ExtravDose Discussions

utilizing VARSKIN+ (V+) Version 2.0, software release: April 1, 2025

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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.

Interactive discussion

1. Open feedback
2. Early adopter questions
3. Open feedback
4. ROI clearance half-time
5. Feedback on using effective half-life
6. How to detect errors
7. Open feedback

Open feedback

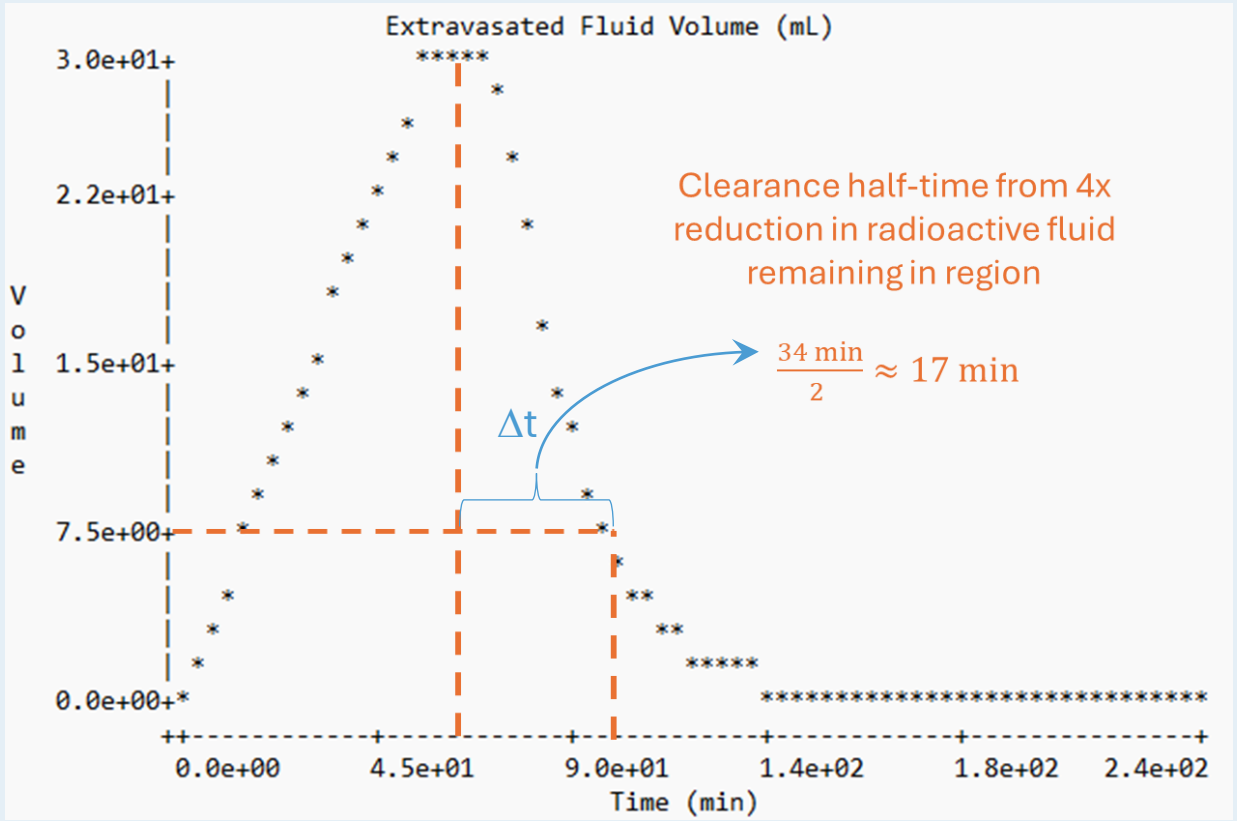
Early Adopter Questions

Open feedback

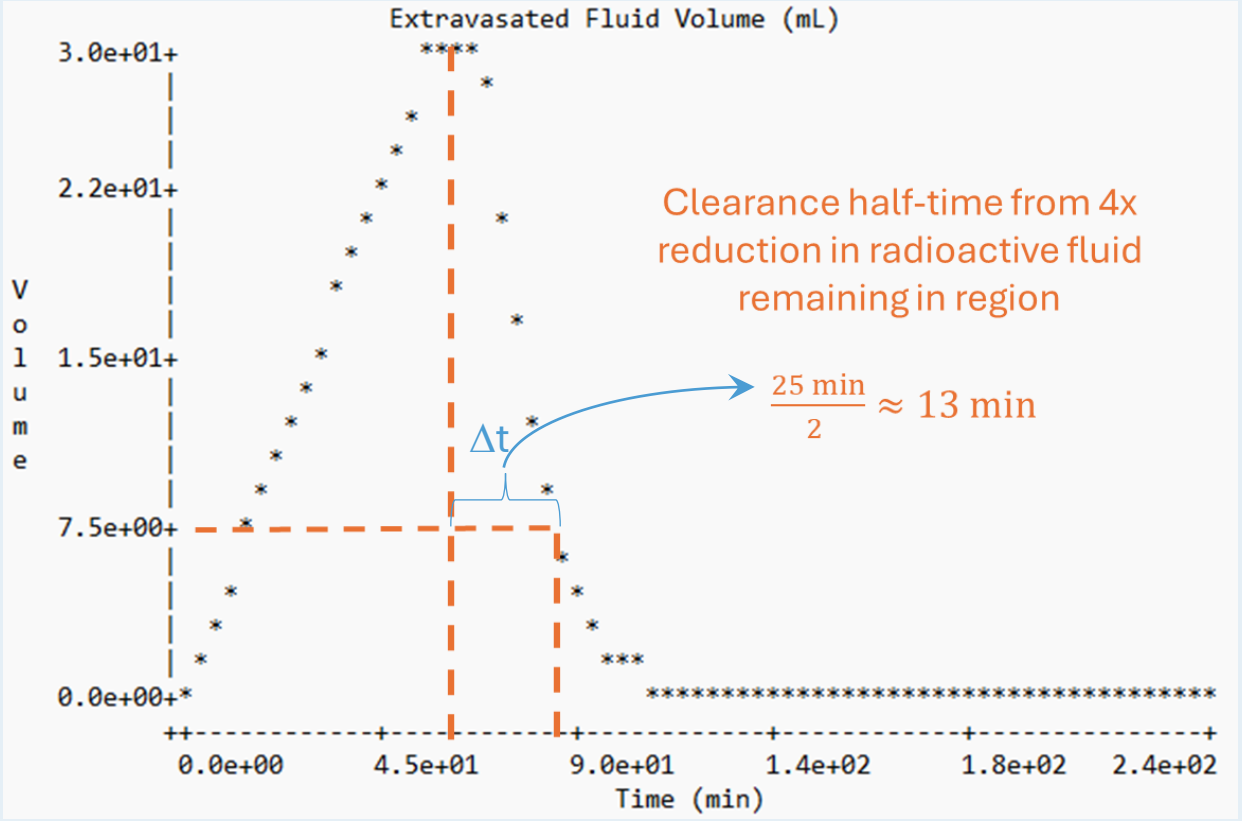
ROI Clearance Half-time Examples

ROI Clearance Half-times: Lateral Transmissivity = 3 cm²/h

16 cm × 16 cm ROI

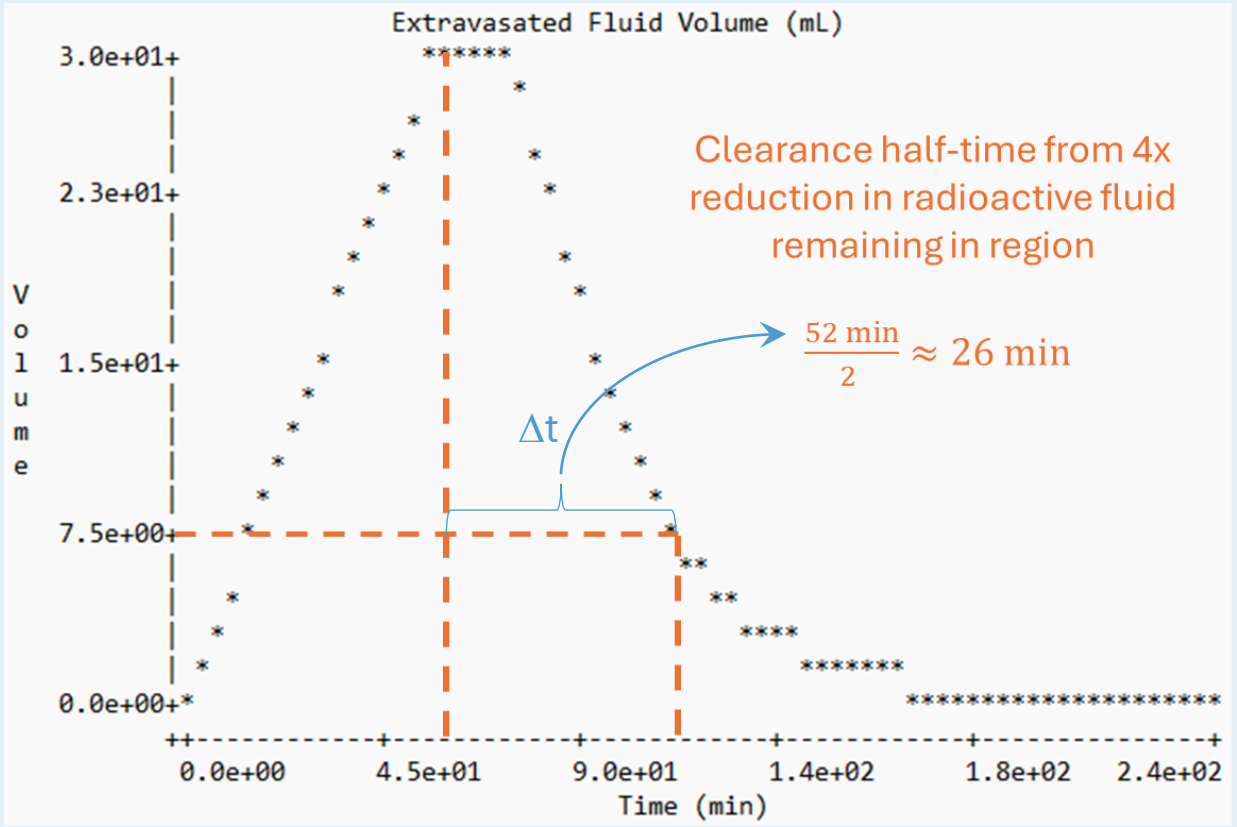


12 cm × 12 cm ROI

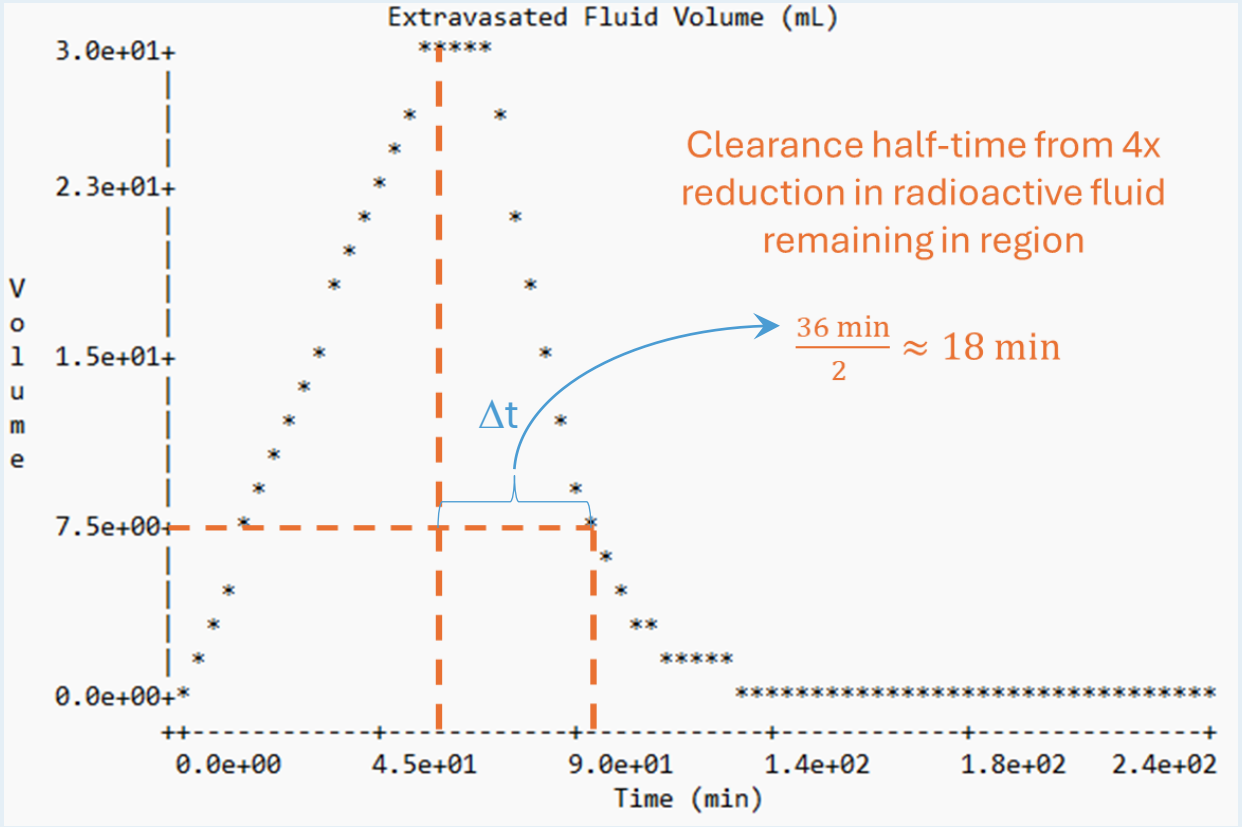


ROI Clearance Half-times: Lateral Transmissivity = 2 cm²/h

16 cm × 16 cm ROI

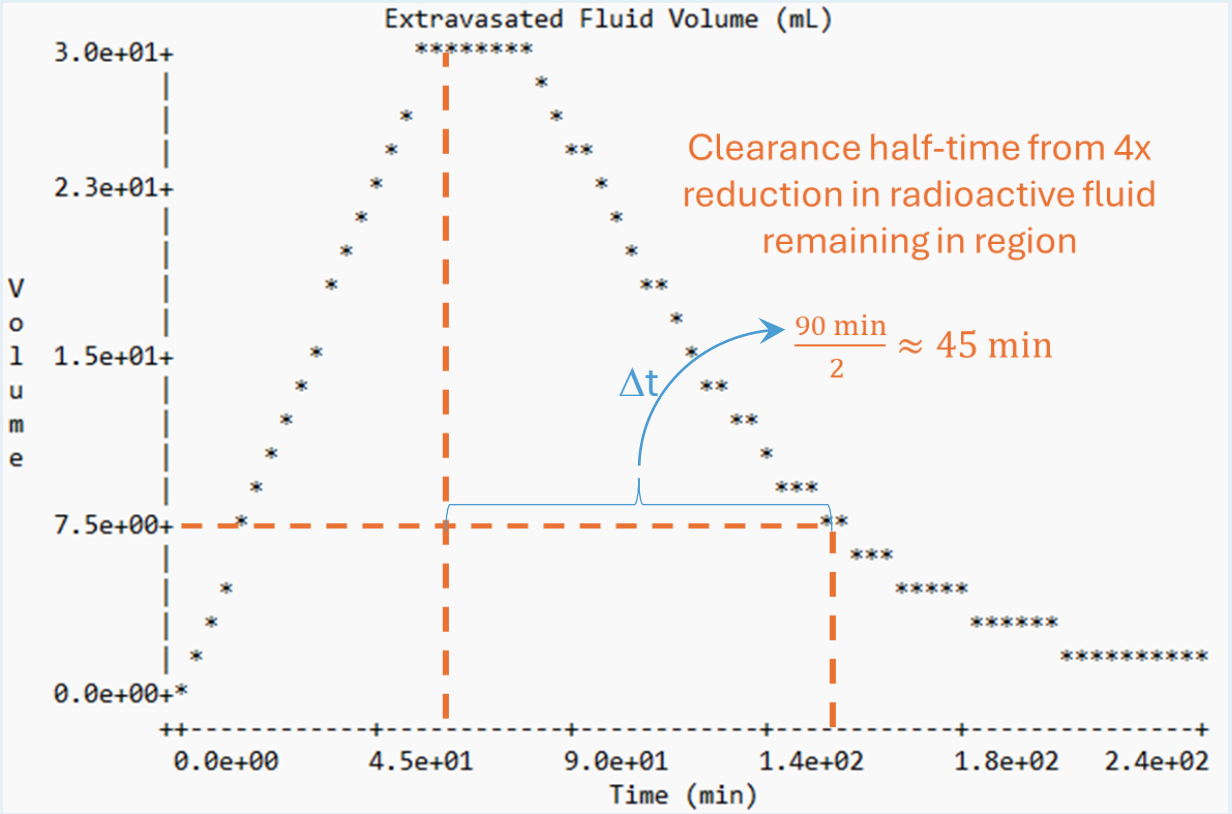


12 cm × 12 cm ROI

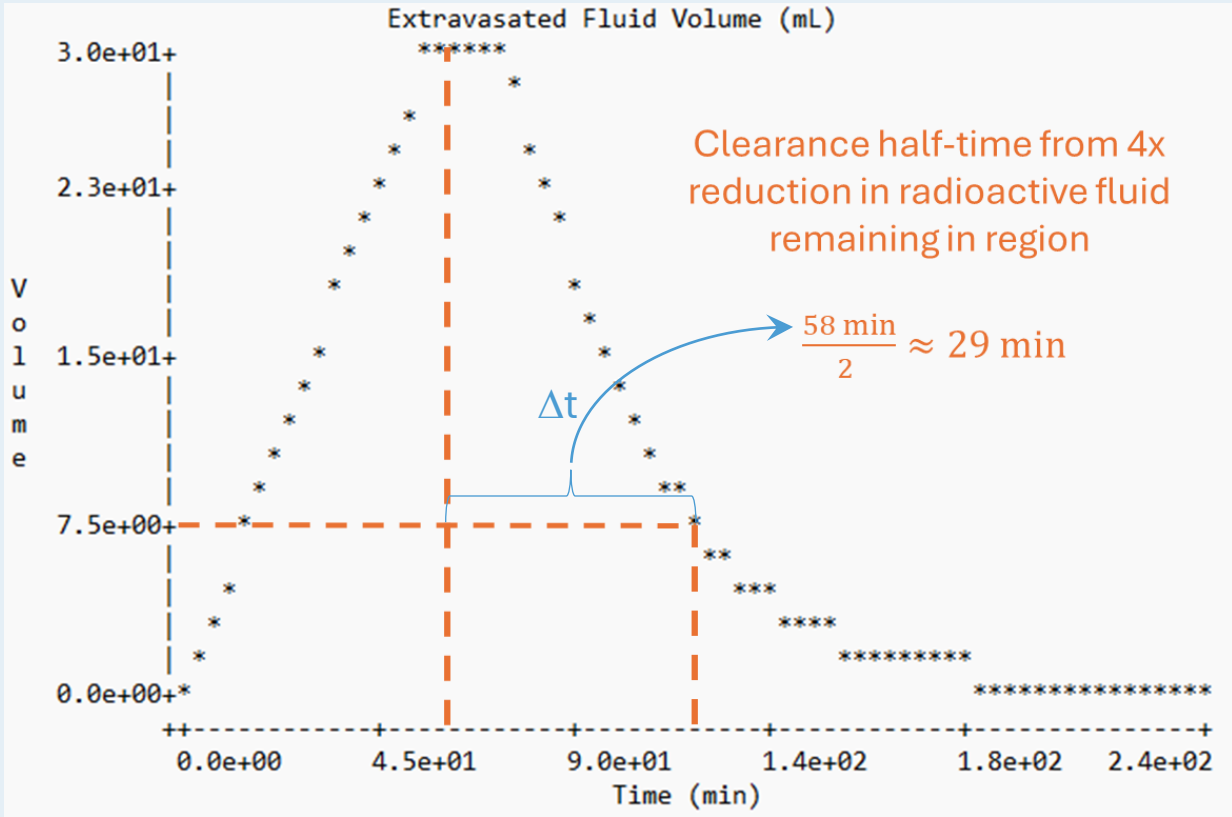


ROI Clearance Half-times: Lateral Transmissivity = 1 cm²/h

16 cm × 16 cm ROI

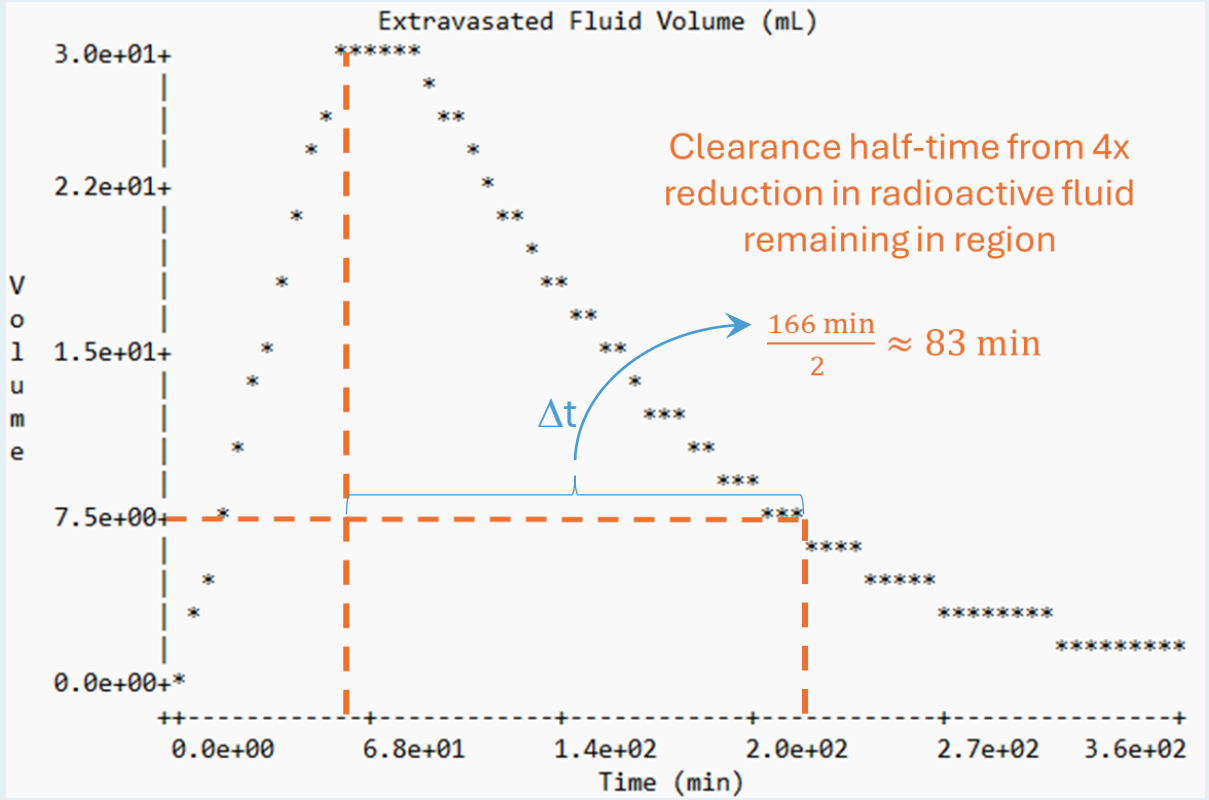


