UVAHealth

Automated Tools for Shielding Design

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AAPM Annual Meeting 2020

Outline

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- Introduction
- Shielding concepts
- Excel spreadsheet
- Xraybarr
- RadShield
- Future work

Shielding calculations

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- Unshielded air kerma at calculation point
- Transmission Factor
- Barrier thickness

- Shielding is formulaic and repetitive
- Underlying distributions are complicated

Distributions

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- Layer 1: energy spectrum for each kVp
- Layer 2: multiple kVp's used in x-ray exam room
- Layer 3: leakage, scatter, primary, isotopes
- Simplified: Transmission curves for surveyed clinical workloads

Multiple distributions

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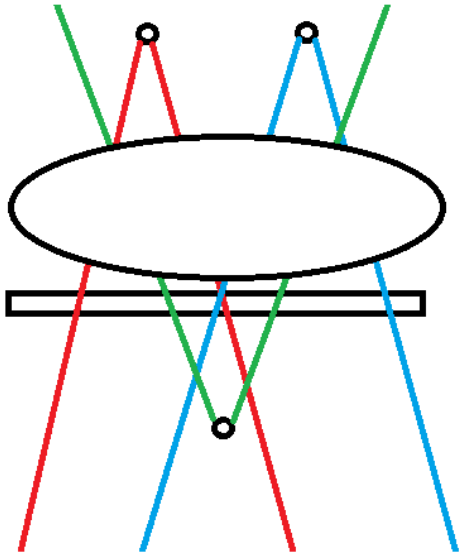
- Multiple workload distributions in the same room
  - NCRP 147 example 5.4.2 : Primary floor barrier in R&F Room
- Assumes same workload distribution
- Even so, still no closed form solution
  - Xpre
- Solve iteratively to get 68 mm concrete



Red: Rad exams only

Blue: Rad used with fluoro exam

Green: Fluoro only

Thickness calculation

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- Guess and test
- Linear search vs binary search

- $[0,1,3,5,19,26,27,31,32,37,38,42,51,56,58,60,67,75,83,90,99,100]$

- Binary search is fastest way to find value in sorted array

Binary Search

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Goal: $K_{tr} = \frac{P}{T} = \sum_{i=0}^{N} K_u[i]B[i]$

Units: $\frac{mGy}{wk}$

This is the maximum allowable weekly air kerma permitted

Method:

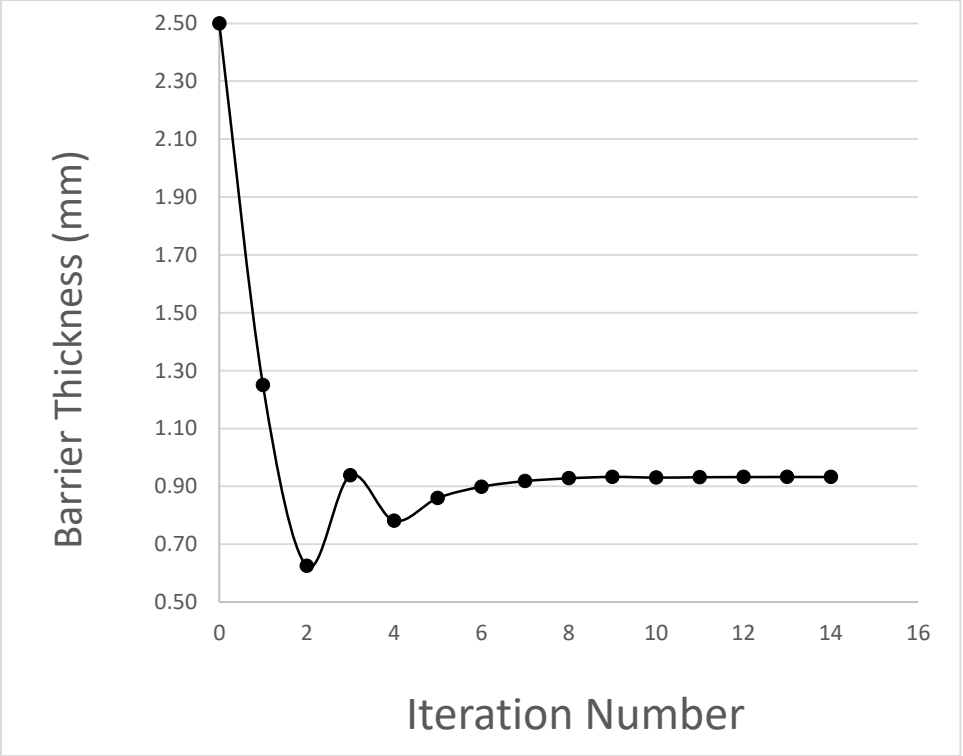
Guess a value for x

See how close it gets us to $\frac{P}{T}$

If $K_{tr} < \frac{P}{T}$, trim some off

If $K_{tr} > \frac{P}{T}$, put more back on

Stop when $K_{tr} = \frac{P}{T}$ to within an error ε



Binary Search

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Defining boundaries

$$x_{est} \approx x_1 + (x_2 - x_1) \frac{\ln\left(\frac{P/T}{D_1}\right)}{\ln\left(\frac{D_2}{D_1}\right)} .$$

