MCNP4C Photon Dose Calculations
Compared to Measurements

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OVERALL GOAL

Re-calculate neutron and photon dose rates for PWR fuel in dry storage.

CONFIGURATIONS
- canisters
- transfer casks
- bunkers (photons reported here)
Two PWRs
NUHOMS 24P Design
Focused on two recent canisters
Had radiation surveys
Figure 1.3-1
NUHOMS®-24P Dry Shielded Canister Assembly Components
SIMILAR (NAC) CANISTER
no shell
CASK TOP SECTION
BUNKERS
LOAD SEQUENCE

1. Canister Into Cask
2. Cask Into Spent Fuel Pool
3. 24 Assemblies Loaded Into the Canister
LOAD SEQUENCE (cont.)

4. Cask Hoisted to Cask Pit and washed
5. Canister Dried, Welded, Surveyed
6. Cask Closed and Surveyed
LOAD SEQUENCE (cont.)

7. Cask hoisted to truck
8. Truck driven to Bunker
LOAD SEQUENCE (cont.)

9. Canister Pushed into Bunker

10. Bunker Door Shut
SOURCE POWER
METHOD

ORIGEN2.1 (*historical reasons*)
Various axial burnups
Luksic flux factors for end–fitting+ Empirical adjustments
<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>metric tons fuel</td>
</tr>
<tr>
<td>21</td>
<td>assemblies</td>
</tr>
<tr>
<td>3</td>
<td>weaker</td>
</tr>
<tr>
<td>12</td>
<td>years decay</td>
</tr>
<tr>
<td>16</td>
<td>kW heat</td>
</tr>
<tr>
<td>4.2E16</td>
<td>photons/s</td>
</tr>
<tr>
<td>3.8E9</td>
<td>neutrons/s</td>
</tr>
<tr>
<td>Assembly</td>
<td>Burnup GWD/MTU</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>44.6</td>
</tr>
<tr>
<td>2</td>
<td>43.5</td>
</tr>
<tr>
<td>3</td>
<td>43.4</td>
</tr>
<tr>
<td>4</td>
<td>43.4</td>
</tr>
<tr>
<td>5</td>
<td>42.7</td>
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<tr>
<td>6</td>
<td>40.0</td>
</tr>
<tr>
<td>7</td>
<td>39.9</td>
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<tr>
<td>8</td>
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</tr>
<tr>
<td>9</td>
<td>39.9</td>
</tr>
<tr>
<td>10</td>
<td>39.8</td>
</tr>
<tr>
<td>11</td>
<td>39.4</td>
</tr>
<tr>
<td>12</td>
<td>39.3</td>
</tr>
<tr>
<td>13</td>
<td>39.1</td>
</tr>
<tr>
<td>14</td>
<td>38.3</td>
</tr>
<tr>
<td>15</td>
<td>38.2</td>
</tr>
<tr>
<td>16</td>
<td>38.1</td>
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<tr>
<td>17</td>
<td>37.6</td>
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<td>21</td>
<td>36.4</td>
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<tr>
<td>22</td>
<td>31.9</td>
</tr>
<tr>
<td>23</td>
<td>30.5</td>
</tr>
<tr>
<td>24</td>
<td>27.5</td>
</tr>
<tr>
<td>ave</td>
<td>38.4</td>
</tr>
<tr>
<td>std err %</td>
<td>10</td>
</tr>
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</table>
DOSE CALCULATION SUMMARY

MCNP4C – four models
Homogenized fuel
Eleven axial source regions
Basket detail
Concrete re–bar/aggregate
R0–2 energy response
BUNKER MODEL

Note
Detectors A through G
BUNKER MODEL VIEW
by MORITZ

(Ken Van Riper)
BUNKER MODEL

cross section
# RESULTS SUMMARY

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Range C/M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base Model</td>
<td>1.8 – 17.5</td>
</tr>
<tr>
<td>2</td>
<td>+basket and rebar</td>
<td>1.8 – 9.5</td>
</tr>
<tr>
<td>3</td>
<td>+axial burn-up</td>
<td>1.6 – 3.3</td>
</tr>
<tr>
<td>4</td>
<td>+Eberline RO–2 response</td>
<td>0.96 – 2.2</td>
</tr>
</tbody>
</table>
CONCLUSION

ORIGEN2.1 and MCNP4C can achieve C/M of 0.96 to 2.2.
CALCULATION CHALLENGES

Source Nuclides
Cs137 Axial Dist.
Co60 End Fittings
Cm244 Fuel

Source Depth
70 cm (18 mfp = infinite)