12 cm × 12 cm ROI

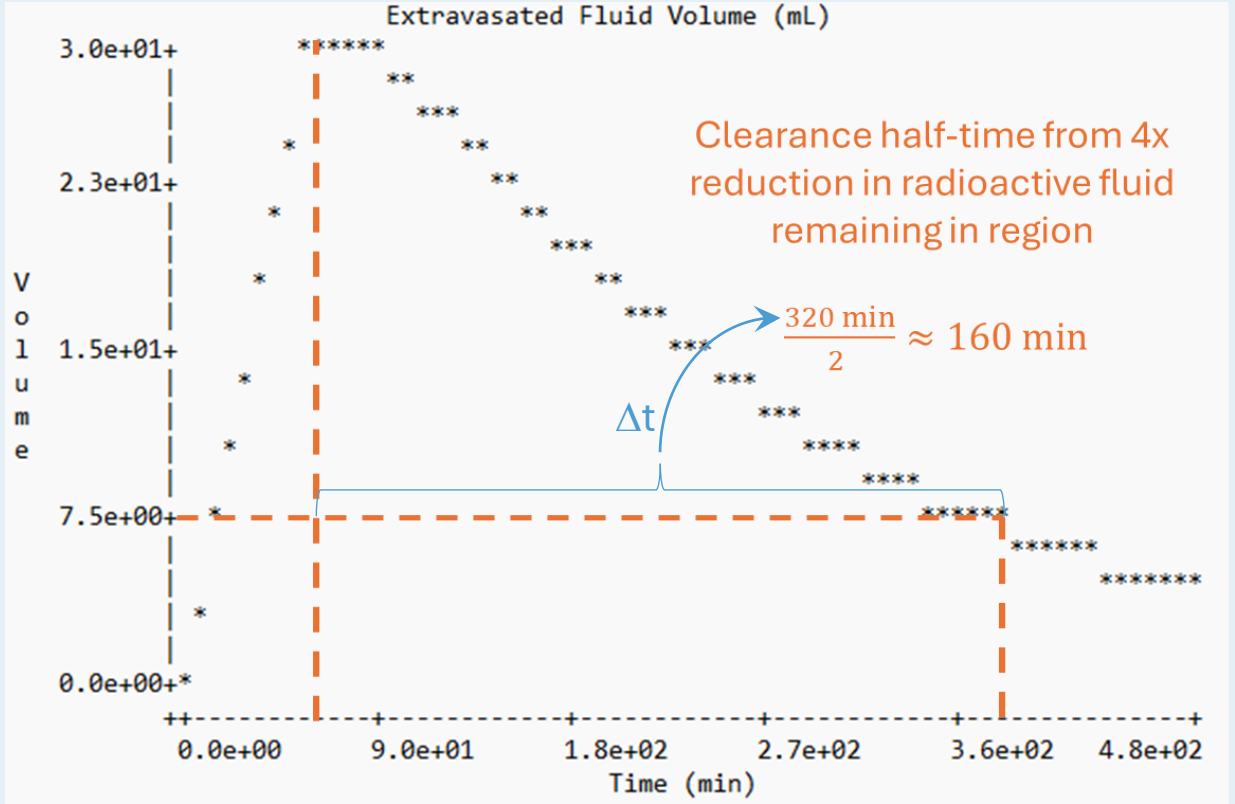


Two Longer ROI Clearance Half-times: 12 cm × 12 cm ROI

Lateral Transmissivity = 0.3 cm²/h



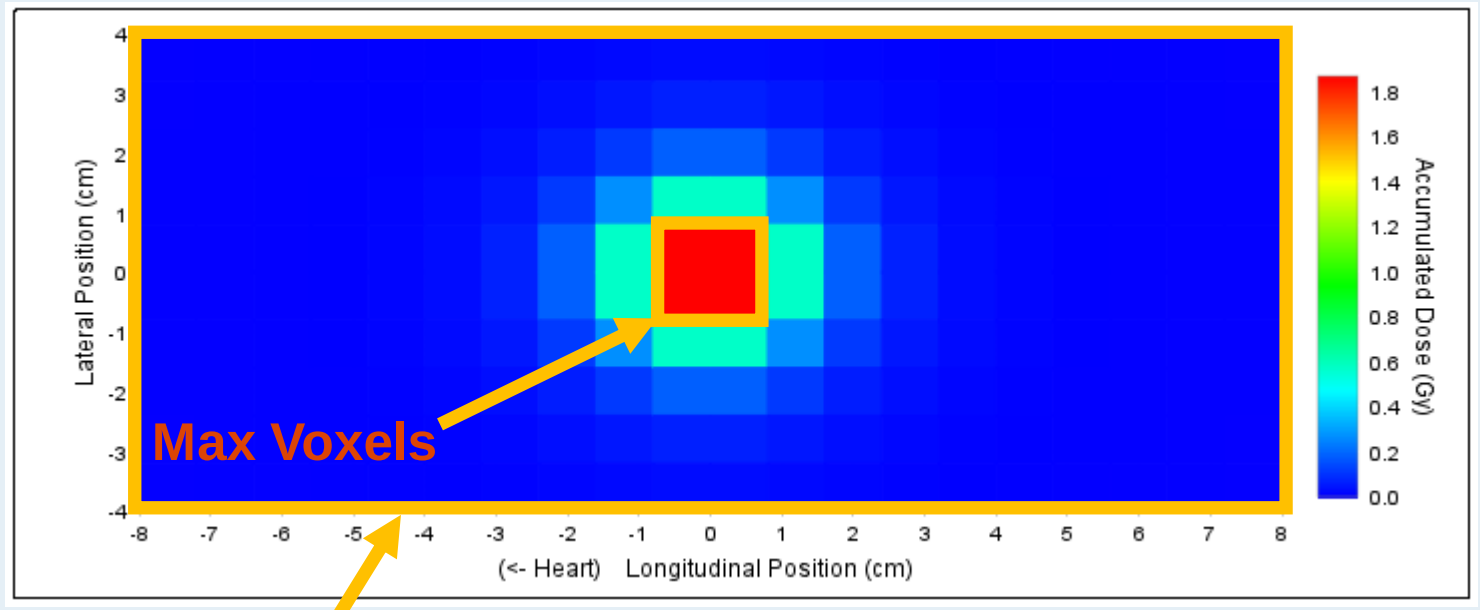
Lateral Transmissivity = 0.1 cm²/h



User Feedback on Effective Half-life for Calculating Extravasation Dose

- **User feedback already logged in V+ issue tracker**
- **Special Use Case illustrates how to determine clearance half-time for extravasation site (maximum voxels) & surrounding tissue ROI**
- **Shows how to model effective half-life behavior**

Clearance defined for Max Voxels & surrounding Tissue ROI



Half-life relationships

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

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

Assumption: **Dose rate to Max Voxels or Tissue ROI over time is approximated by single exponential with different reduction rates.**

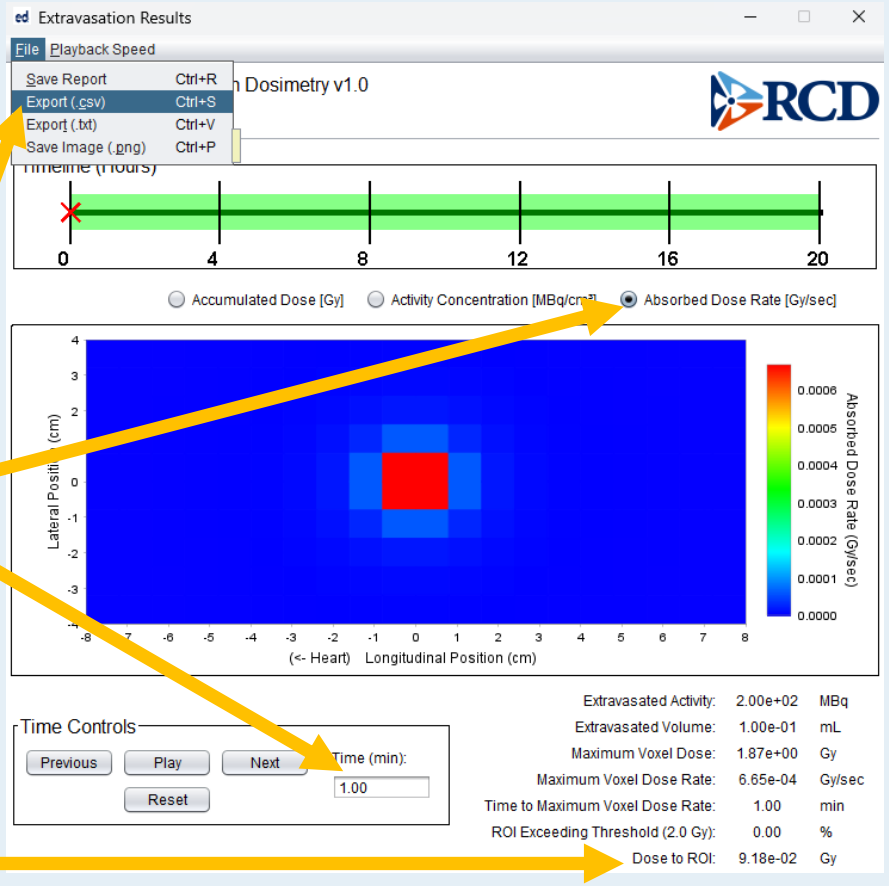
Outputs needed for Tissue ROI clearance & Max Voxels clearance

Tissue ROI

Utilizes two outputs