- Simple starting points: 0 and 50 mm Pb

  Slow and less elegant

- Better: consider two test thicknesses for which transmitted air kerma is above and below P/T

- Jump closer to correct value on the third calculation

Excel Spreadsheet

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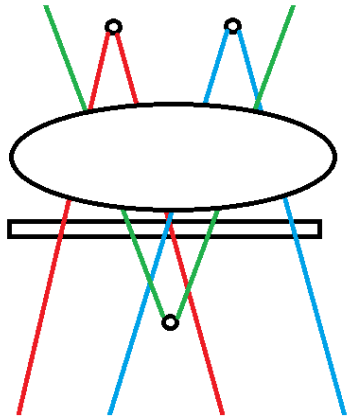
- Macro enabled workbook – visual basic
- Work NCRP example as test



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Excel Binary Search

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P & T | Pulldown Menus | Num patients, direction | Distance | Results

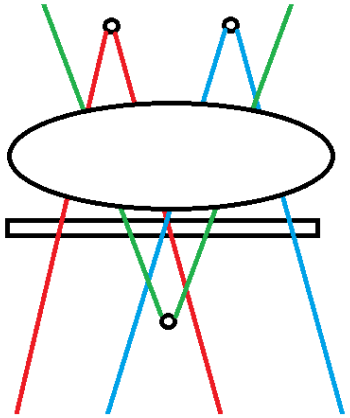
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Design G	Occu	Sources	Modality		Workload		N patients		Direction		Preshielding		Use F		K at 1m per Pt		Dist		K at CP		X (mm)		Ktr	
2	0.02	1	1	Rad		Rad Room (floor and other barriers)		60		Pri		bucky		1		5.2		4.1		18.56038073		Pb	0.927734		0.019978
3			2	Rad		Rad Tube (R&F Room)		20		Pri		bucky		1		5.9		4.1		7.019631172		Conc	68.35938		0.019928
4			3	Fluoro		Fluoroscopy Tube (R&F Room)		20		FBS		none				0.44		3		0.977777778		Gyp	208.252		0.019941
5			4	Fluoro		Fluoroscopy Tube (R&F Room)		20		L		none				0.012		2.4		0.041666667		Steel	8.209229		0.019921
6																						Glass	77.05688		0.019935
7																						Wood	556.1113		0.019933
8																									
9												Calculate													
10																									

- Reference other sheets for K, fitting parameter lookups
- Keep adjusting x until $K_{tr} < \frac{P}{T}$ and $\left|K_{tr} - \frac{P}{T}\right| < 10^{-4}$

$$K_{tr} = \frac{P}{T} = \sum_{i=0}^{N} K_u[i]B(x)[i]$$

- Press calculate to do binary search on thickness

NCRP 147 Example 5.4.2



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Shared Control Room

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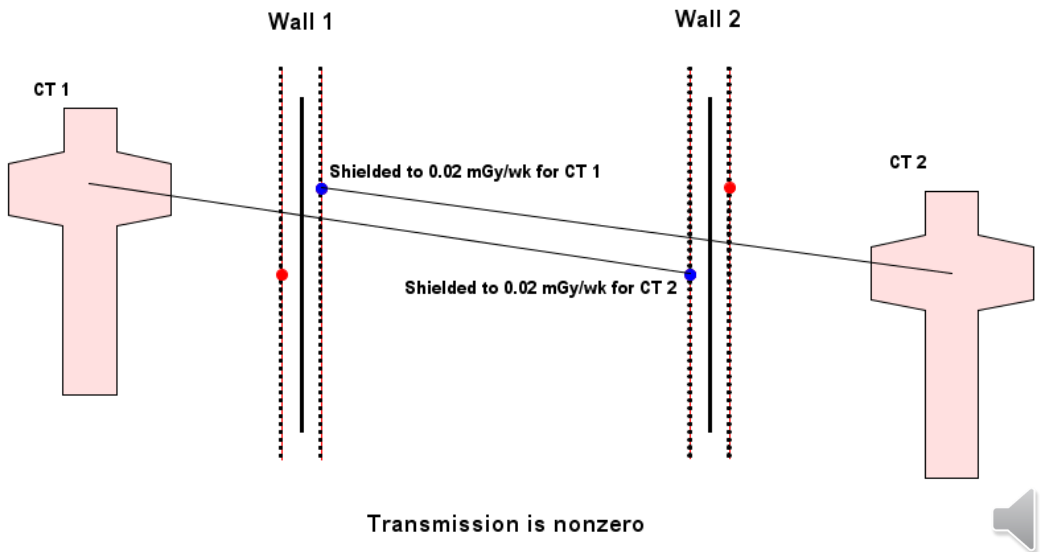
Multiple Room Transmission

