Review of Environmental Analysis of the Uranium Fuel Cycle

July 28, 2010
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SNL performed a review of:

- Title 40 CFR Part 190
- EPA’s environmental analysis of nuclear fuel reprocessing (EPA 1 520-9-73-003-D)

Part of this review involved:

- Understanding EPA’s treatment of doses and health effects
- Verification of the doses and health effects
- Comparison with current methods
Overview

- EPA methods
- Verification of EPA results
- Independent assessment of I-129 doses
- Summary
EPA Methods for Estimating Doses

- **Standard methods for estimating atmospheric transport and dispersion**
  - Dose to maximally exposed individual (MEI) at site boundary (3 km)
  - Regional (80-km circular area) population dose
  - US population beyond the 80-km zone
  - Worldwide population

- **Five isotopes**
  - H-3 (12 years)
  - Kr-85 (11 years)
  - I-129 (16 million years)
  - I-131 (8 days)
  - Actinides (18 to 2 million years)

- **Cooling time chosen to be 150 days**
EPA Methods for Estimating Doses

- **Simplifying assumptions for dose pathways**
  - Exposure to H-3 by ingestion of water
  - Exposure to Kr-85 by immersion
  - Exposure to I-129 and I-131 by ingestion of milk
  - Exposure to actinides by inhalation of resuspended aerosols

- **Simplifying assumptions for worldwide dose estimates**
  - Uniform dilution of Kr-85 throughout atmosphere
  - Dilution of H-3 in circulating waters of northern hemisphere

- **Assumptions for decontamination factors**
  - No decontamination (DF = 1) for H-3 and Kr-85
  - DF = 1000 for iodines
  - DF = $10^9$ for actinides
Verification of EPA’s Dose Values

<table>
<thead>
<tr>
<th>Radio-nuclide</th>
<th>Organ</th>
<th>MEI</th>
<th>Regional</th>
<th>US</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mrem/yr</td>
<td>µrem/yr</td>
<td>person-rem/yr</td>
<td>µrem/yr</td>
</tr>
<tr>
<td>Kr-85</td>
<td>Effective</td>
<td>0.37</td>
<td>10</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Lung</td>
<td>0.75</td>
<td>21</td>
<td>47</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>12</td>
<td>350</td>
<td>790</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Gonads</td>
<td>0.44</td>
<td>12</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>H-3</td>
<td>Effective</td>
<td>3.2</td>
<td>89</td>
<td>200</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Gonads</td>
<td>3.2</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>I-129</td>
<td>Thyroid Infant</td>
<td>1.4</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thyroid Adult</td>
<td>0.4</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SNL Comments on EPA’s Dose Values

- Doses to MEI and region
  - Atmospheric transport estimates are reasonable
  - Doses from ingestion of I-129 appear to be very conservative (more later)

- US doses
  - Atmospheric transport estimates are reasonable
  - Minor conservatisms

- Worldwide doses
  - Doses from ingestion of H-3 appear to be conservative because dilution is into a small fraction (1.8%) of surface waters
EPA Methods for Estimating Health Effects

- Health effects are assumed to be proportional to population doses
- Health effects are estimated for 40 years of plant operation
- SNL confirmed EPA health effect predictions to within 3%
### Verification of EPA’s Health Effect Values

<table>
<thead>
<tr>
<th>Radio-nuclide</th>
<th>Organ</th>
<th>Estimated Health Effects from 40 Years of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 km</td>
<td>Regional</td>
</tr>
<tr>
<td>Kr-85</td>
<td>Effective</td>
<td>6.0E-6</td>
</tr>
<tr>
<td></td>
<td>Lung</td>
<td>1.5E-6</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>1.5E-6</td>
</tr>
<tr>
<td></td>
<td>Gonads</td>
<td>5.2E-6</td>
</tr>
<tr>
<td>H-3</td>
<td>Effective</td>
<td>5.2E-5</td>
</tr>
<tr>
<td></td>
<td>Gonads</td>
<td>3.9E-5</td>
</tr>
<tr>
<td>I-129</td>
<td>Thyroid Infant</td>
<td>8.6E-6</td>
</tr>
<tr>
<td></td>
<td>Thyroid Adult</td>
<td>8.7E-8</td>
</tr>
</tbody>
</table>
Motivation for an Independent Evaluation of Iodine-129 Doses Using MACCS2

- Iodine-129 appeared to be the limiting isotope in terms of regulation
  - A DF of 1000 would be difficult to achieve
- Iodine-129 dose estimates in the EPA report seemed larger than expected
- Some of the assumptions associated with the food-chain pathway were difficult to reconstruct and evaluate
- Some of the assumptions seemed very conservative
Comparison of I-129 Ingestion Assumptions

**EPA assumptions**
- Annual release is continuous
- Exposure is by consumption of milk
  - 0.76 l/dy for infants
  - 0.5 l/dy for adults
- Deposition velocity is 0.5 cm/s
- I-129 in thyroid is based on lower than average level of stable iodine in environment
- Milk is produced where it is consumed
- No remediation or limits on ingestion doses are considered

**MACCS2 assumptions**
- Annual release occurs in 1 hr
- Exposure is by consumption of milk and other foodstuffs
  - Typical food basket
  - 0.27 l/dy milk for adults
- Deposition velocity is 0.5 cm/s
- I-129 in thyroid is based on metabolic model used in ICRP-72 and FGR-13
- Milk and other food are produced where they are consumed
- No remediation or limits on ingestion doses are treated
Averaging Over Annual Weather Data Is Equivalent to a Continuous, Annual Release