- **Dose Rate to ROI [Gy/s] at End Time for Extravasation Event**
  1. Requires user to export .csv file of Absorbed Dose Rates at the correct time (e.g., 1 min as shown)
  2. Compute average Absorbed Dose Rate for all voxels in ROI
- **Dose to ROI [Gy]**

Example simulation result for ^{68}Ga



$$\text{Effective half-life} = \left(\frac{\ln 2}{60\ \frac{s}{min}}\right)\left(\frac{D_{\text{ROI}}}{\dot{D}_{\text{ROI}}}\right) = \left(\frac{\ln 2}{60\ \frac{s}{min}}\right)\left(\frac{0.0918\ Gy}{0.0000196\ Gy\ s^{-1}}\right) = 54.1\ min$$

Max Voxels

Effective half-life

$$= \left(\frac{\ln 2}{60\ \frac{s}{min}}\right)\left(\frac{D_{\text{max\_voxels}}}{\dot{D}_{\text{max\_voxels}}}\right)$$

$$= \left(\frac{\ln 2}{60\ \frac{s}{min}}\right)\left(\frac{1.87\ Gy}{0.000665\ Gy\ s^{-1}}\right)$$

$$= 32.5\ min$$

Max Voxels simulation outputs for effective half-life calculation

Clearance from effective half-lives for Tissue ROI & Max Voxels

Assumption: Dose rate to Max Voxels or Tissue ROI over time is approximated by single exponential with different reduction rates.