For one room:

One unique thickness exists such that $K_{tr} = \frac{P}{T}$

Transmitted kerma and transmission: $K_{tr} = \sum_{i=0}^{N} K_u[i]B(x)[i]$, $B = \left[e^{\alpha\gamma x}\left(1+\frac{\beta}{\alpha}\right) - \frac{\beta}{\alpha}\right]^{-\frac{1}{\gamma}}$ were functions of one variable

Infinite solutions



Shared Control Room

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Strategies

- Shield to $\frac{P}{2T}$, sum of $K_{tr} = \frac{P}{T}$
- Round one barrier to nearest 1/32” Pb and solve for other barrier with new dose constraint
- Solve to minimize barrier material cost

PShield: An exact three-dimensional numerical solution for determining optimal shielding designs for PET/CT facilities

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XRAYBARR

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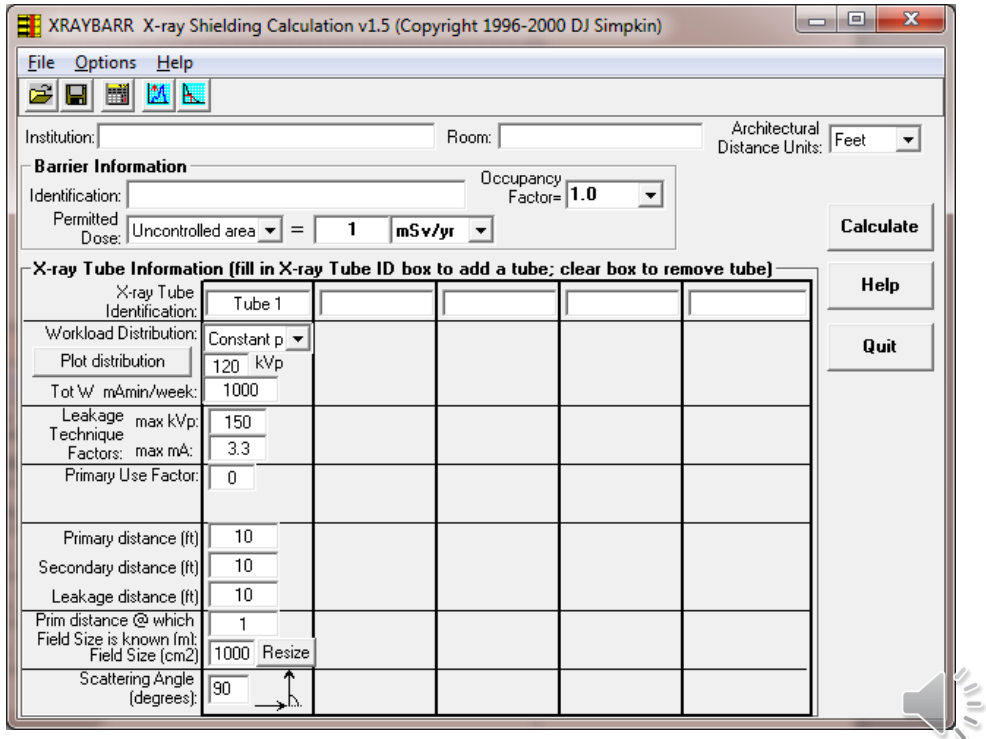
- Written by DJ Simpkin – investigative use only
- Enter tube info and distances
- Custom workload distributions
- In depth look at transmission



