Automated Tools for Shielding Design

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• Introduction
• Shielding concepts
• Excel spreadsheet
• Xraybarr
• RadShield
• Future work
Shielding calculations

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

• Shielding is formulaic and repetitive
• Underlying distributions are complicated
• 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

- 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
Thickness calculation

- 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
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 \( \epsilon \)
Binary Search

Defining boundaries

- 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

\[ x_{ex} \approx x_1 + \left( x_2 - x_1 \right) \frac{\ln \left( \frac{P/T}{D_1} \right)}{\ln \left( \frac{D_2}{D_1} \right)} \]
• Macro enabled workbook – visual basic

• Work NCRP example as test
- 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

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**NCRP 147 Example 5.4.2**

Red: Rad exams only

Blue: Rad used with fluoro exam

Green: Fluoro only
Shared Control Room

Multiple Room Transmission

For one room:

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

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

Infinite solutions
Shared Control Room

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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• Written by DJ Simpkin – investigative use only

• Enter tube info and distances

• Custom workload distributions

• In depth look at transmission
XRAYBARR

Tube columns

Workload Distr

Distances

Scatter Dir

Results
• Check distributions, see if applicable

• Possibly investigate your institution’s workload distribution

• Dose tracking software collects rad, fluoro, IR exams
• Java software [www.radshield.org](http://www.radshield.org)

• Shielding on scaled floor plan

• Calculates $K$, $B$, $x$ at many points
  – Beyond barriers
  – Nonadjacent rooms

• Max thickness points
RadShield

• 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
Note: tubes are almost in same location in x and y

Fluoro Tube
Rad Only
Rad used with fluoro exam

2 cm

Concrete (mm)
69.8767
Isodose Maps

- 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

\[ b = \frac{\sum_{i=1}^{n} (\ln x_i \ln y_i) - \sum_{i=1}^{n} (\ln x_i) \sum_{i=1}^{n} (\ln y_i)}{\sum_{i=1}^{n} (\ln x_i)^2 - (\sum_{i=1}^{n} \ln x_i)^2}, \]

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

where \( B \equiv b \) and \( A \equiv e^a \).

Red: head scans
Blue: body scans

\[ x = \text{distance from isocenter to int point} \]
\[ y = \text{isodose curve value} \]
Isodose Maps

P = 0.02, T = 1
Future Work

• Multiple material transmission
  – Steel deck + concrete

• Updated workloads for special procedures
  – IR labs with RDSR irradiation event data

• Thank you!