Tissue ROI

Clearance half–time

$$T_b = \frac{(67.7)\cdot(54.1)}{(67.7-54.1)} = 269\ min$$

Max Voxels

Clearance half–time

$$T_b = \frac{(67.7)\cdot(32.5)}{(67.7-32.5)} = 62.5\ min$$

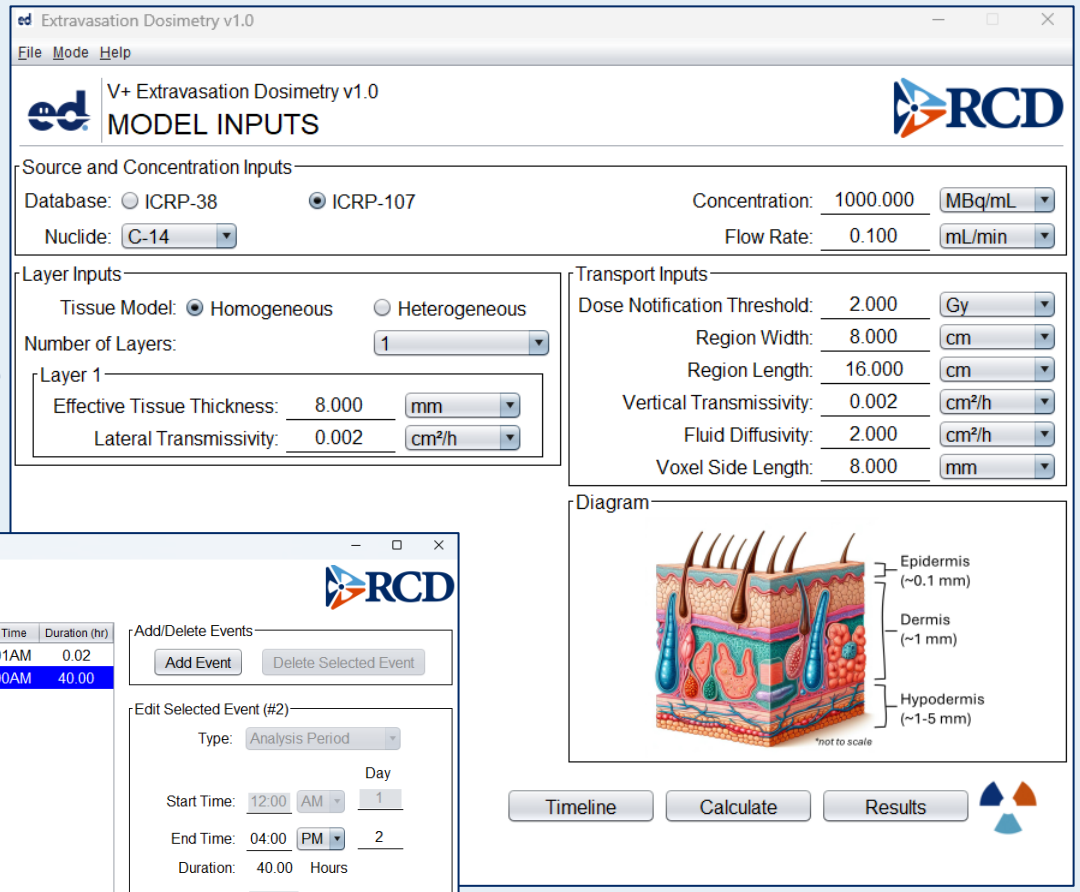
Modeling Fluid Clearance Rate with Diffusivity in SPECIAL USE CASE

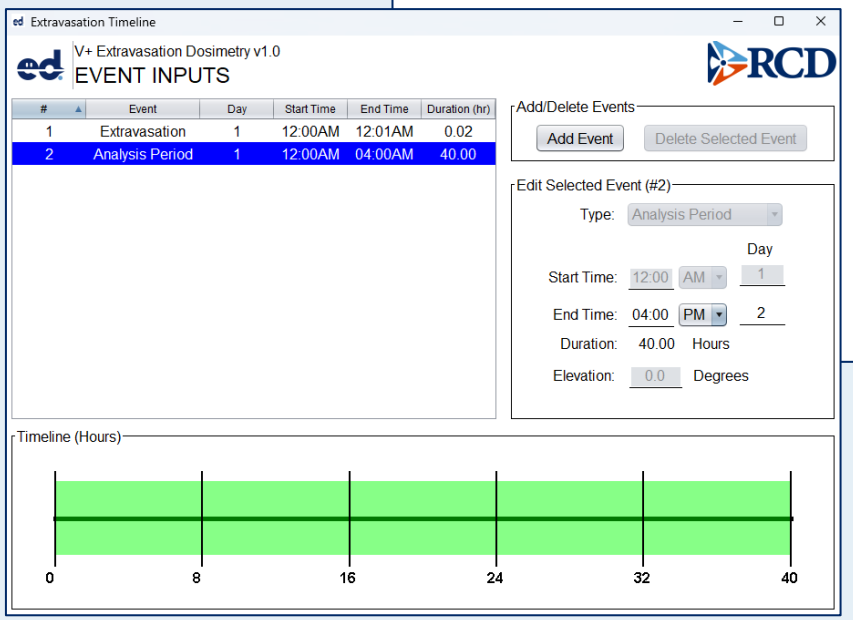
Clearance Rates determined for Max Voxels & Surrounding Tissue ROI

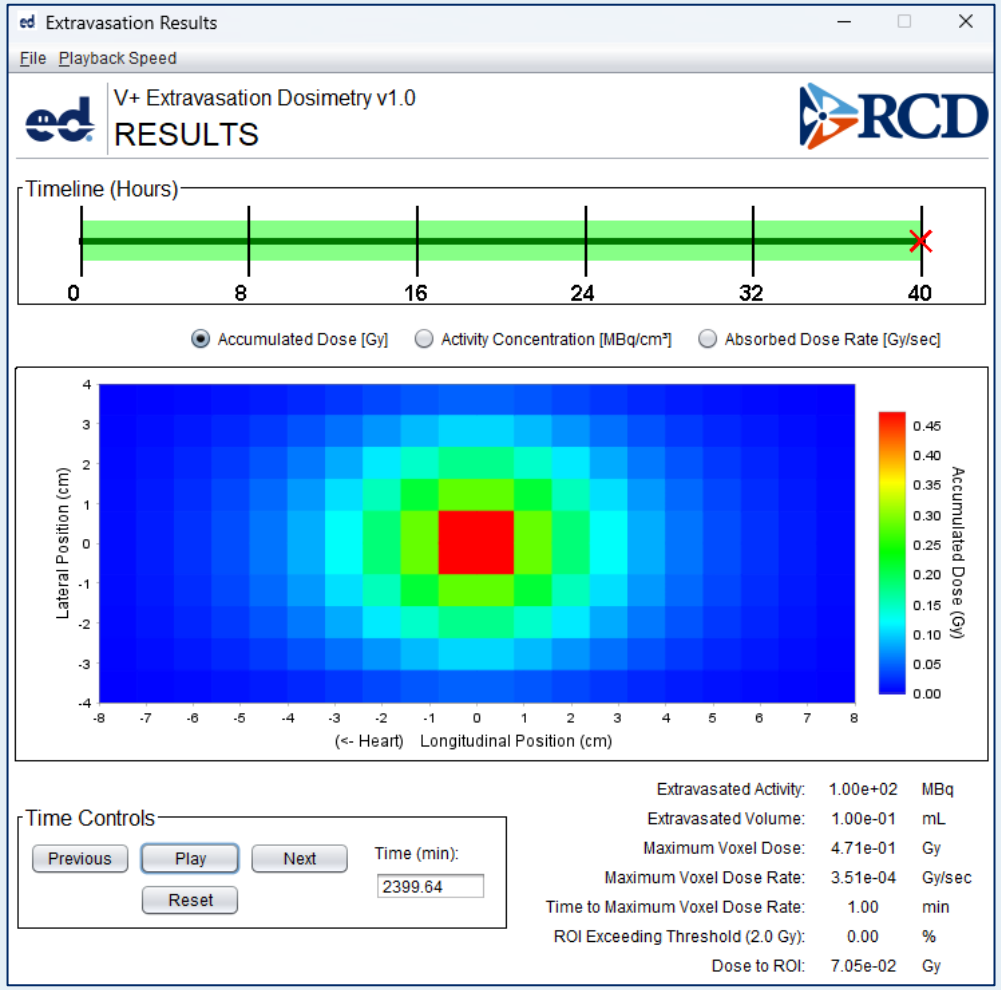
Select long-lived radionuclide (e.g., ^{14}C) to ensure negligible effect of radioactive decay on total loss.

∴ Simulated clearance represents flow and biological losses.