XRAYBARR

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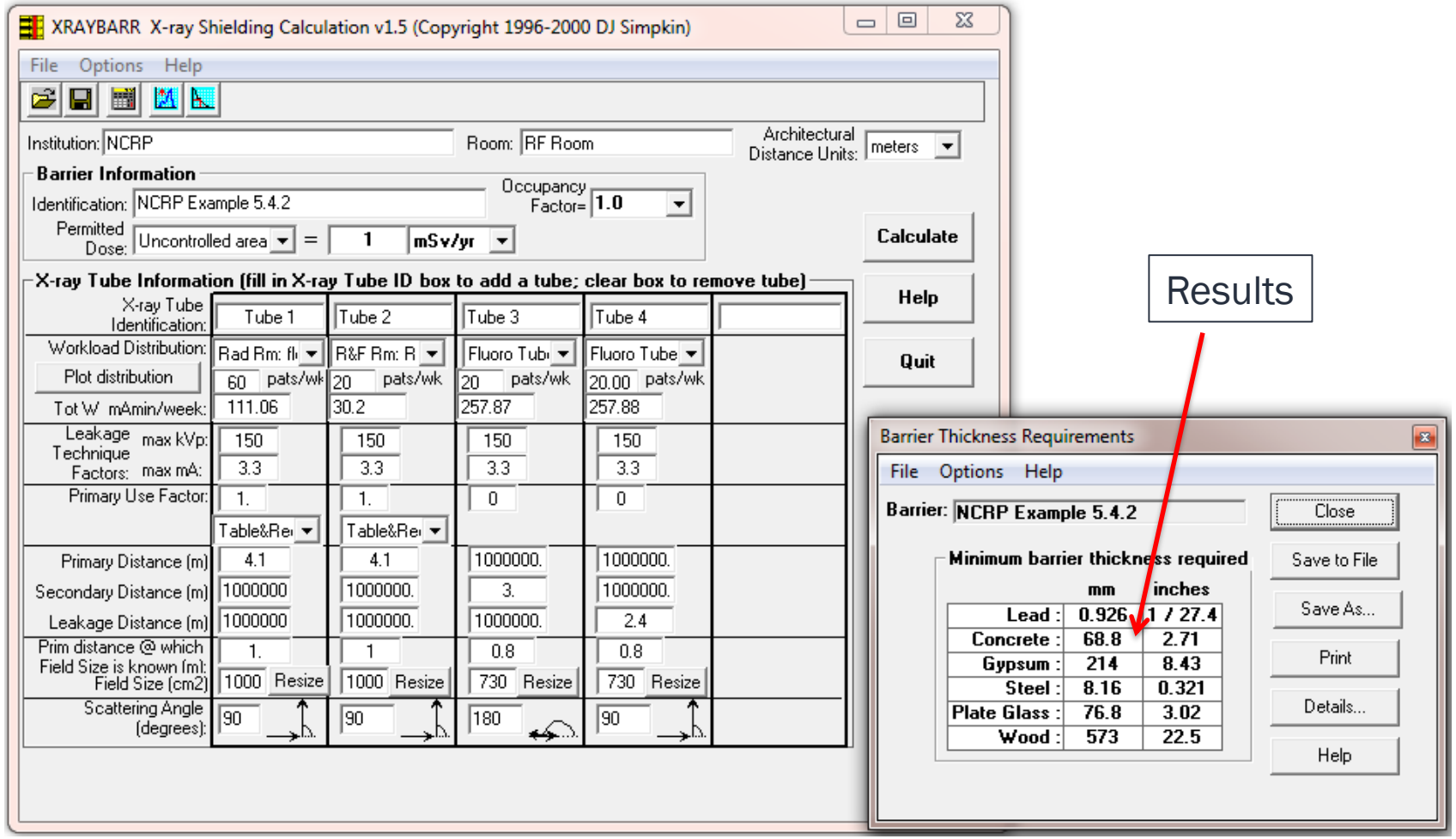
Tube columns

Workload Distr

Distances

Scatter Dir

Results



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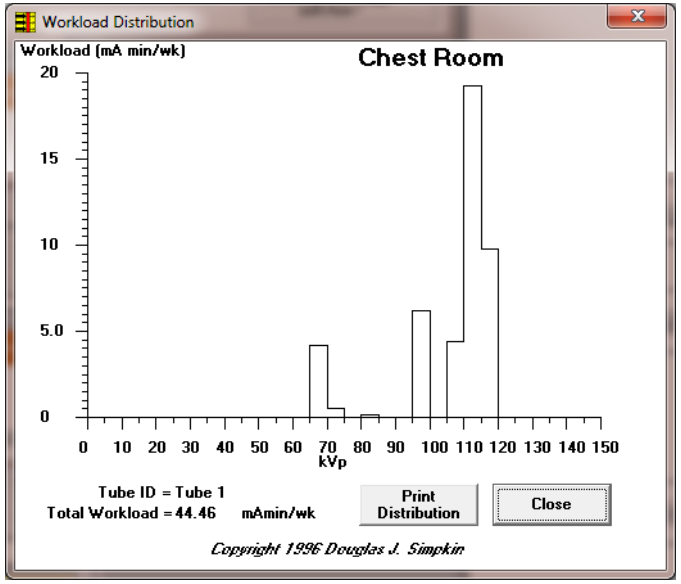
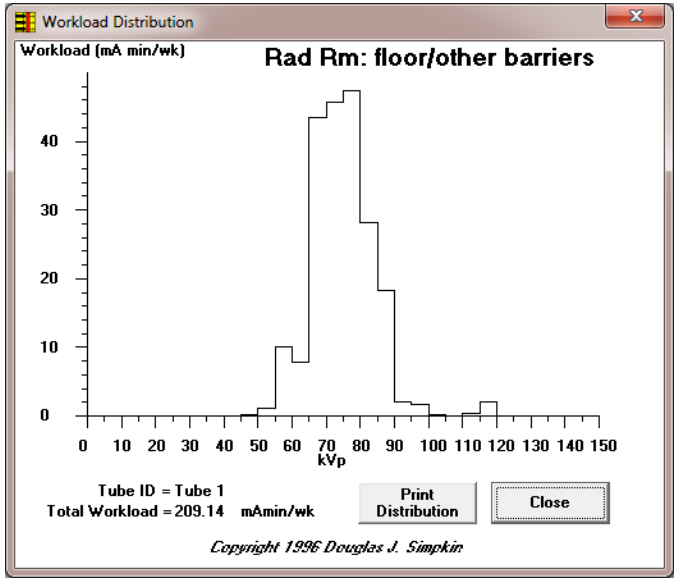
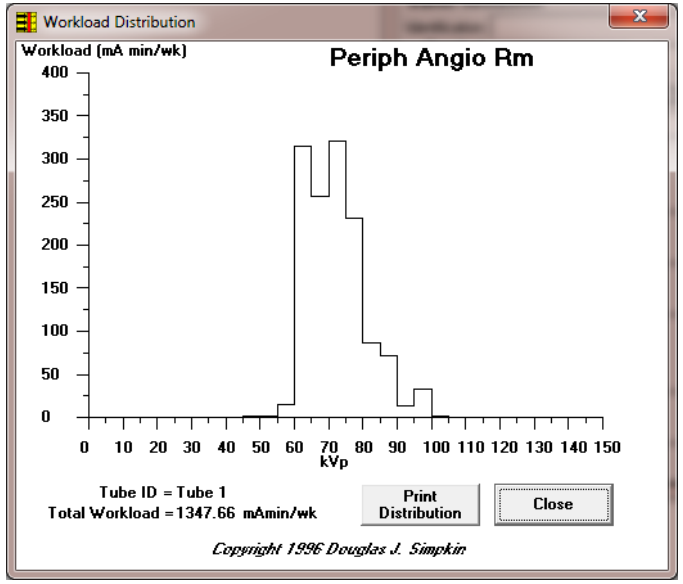


