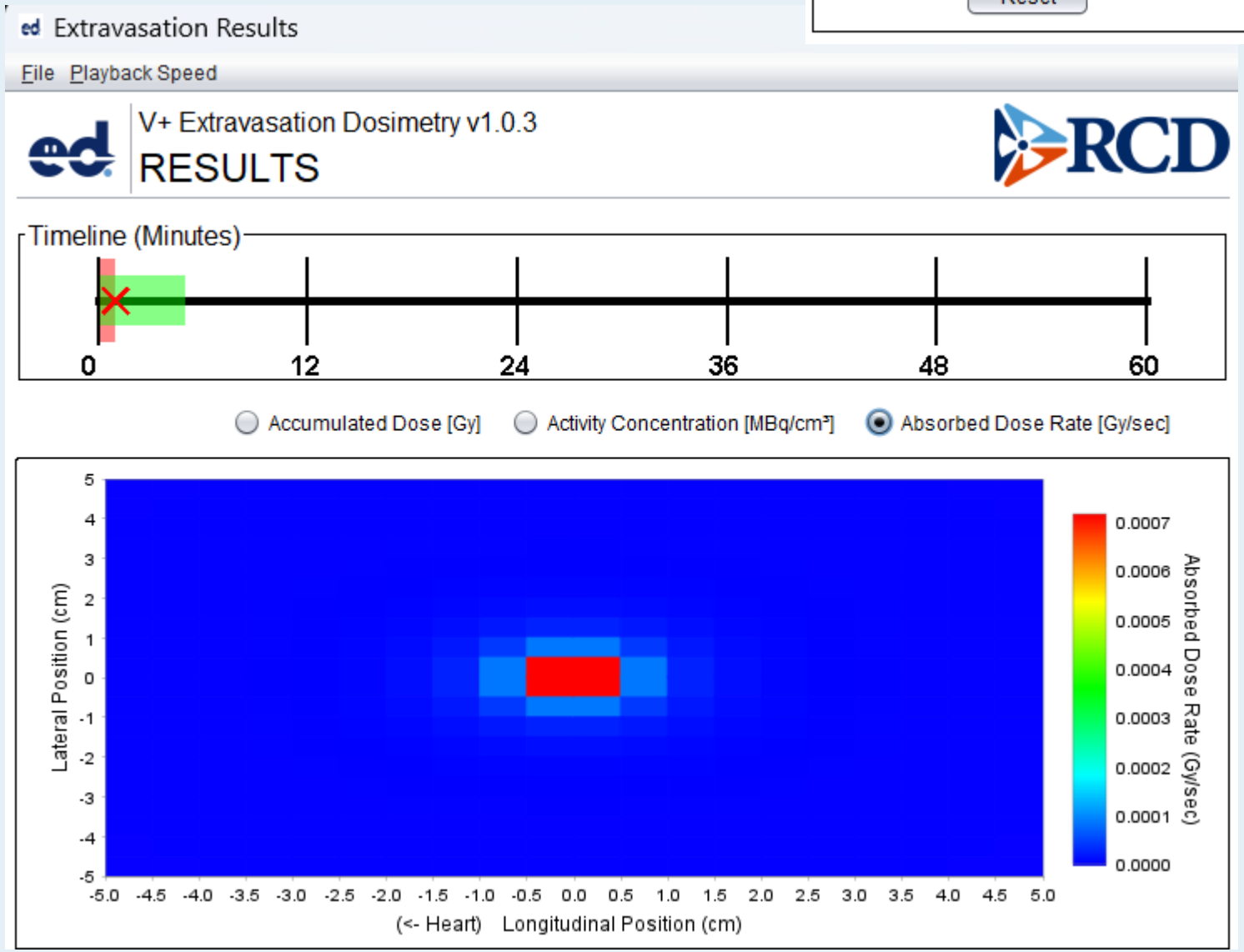
Theoretical maximum dose from 1st minute, no-fluid simulation & manual accumulated dose conversion

- Maximizes system activity, radiation absorption, & ROI dose rates
- Default inputs shown, 2 proposed updates*





1st minute, no-fluid simulation



Extravasated Activity:	1.00e+03	MBq
Extravasated Volume:	1.00e-01	mL
Maximum Voxel Dose:	3.98e-02	Gy
Maximum Voxel Dose Rate:	7.15e-04	Gy/sec
Time to Maximum Voxel Dose Rate:	1.00	min
ROI Exceeding Threshold (2.0 Gy):	0.00	%
Dose to ROI:	3.05e-03	Gy