Shield Depth
90 cm concrete (18 mfp)
11 cm lead (11 mfp)

Vent Streaming
3–dimensional
energy shift from 1 to 0.1 MeV
CALCULATIONAL OPTIONS

1. Parametrics (QAD and GGG)
   Not made for neutrons
   Not made for penetrations

2. Discrete Ordinates (DORT)
   Quadrature sets require user attention
   Not made for 3D
CALCULATIONAL OPTIONS

3. Monte Carlo – Detailed Geometry
   Pin or Assembly detail
   Not required – 1 mfp = 4 cm

4. Monte Carlo – Homogenized Geometry
   Measurements
   Increase Detail Until Desired C/M
   C/M = Calculated/Measured Ratios
fuel

assemblies

MODELING DETAIL

pins
MCNP4C Models – Increasing Detail

Model 1 – Base Model

Model 2 – added re-bar and basket

Model 3 – added axial detail

Model 4 – added detector energy response
MCNP MODEL 1

Three axial source regions:
   Lower end fitting
   Active fuel
   Upper end fitting
Concrete density 2.4 g/cc
Dose rates in mrem/h (ANSI 6.1.1.–77)

RESULTS
   2 < C/M < 18
MCNP MODEL 2

Added canister basket
Added multiple concrete regions
  re–bar
  empirical aggregate
  \[2.44 < \text{density} < 2.52 \text{ g/cc}\]

RESULTS
\[2 < \frac{C}{M} < 10\]
MODEL 2
(showing re–bar)
# MODEL 2
*Effect of Re–bar*

<table>
<thead>
<tr>
<th>Concrete thickness (cm)</th>
<th>mR/h measured</th>
<th>C/M no rebar</th>
<th>C/M with rebar</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>425</td>
<td>3.5</td>
<td>1.6</td>
</tr>
<tr>
<td>91</td>
<td>25</td>
<td>3.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>
MODEL 2
(Axial Sensitivity of Detectors E and G)
MODEL 3

Added Axial Source Refinement
Active Fuel – 7 Zones
Upper End Fitting
  3 Zones
Luksic (PNL–6906) Flux Factors
Springs reduced 3x (empirical data)

RESULTS
1.6 < C/M < 3.3
MODEL 3
Upper End Fitting Springs
MODEL 3
Canister
MODEL 3
Axial Photon Distribution

Fraction of Ave

1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03

cm above bottom of active fuel
MODEL 4
Eberline RO–2 Energy Response
MODEL 4

Added Eberline RO–2 Energy Response
Rem vs Roentgen
(Calibrated within 10%)
Calculated Roentgen
Corrected from 40 to 70 Degrees F

RESULTS
.96 < C/M < 2.2
Rem = 2 x Roentgen at 80 KeV
### PHOTON RESULTS BY MODEL

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Photon C/M by Detector and Model

![Graph showing Photon C/M by Detector and Model](image_url)
## % CONTRIBUTION
## BY PHOTON SOURCE

<table>
<thead>
<tr>
<th>Detector</th>
<th>Lower EF</th>
<th>Fuel</th>
<th>Upper EF</th>
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<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>96</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>83</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>82</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>14</td>
<td>84</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>83</td>
<td>12</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>69</td>
<td>30</td>
</tr>
<tr>
<td>G</td>
<td>0</td>
<td>67</td>
<td>33</td>
</tr>
</tbody>
</table>
# Neutron C/M

<table>
<thead>
<tr>
<th>Location</th>
<th>C/M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Vents</td>
<td>0.2 to 0.3</td>
</tr>
<tr>
<td>Contact Bottom DSC</td>
<td>0.7 to 0.8</td>
</tr>
<tr>
<td>Through 2 Ft Concrete</td>
<td>1.6</td>
</tr>
</tbody>
</table>
CONCLUSIONS

ORIGEN2.1 and MCNP4C can model photons from bunkerized fuel within factor of two. We achieved this with:

- iteration against measurements
- homogenized assemblies
- eleven axial source zones
- end-fitting data beyond Luksic basket and discs
- multiple re-bar zones
- aggregate detail for concrete
- exposure energy response for detectors
NEXT TIME

Accelerate – Some runs took 3000 minutes
  Partition at Canister Surface
  Run Sources Separately
Balance Model
  Better Cell Splitting
  More regions in fuel
  Weight Windows
ORIGEN–S (more accurate energies and transuranics)
Characterize Co–60 by Measurement in Fuel Pool
Fuel Placement
MCNP4C Photon Dose Calculations Compared to Measurements

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