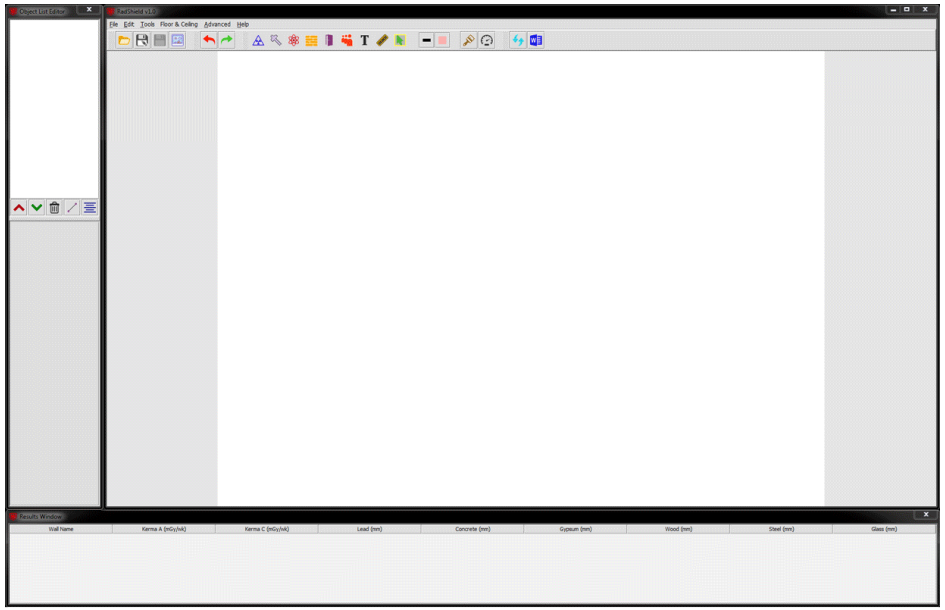


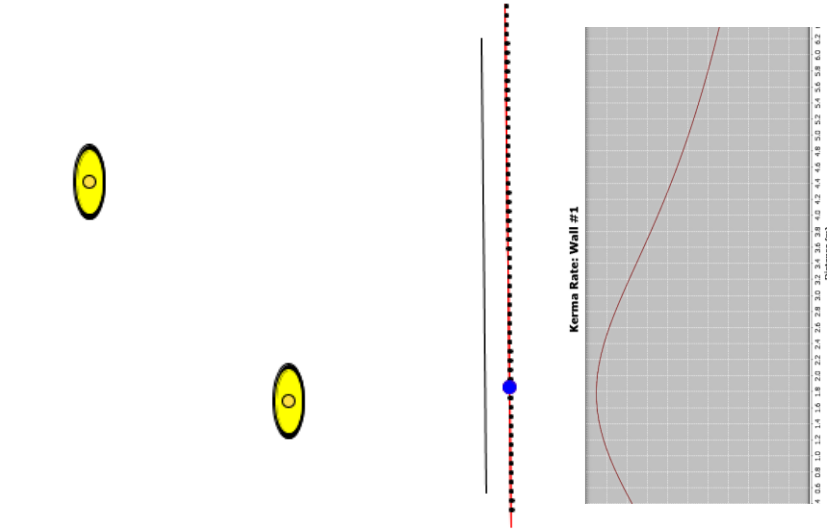


- Check distributions, see if applicable
- Possibly investigate your institution's workload distribution
- Dose tracking software collects rad, fluoro, IR exams