- Peak dose rate occurs at end of extravasation event, 1 min here
- Manually export peak dose rates (.csv file)

Peak dose rate (Gy/s) data file

- Average dose rate for various areas
- Normalized for 1 GBq extravasated

	Area (cm^2)	Max Dose Rate (Gy/GBq-s)
Max Voxels	1	7.15E-04
	16	6.84E-05
	49	2.44E-05
Full ROI	100	1.24E-05

3.44E-07	4.02E-07	4.69E-07	5.43E-07	6.23E-07	7.04E-07	7.83E-07	8.52E-07	9.03E-07	9.31E-07	9.31E-07	9.03E-07	8.52E-07	7.83E-07	7.04E-07	6.23E-07	5.43E-07	4.69E-07	4.02E-07	3.44E-07
4.02E-07	4.79E-07	5.68E-07	6.70E-07	7.83E-07	9.03E-07	1.02E-06	1.13E-06	1.21E-06	1.26E-06	1.26E-06	1.21E-06	1.13E-06	1.02E-06	9.03E-07	7.83E-07	6.70E-07	5.68E-07	4.79E-07	4.02E-07
4.69E-07	5.68E-07	6.87E-07	8.28E-07	9.91E-07	1.17E-06	1.36E-06	1.54E-06	1.68E-06	1.76E-06	1.76E-06	1.68E-06	1.54E-06	1.36E-06	1.17E-06	9.91E-07	8.28E-07	6.87E-07	5.68E-07	4.69E-07
5.43E-07	6.70E-07	8.28E-07	1.02E-06	1.26E-06	1.54E-06	1.84E-06	2.15E-06	2.40E-06	2.55E-06	2.55E-06	2.40E-06	2.15E-06	1.84E-06	1.54E-06	1.26E-06	1.02E-06	8.28E-07	6.70E-07	5.43E-07
6.23E-07	7.83E-07	9.91E-07	1.26E-06	1.61E-06	2.04E-06	2.55E-06	3.09E-06	3.59E-06	3.88E-06	3.88E-06	3.59E-06	3.09E-06	2.55E-06	2.04E-06	1.61E-06	1.26E-06	9.91E-07	7.83E-07	6.23E-07
7.04E-07	9.03E-07	1.17E-06	1.54E-06	2.04E-06	2.71E-06	3.59E-06	4.64E-06	5.69E-06	6.38E-06	6.38E-06	5.69E-06	4.64E-06	3.59E-06	2.71E-06	2.04E-06	1.54E-06	1.17E-06	9.03E-07	7.04E-07
7.83E-07	1.02E-06	1.36E-06	1.84E-06	2.55E-06	3.59E-06	5.12E-06	7.27E-06	9.80E-06	1.17E-05	1.17E-05	9.80E-06	7.27E-06	5.12E-06	3.59E-06	2.55E-06	1.84E-06	1.36E-06	1.02E-06	7.83E-07
8.52E-07	1.13E-06	1.54E-06	2.15E-06	3.09E-06	4.64E-06	7.27E-06	1.18E-05	1.89E-05	2.59E-05	2.59E-05	1.89E-05	1.18E-05	7.27E-06	4.64E-06	3.09E-06	2.15E-06	1.54E-06	1.13E-06	8.52E-07
9.03E-07	1.21E-06	1.68E-06	2.40E-06	3.59E-06	5.69E-06	9.80E-06	1.89E-05	4.27E-05	8.67E-05	8.67E-05	4.27E-05	1.89E-05	9.80E-06	5.69E-06	3.59E-06	2.40E-06	1.68E-06	1.21E-06	9.03E-07
9.31E-07	1.26E-06	1.76E-06	2.55E-06	3.88E-06	6.38E-06	1.17E-05	2.59E-05	8.67E-05	7.15E-04	7.15E-04	8.67E-05	2.59E-05	1.17E-05	6.38E-06	3.88E-06	2.55E-06	1.76E-06	1.26E-06	9.31E-07
9.31E-07	1.26E-06	1.76E-06	2.55E-06	3.88E-06	6.38E-06	1.17E-05	2.59E-05	8.67E-05	7.15E-04	7.15E-04	8.67E-05	2.59E-05	1.17E-05	6.38E-06	3.88E-06	2.55E-06	1.76E-06	1.26E-06	9.31E-07