Minimize Flow Rate, Extrav. Duration, & Transmissivities in order to control fluid clearance rate by Diffusivity



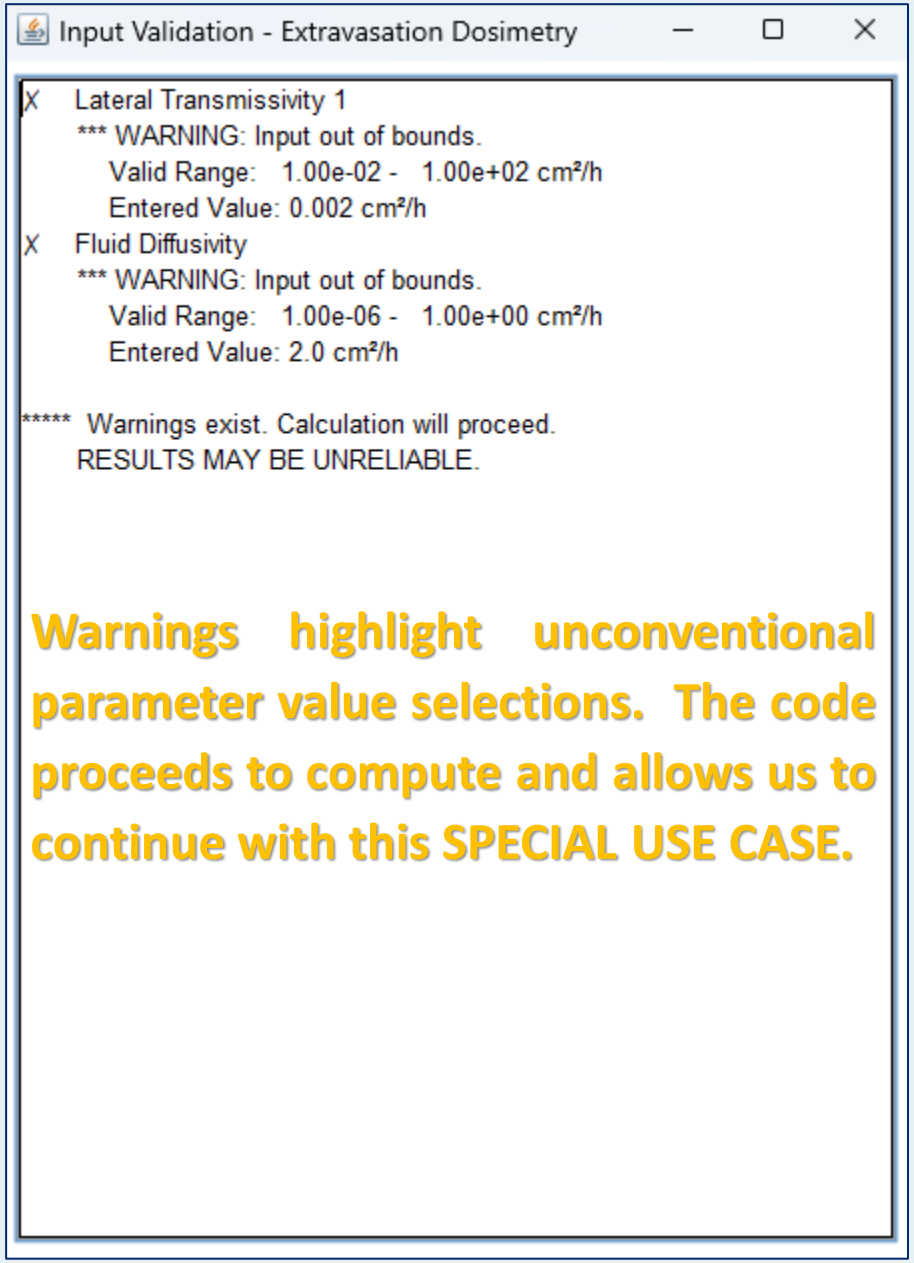




8-mm effective tissue thickness for this example

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

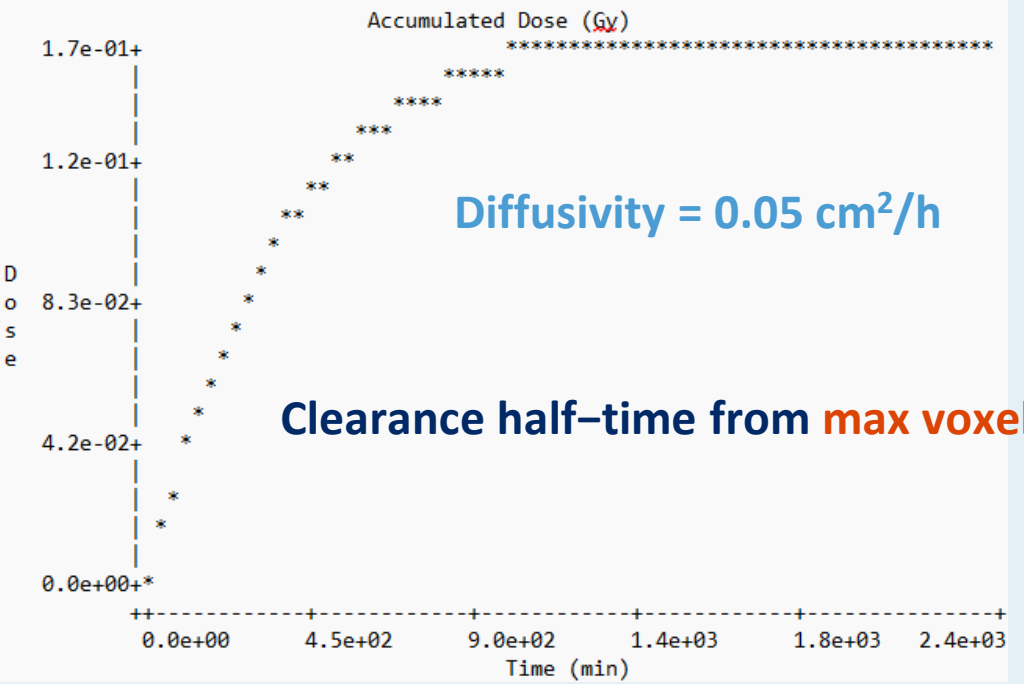
Input Warnings Received



Calculate Clearance Half-time for Small Diffusivity = 0.05 cm²/h

```
**********************************************************************
Outputs
**********************************************************************
                        Max Voxel Dose:    3.65e+00        Gy
                    Max Voxel Dose Rate:   3.51e-04        Gy/s
          Time to Max Voxel Dose Rate:     1.0           min
       ROI Exceeding Dose Threshold:       2.0           %
                           Dose to ROI:    1.66e-01        Gy
                         Region Volume:    102.4           cm³

----------------------------------------------------------------------
Plot(s)
----------------------------------------------------------------------
```



✓ ***Appropriate ROI***: **Boundary effects are minimized when max voxel dose doesn't increase from increases in ROI width or length**

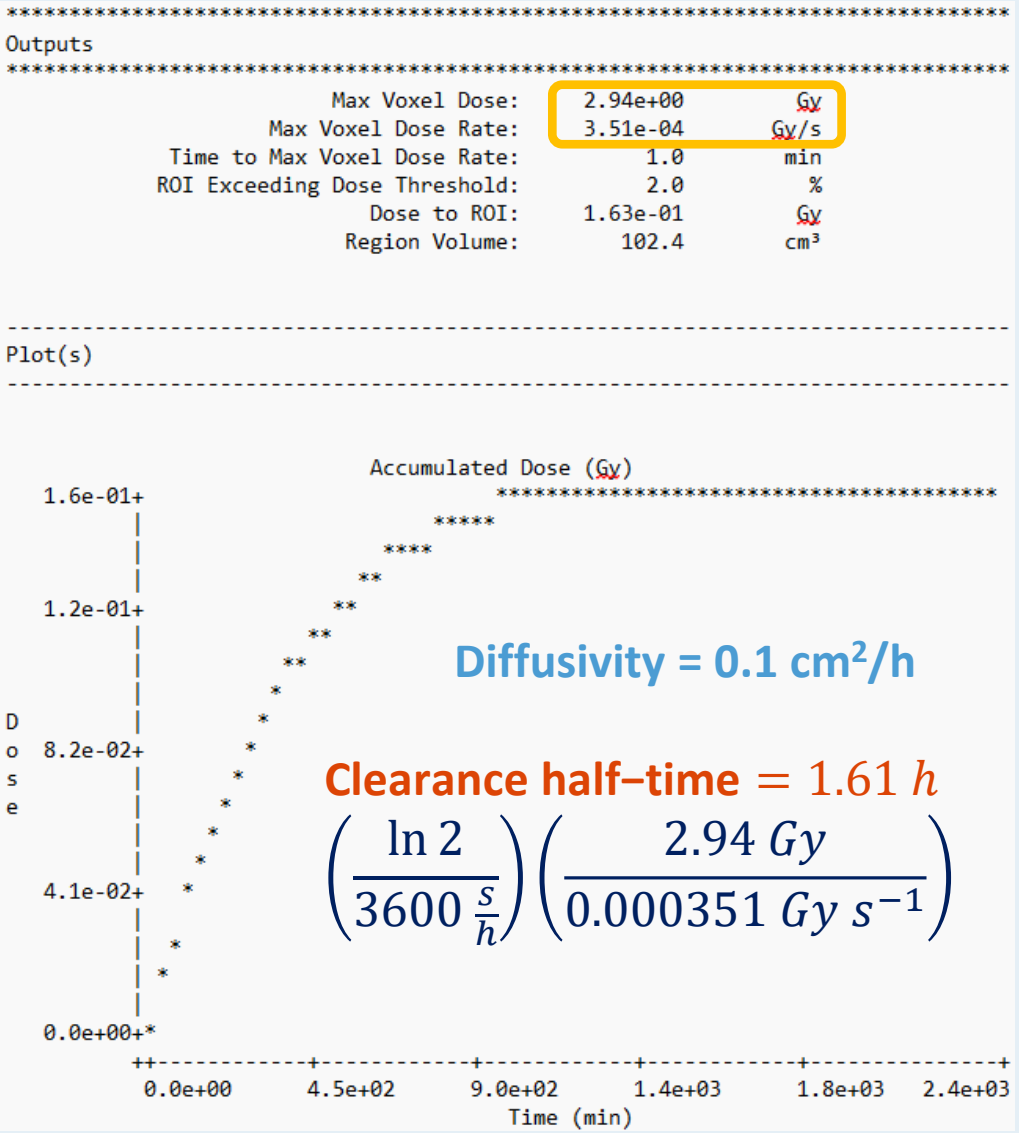
✓ ***Appropriate simulation time***: **Clear plateau in Accumulated Dose to ROI**

Effective clearance rate $\lambda = \frac{\dot{D}_{\text{max\_voxel}}}{D_{\text{max\_voxel}}}$

Diffusivity = 0.05 cm²/h

Clearance half–time from max voxels $= \left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{D_{\text{max\_voxel}}}{\dot{D}_{\text{max\_voxel}}}\right) = \left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{3.65\ Gy}{0.000351\ Gy\ s^{-1}}\right) = 2.00\ h$