RadShield

- Java software www.radshield.org
- Shielding on scaled floor plan
- Calculates *K, B, x* at many points
  - Beyond barriers
  - Nonadjacent rooms
- Max thickness points





RadShield

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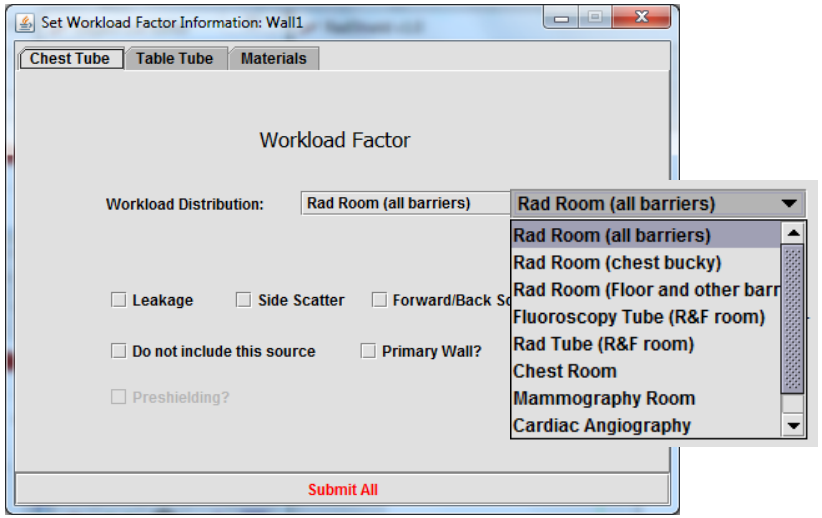
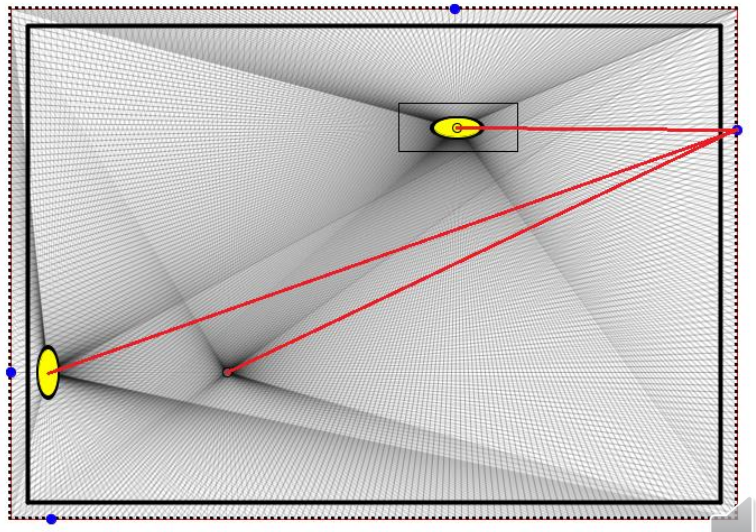
- Data entered follows NCRP 147 and TG 108
  - Checkboxes, pulldown menus
- Distances measured automatically
- Thicknesses found using binary search
- Max value for each barrier in results window