9.03E-07	1.21E-06	1.68E-06	2.40E-06	3.59E-06	5.69E-06	9.80E-06	1.89E-05	4.27E-05	8.67E-05	8.67E-05	4.27E-05	1.89E-05	9.80E-06	5.69E-06	3.59E-06	2.40E-06	1.68E-06	1.21E-06	9.03E-07
8.52E-07	1.13E-06	1.54E-06	2.15E-06	3.09E-06	4.64E-06	7.27E-06	1.18E-05	1.89E-05	2.59E-05	2.59E-05	1.89E-05	1.18E-05	7.27E-06	4.64E-06	3.09E-06	2.15E-06	1.54E-06	1.13E-06	8.52E-07
7.83E-07	1.02E-06	1.36E-06	1.84E-06	2.55E-06	3.59E-06	5.12E-06	7.27E-06	9.80E-06	1.17E-05	1.17E-05	9.80E-06	7.27E-06	5.12E-06	3.59E-06	2.55E-06	1.84E-06	1.36E-06	1.02E-06	7.83E-07
7.04E-07	9.03E-07	1.17E-06	1.54E-06	2.04E-06	2.71E-06	3.59E-06	4.64E-06	5.69E-06	6.38E-06	6.38E-06	5.69E-06	4.64E-06	3.59E-06	2.71E-06	2.04E-06	1.54E-06	1.17E-06	9.03E-07	7.04E-07
6.23E-07	7.83E-07	9.91E-07	1.26E-06	1.61E-06	2.04E-06	2.55E-06	3.09E-06	3.59E-06	3.88E-06	3.88E-06	3.59E-06	3.09E-06	2.55E-06	2.04E-06	1.61E-06	1.26E-06	9.91E-07	7.83E-07	6.23E-07
5.43E-07	6.70E-07	8.28E-07	1.02E-06	1.26E-06	1.54E-06	1.84E-06	2.15E-06	2.40E-06	2.55E-06	2.55E-06	2.40E-06	2.15E-06	1.84E-06	1.54E-06	1.26E-06	1.02E-06	8.28E-07	6.70E-07	5.43E-07
4.69E-07	5.68E-07	6.87E-07	8.28E-07	9.91E-07	1.17E-06	1.36E-06	1.54E-06	1.68E-06	1.76E-06	1.76E-06	1.68E-06	1.54E-06	1.36E-06	1.17E-06	9.91E-07	8.28E-07	6.87E-07	5.68E-07	4.69E-07
4.02E-07	4.79E-07	5.68E-07	6.70E-07	7.83E-07	9.03E-07	1.02E-06	1.13E-06	1.21E-06	1.26E-06	1.26E-06	1.21E-06	1.13E-06	1.02E-06	9.03E-07	7.83E-07	6.70E-07	5.68E-07	4.79E-07	4.02E-07
3.44E-07	4.02E-07	4.69E-07	5.43E-07	6.23E-07	7.04E-07	7.83E-07	8.52E-07	9.03E-07	9.31E-07	9.31E-07	9.03E-07	8.52E-07	7.83E-07	7.04E-07	6.23E-07	5.43E-07	4.69E-07	4.02E-07	3.44E-07

Example theoretical maximum extravasation dose for ^{99m}Tc

Peak dose rate (Gy/s) data file

- Average dose rate for various tissue areas
- 4 infiltrated areas shown
- Normalized for 1 GBq extravasated

Accumulate dose with biological half-life

- 3 biological half-life examples shown

$$D_{\mathrm{ROI}} = T_e \left(\frac{3600 \frac{s}{h}}{\ln 2} \right) \dot{D}_{\mathrm{ROI}}$$

	Area (cm^2)	Max Dose Rate (Gy/GBq-s)
Max Voxels	1	7.15E-04
	16	6.84E-05
	49	2.44E-05
Full ROI	100	1.24E-05

Biological half-life, T_b (h)		
0.25	0.5	1
fast	moderate	slow
Effective half-life, T_e (h)		
0.24	0.46	0.86
Max Extravasation Dose (Gy/GBq)		
0.89	1.7	3.2
0.085	0.16	0.31
0.030	0.058	0.11
0.015	0.030	0.055

Open feedback