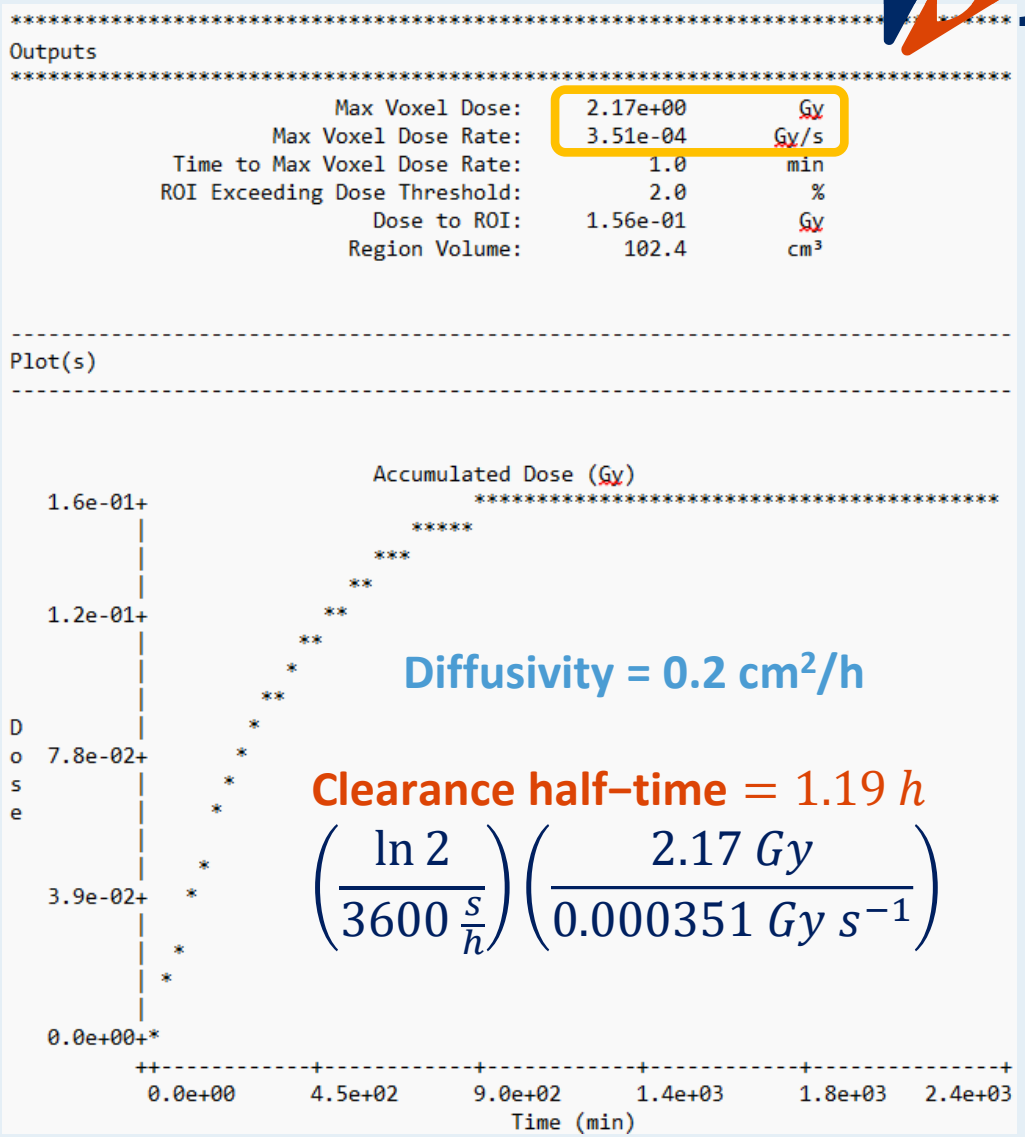
Clearance Half-times for Diffusivities: 0.1 and 0.2 cm²/h



Diffusivity = 0.1 cm²/h

Clearance half–time $= 1.61\ h$

$$\left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{2.94\ Gy}{0.000351\ Gy\ s^{-1}}\right)$$



Diffusivity = 0.2 cm²/h

Clearance half–time $= 1.19\ h$

$$\left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{2.17\ Gy}{0.000351\ Gy\ s^{-1}}\right)$$

Clearance Half-times for Diffusivities: 0.5 and 1.0 cm²/h

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Outputs

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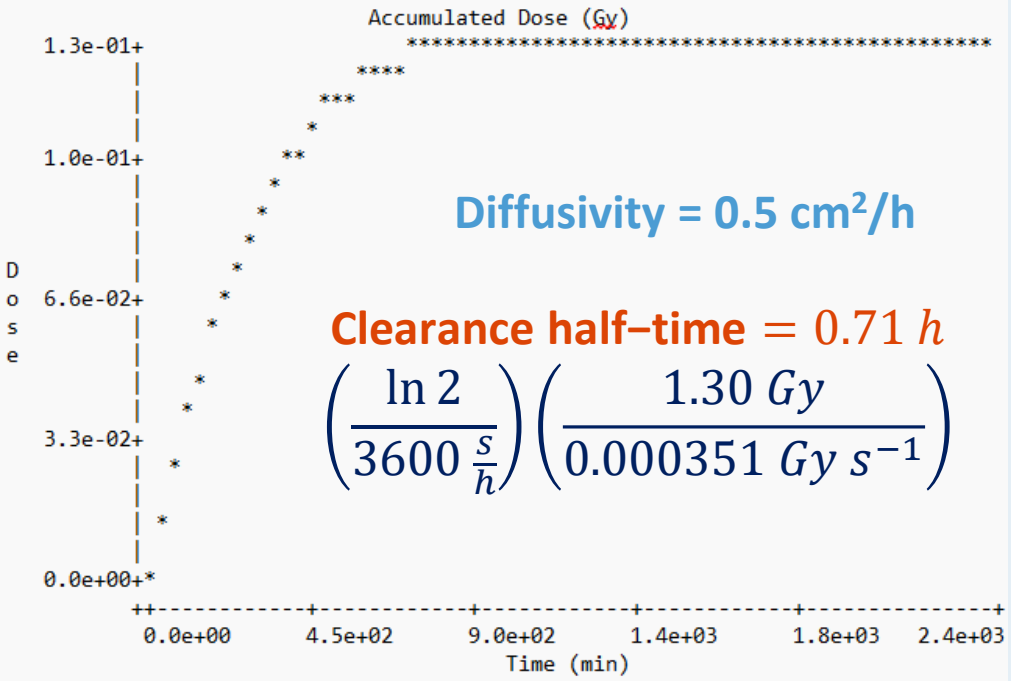
Max Voxel Dose:	1.30e+00	Gy
Max Voxel Dose Rate:	3.51e-04	Gy/s
Time to Max Voxel Dose Rate:	1.0	min
ROI Exceeding Dose Threshold:	0.0	%
Dose to ROI:	1.33e-01	Gy
Region Volume:	102.4	cm³

Plot(s)



Diffusivity = 0.5 cm²/h

Clearance half–time $= 0.71\ h$

$$\left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{1.30\ Gy}{0.000351\ Gy\ s^{-1}}\right)$$

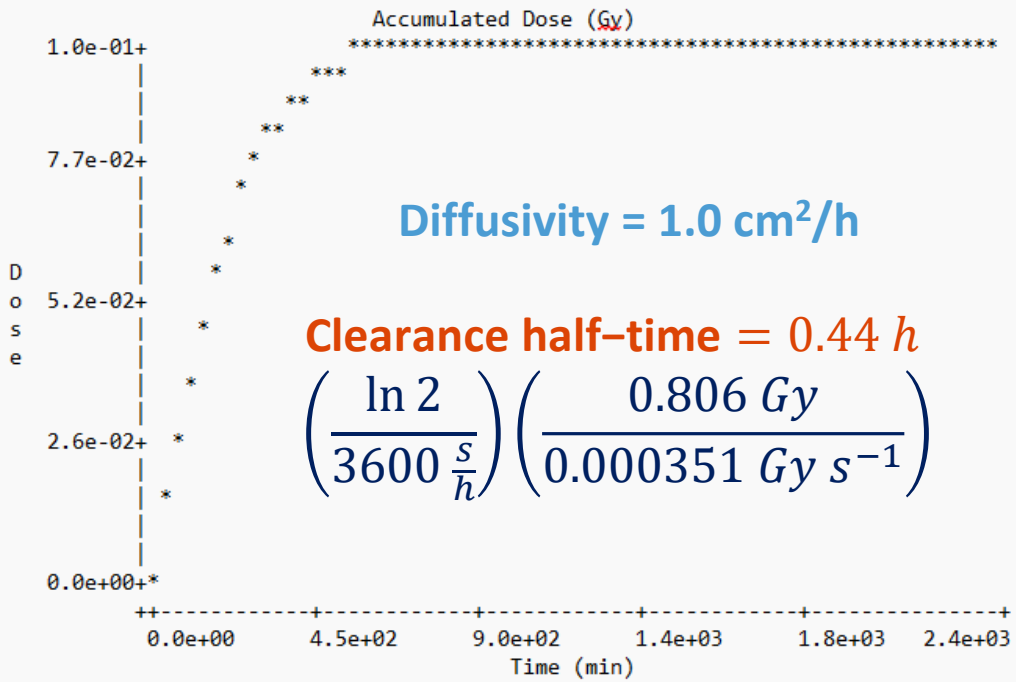
****

Outputs

****

Max Voxel Dose:	8.06e-01	Gy
Max Voxel Dose Rate:	3.51e-04	Gy/s
Time to Max Voxel Dose Rate:	1.0	min
ROI Exceeding Dose Threshold:	0.0	%
Dose to ROI:	1.03e-01	Gy
Region Volume:	102.4	cm³

Plot(s)



Diffusivity = 1.0 cm²/h

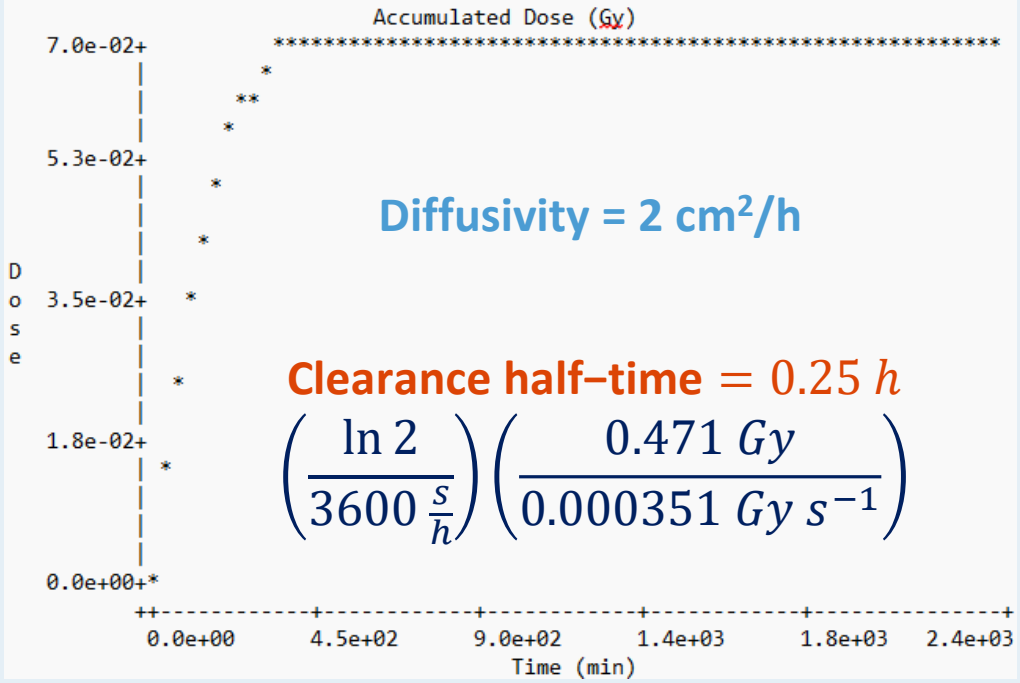
Clearance half–time $= 0.44\ h$

$$\left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{0.806\ Gy}{0.000351\ Gy\ s^{-1}}\right)$$

Clearance Half-time for Large Diffusivity = 2 cm²/h

```
**********************************************************************************
Outputs
**********************************************************************************
                        Max Voxel Dose:    4.71e-01        Gy
                   Max Voxel Dose Rate:    3.51e-04        Gy/s
          Time to Max Voxel Dose Rate:         1.0        min
        ROI Exceeding Dose Threshold:         0.0          %
                             Dose to ROI:    7.05e-02        Gy
                           Region Volume:       102.4        cm³


----------------------------------------------------------------------------------
Plot(s)
----------------------------------------------------------------------------------
```