RadShield NCRP

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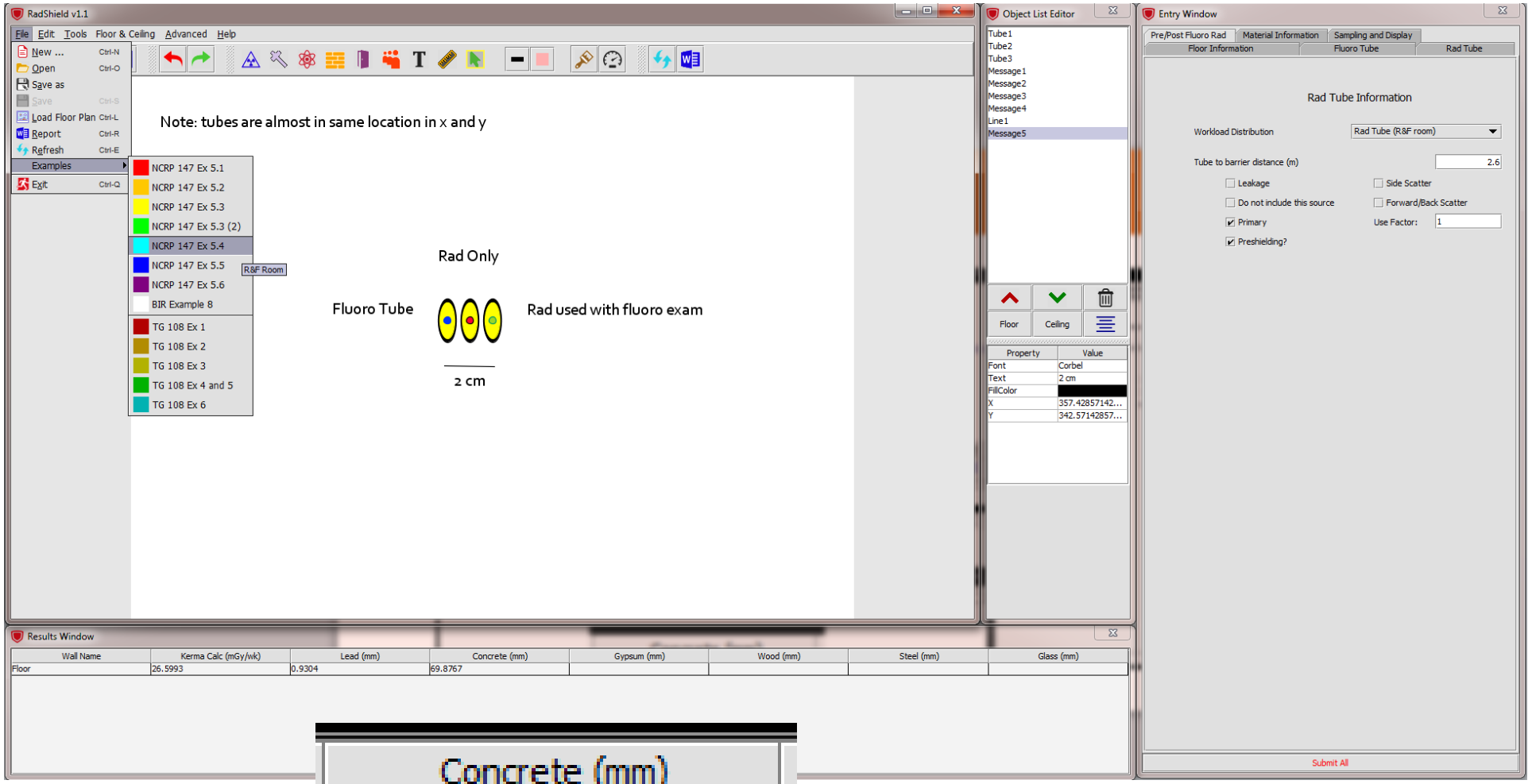

Isodose Maps

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- Approximately inverse square fall off

- **Method 1**
  - Interpolate between isodose curves
  - Inverse square from closest curve
- **Method 2**
  - Fit points to an equation (power law)

Given a function of the form

$$y = A\,x^{B},$$

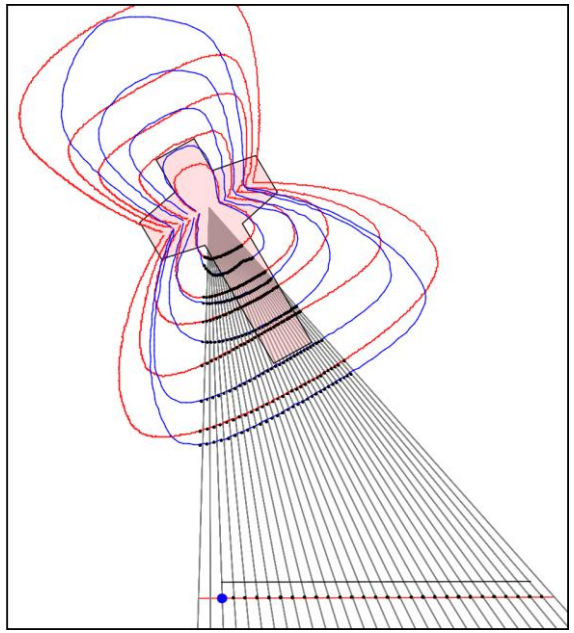
least squares fitting gives the coefficients as

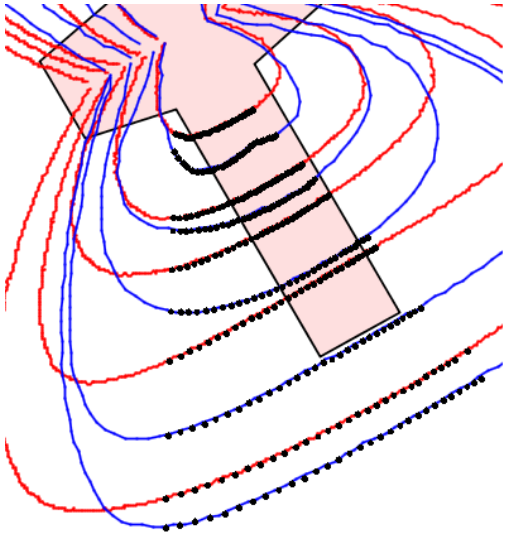
$$b = \frac{n\sum_{i=1}^{n}(\ln x_i \ln y_i) - \sum_{i=1}^{n}(\ln x_i)\sum_{i=1}^{n}(\ln y_i)}{n\sum_{i=1}^{n}(\ln x_i)^2 - \left(\sum_{i=1}^{n}\ln x_i\right)^2}$$

$$a = \frac{\sum_{i=1}^{n}(\ln y_i) - b\sum_{i=1}^{n}(\ln x_i)}{n},$$

where $B \equiv b$ and $A \equiv e^{a}$.