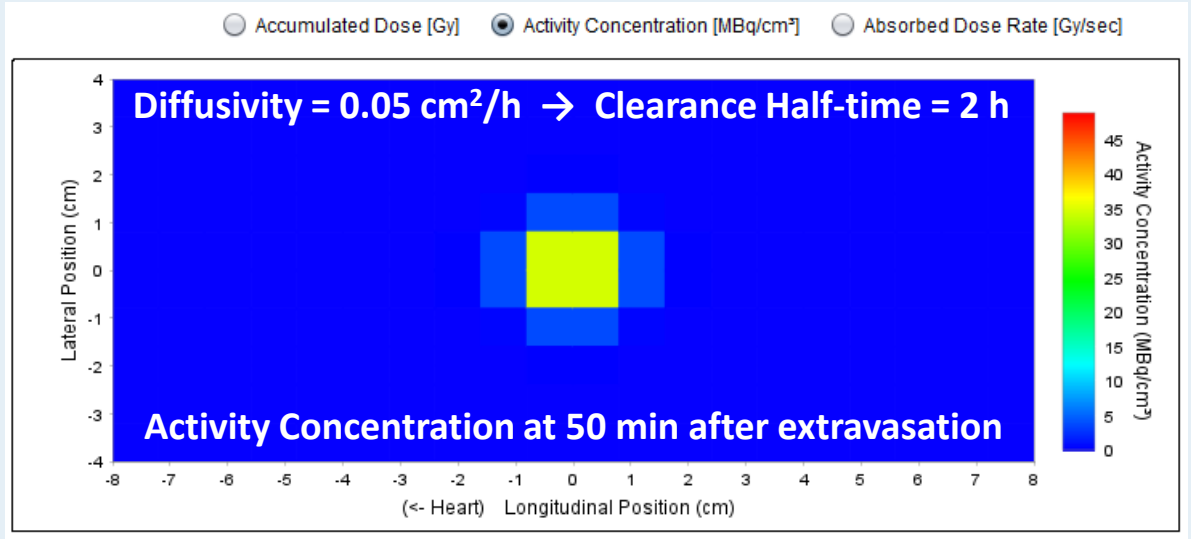
Diffusivity = 2 cm²/h

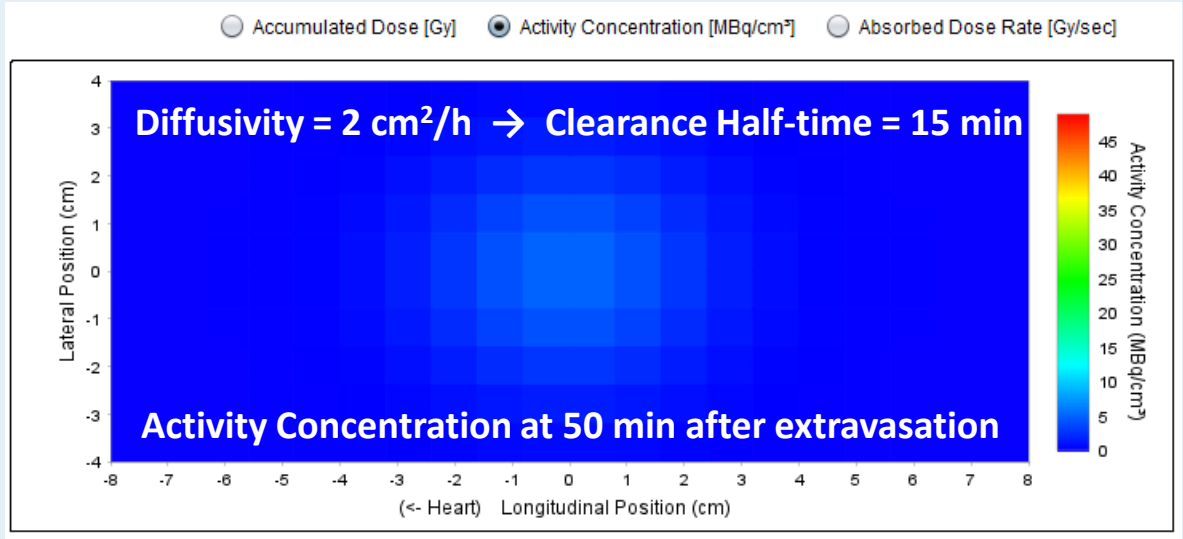
Clearance half–time $= 0.25\ h$

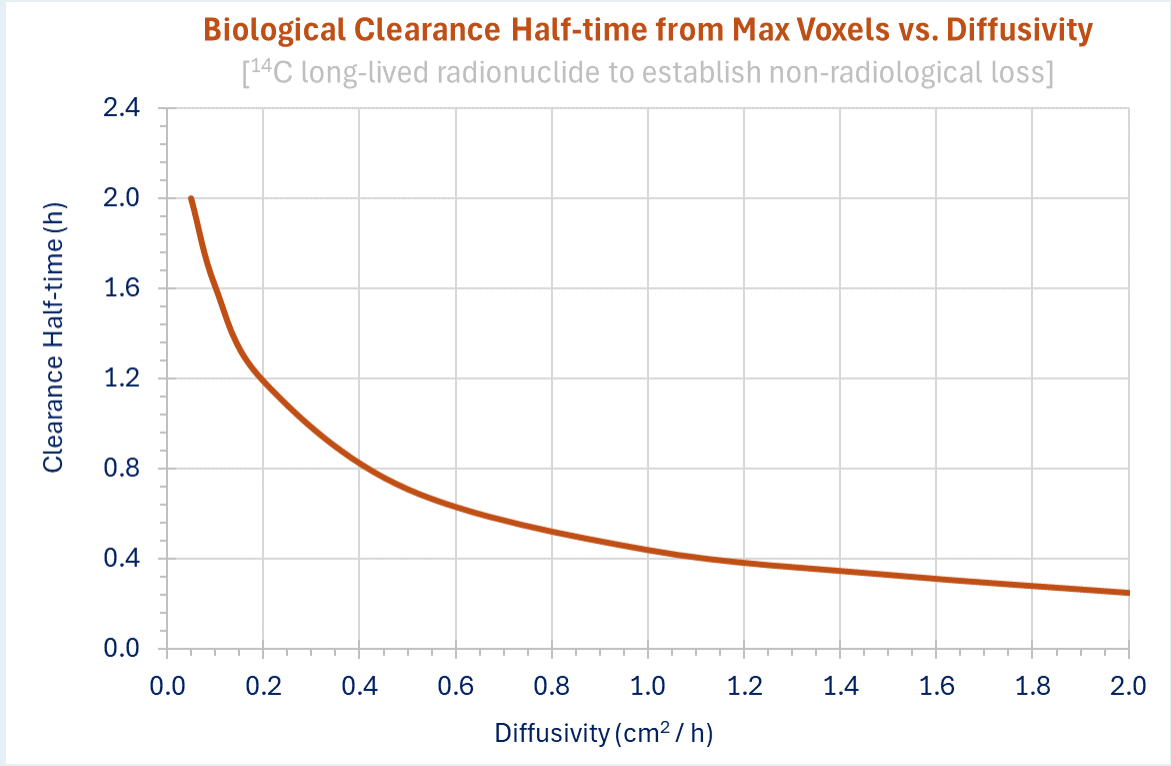
$$\left(\frac{\ln 2}{3600\ \frac{s}{h}}\right)\left(\frac{0.471\ Gy}{0.000351\ Gy\ s^{-1}}\right)$$

Clearance Half-time from Max Voxels Modeled with Diffusivity

(Voxel Side Length = Effective Thickness = 8 mm for this demonstration)





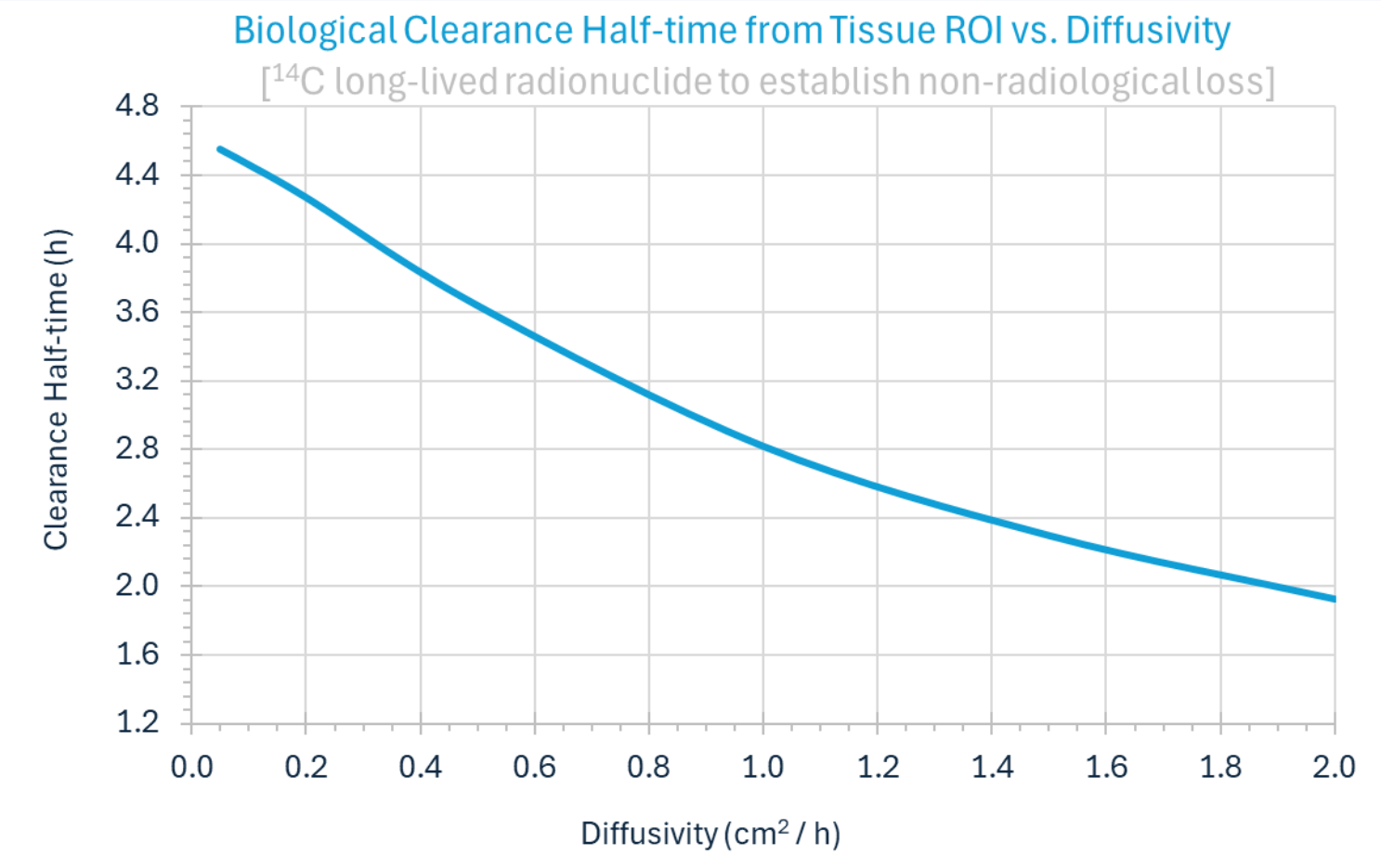


SPECIAL USE CASE for ExtravDose relates clearance half-time to dose rate at extravasation site