Red: head scans
Blue: body scans





x = distance from isocenter to int point
y = isodose curve value

Isodose Maps

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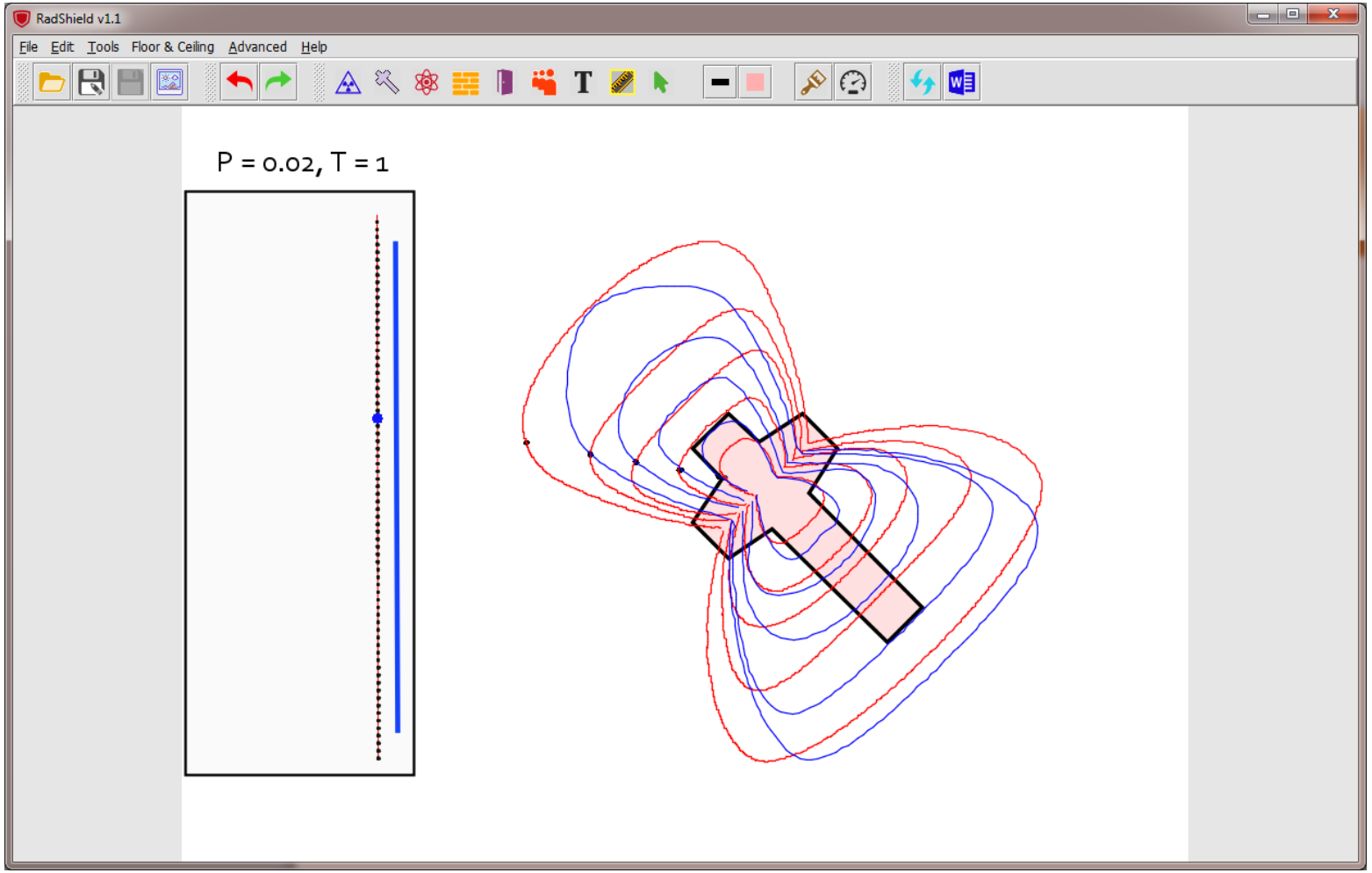

Future Work

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- Multiple material transmission
  - Steel deck + concrete
- Updated workloads for special procedures
  - IR labs with RDSR irradiation event data
- Thank you!