- Applied to Maximum Voxels
- Activity uniformly distributed within a voxel
- Radioactivity considered "lost" when it provides no max voxel dose
- Advanced cases for volumes > Maximum Voxels not covered here

Clearance Half-time from Tissue ROI Modeled with Diffusivity

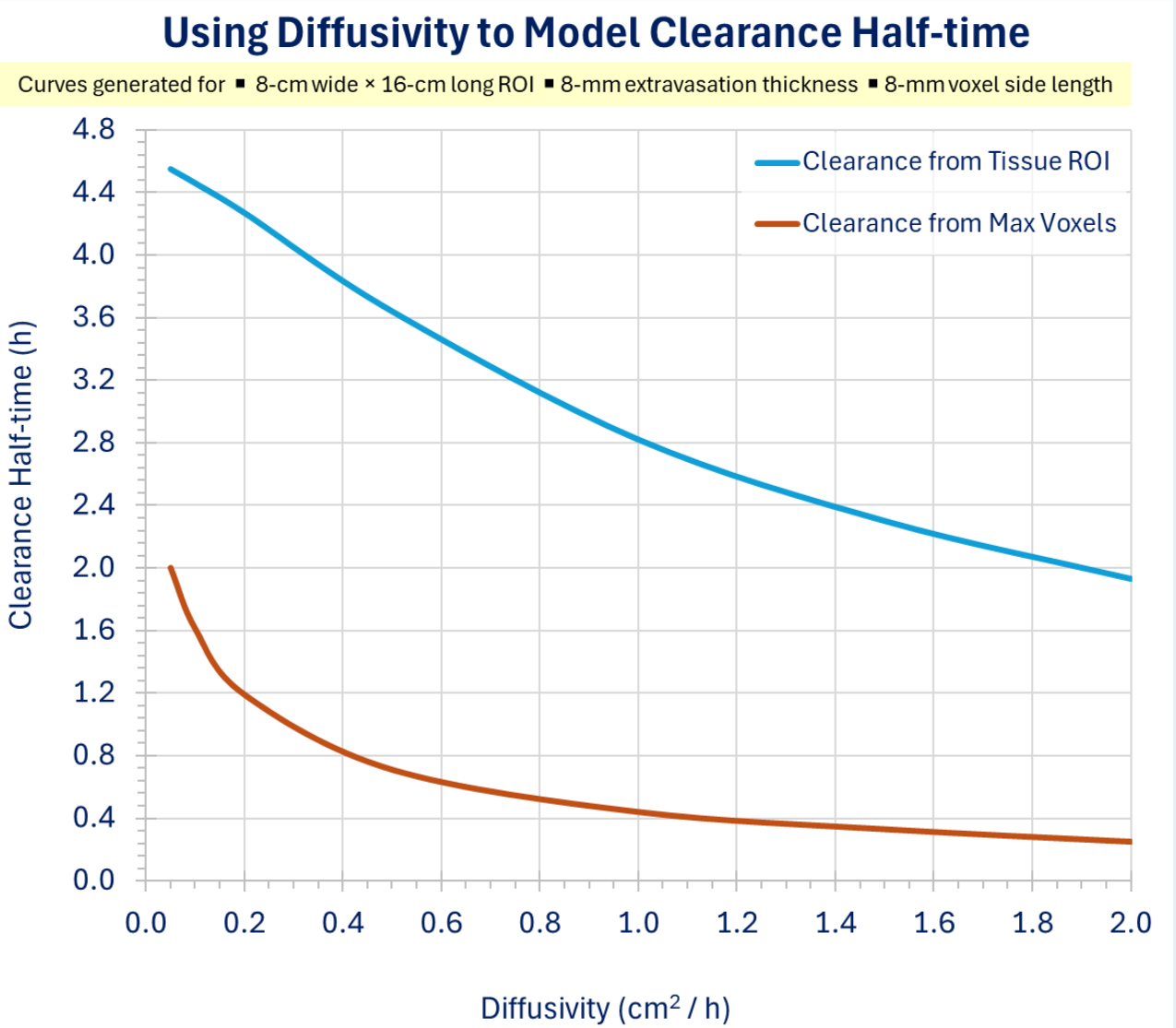
(Voxel Side Length = Effective Thickness = 8 mm for this demonstration)



SPECIAL USE CASE for ExtravDose develops clearance half-time as a function of diffusivity

- **Applied to surrounding Tissue ROI**
- **Radioactivity considered "lost" from ROI when it no longer contributes Dose to ROI**
- **Advanced cases for volumes < Tissue ROI not covered here**

Different Clearance Rates from Tissue ROI & Max Voxels



Illustrative examples of biological clearance rates established for long-lived ^{14}C with negligible radioactive decay loss

- **Allows ExtravDose to replicate effective half-live behavior**
- **Users convert effective half-life (*approximated from clinical measurements*) into biological clearance half-time, T_b**
- **Users enter Diffusivity input value consistent with T_b to perform special-use-case calculations with ExtravDose**

Demonstrated for small & large tissue volumes

Diffusivity curves (left) were established for

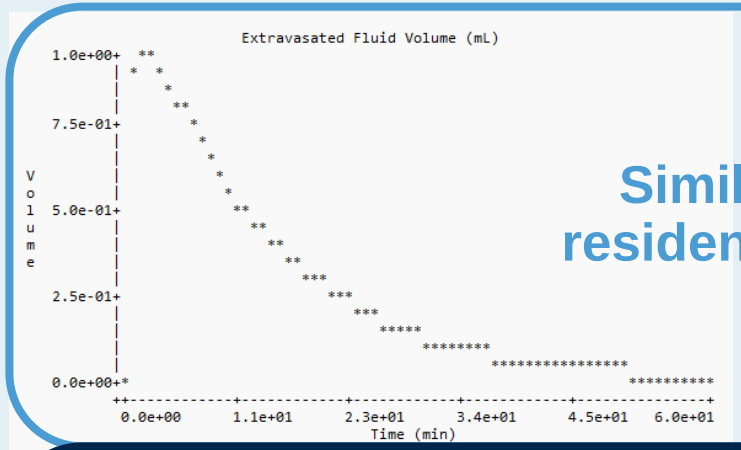
- **8-cm wide & 16-cm long ROI**
- **8-mm extravasation thickness**
- **8-mm voxel size**

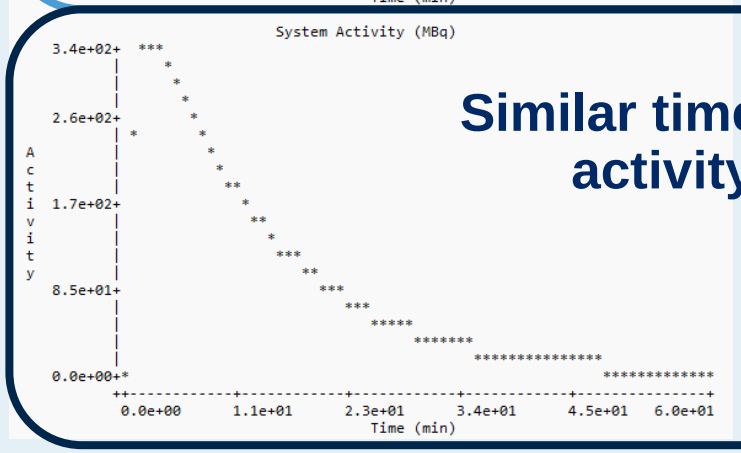
Recompute curves for other dimensions & input parameters

Troubleshooting: How to Detect Errors

Look for result anomalies in ExtravDose reports

Simulation 1

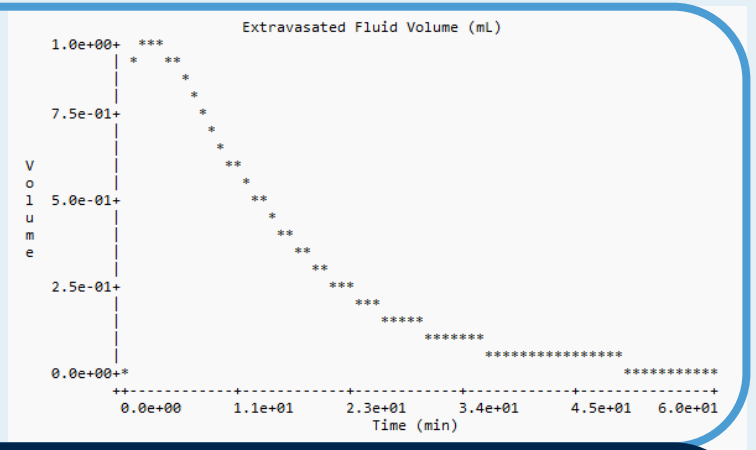


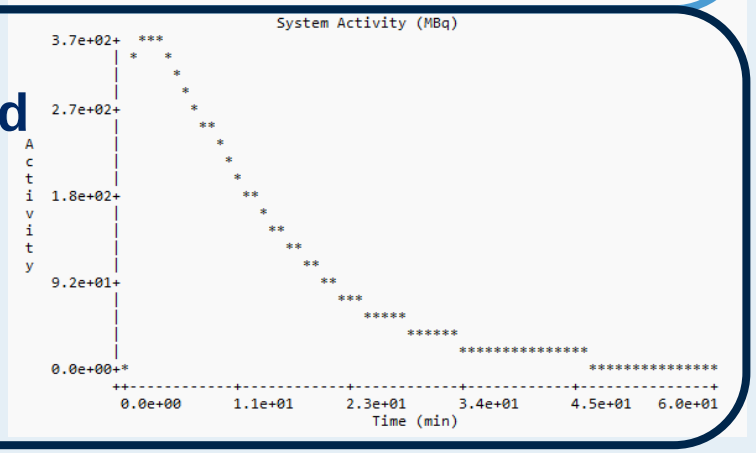


Similar fluid residence in ROI

Similar time-integrated activity in ROI

Simulation 2





Two simulations

Same ROI volume for 1-min ^{18}F injection with differences in flow & voxel parameters yield

- Very similar activity concentrations over time
- Unexplained large difference in dose results

```
**********************************************************************************
Outputs
**********************************************************************************
                        Max Voxel Dose:      2.14e-01        Gy
                   Max Voxel Dose Rate:      4.29e-04        Gy/s
          Time to Max Voxel Dose Rate:      1.70e+00        min
    ROI Exceeding Dose Threshold:           0.0             %
                        Dose to ROI:      5.74e-02        Gy
                      Region Volume:      26.244          cm³
```

```
**********************************************************************************
Outputs
**********************************************************************************
                        Max Voxel Dose:      2.16e+00        Gy
                   Max Voxel Dose Rate:      4.45e-03        Gy/s
          Time to Max Voxel Dose Rate:      1.0             min
    ROI Exceeding Dose Threshold:           1.11e+01        %
                        Dose to ROI:      4.66e-01        Gy
                      Region Volume:      26.244          cm³
```

Unexpected order of magnitude differences in dose results

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

Open feedback