**Continuous Release (EPA)**
- Fraction of annual release travels in a direction (based on wind rose)

**1-Hour Release (MACCS2)**
- Entire annual release travels in a direction in a single weather trial
- Fraction of the weather trials travel in a direction (based on wind rose)
- Average is the same for any result that behaves linearly

\[
\text{Average} \left[ \begin{array}{c}
\text{↑} \\
\text{↓}
\end{array} \right] = \text{π}
\]
Other MACCS2 Assumptions

- Calculations based on recycling plant collocated with Sequoyah NPP
  - Weather data
  - Population (about 1 million within 80 km)
  - Other site information (30% of land used for farming, etc.)

- Standard choices for
  - Atmospheric transport and dispersion
  - Resuspension of deposited aerosols
  - Food chain parameters
### Food Basket Assumptions

- EPA analysis only considers doses from milk
- MACCS2 normally considers a typical food basket
  - Based on typical diet at the time of NUREG-1150

<table>
<thead>
<tr>
<th>Food Type</th>
<th>Consumption Rate (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EPA</td>
</tr>
<tr>
<td>Milk</td>
<td>188</td>
</tr>
<tr>
<td>Grains</td>
<td>69</td>
</tr>
<tr>
<td>Leafy Vegetables</td>
<td>11</td>
</tr>
<tr>
<td>Roots</td>
<td>26</td>
</tr>
<tr>
<td>Fruits</td>
<td>46</td>
</tr>
<tr>
<td>Legumes</td>
<td>26</td>
</tr>
<tr>
<td>Beef</td>
<td>59</td>
</tr>
<tr>
<td>Poultry</td>
<td>9</td>
</tr>
<tr>
<td>Other Meat</td>
<td>10</td>
</tr>
</tbody>
</table>
Population Dose Comparison

Table compares EPA and MACCS2 population doses assuming iodine DF = 1

Compared with the EPA analysis
  - Milk dose is a factor of 8 lower
  - Ingestion dose is a factor of 2.5 lower

<table>
<thead>
<tr>
<th>Dose Pathway</th>
<th>Annual Dose (Person-rem)</th>
<th>EPA</th>
<th>MACCS2 without Ingestion Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Effective</td>
<td>Thyroid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Effective</td>
<td>Thyroid</td>
</tr>
<tr>
<td>Direct Inhalation</td>
<td></td>
<td>9</td>
<td>179</td>
</tr>
<tr>
<td>Groundshine</td>
<td></td>
<td>36</td>
<td>42</td>
</tr>
<tr>
<td>Resuspension Inhalation</td>
<td></td>
<td>12</td>
<td>236</td>
</tr>
<tr>
<td>Ingestion</td>
<td>27000</td>
<td>562</td>
<td>11194</td>
</tr>
<tr>
<td>Milk</td>
<td>27000</td>
<td>194</td>
<td>3873</td>
</tr>
<tr>
<td>Grains</td>
<td></td>
<td>38</td>
<td>765</td>
</tr>
<tr>
<td>Leafy Vegetables</td>
<td></td>
<td>51</td>
<td>1026</td>
</tr>
<tr>
<td>Roots</td>
<td></td>
<td>50</td>
<td>1002</td>
</tr>
<tr>
<td>Fruits</td>
<td></td>
<td>74</td>
<td>1467</td>
</tr>
<tr>
<td>Legumes</td>
<td></td>
<td>42</td>
<td>842</td>
</tr>
<tr>
<td>Beef</td>
<td></td>
<td>111</td>
<td>2216</td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Other Meat</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Ingestion dominates the thyroid dose pathways

Milk comprises about one-third of the ingestion dose

Relative Contribution From Food Types

- Beef: 20%
- Legumes: 8%
- Fruits: 13%
- Roots: 9%
- Leafy Vegetables: 9%
- Grains: 7%
- Milk: 34%

Evaluation of Dose Pathways

- Ingestion dominates the thyroid dose pathways
- Milk comprises about one-third of the ingestion dose

Relative Contribution From Dose Pathways

- Ingestion: 96%
- Direct Inhalation: 1%
- Resuspension Inhalation: 2%
- Groundshine: 0%
- MACCS2 ingestion dose at site boundary
  - 140 mrem if food is grown at site boundary
  - 11 mrem if food is grown within 80 km

### Average Dose to Individuals

<table>
<thead>
<tr>
<th>Distance from Site (km)</th>
<th>Dose (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>140</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>

### Adult Thyroid Dose at Site Boundary

<table>
<thead>
<tr>
<th>Dose (mrem/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA</td>
</tr>
<tr>
<td>MACCS2 Direct Exposure</td>
</tr>
<tr>
<td>MACCS2 Local Ingestion</td>
</tr>
<tr>
<td>MACCS2 Average Ingestion</td>
</tr>
<tr>
<td>MACCS2 Dir. Exp. Plus Ave. Ing.</td>
</tr>
</tbody>
</table>
Sandia has reassessed and confirmed EPA analysis

Some EPA assumptions are conservative

EPA estimates of I-129 regional doses
  - Reasonable for population dose
  - Conservative at site boundary because food is assumed to be produced there

EPA restrictions on site boundary dose (25 mrem/yr) could be achieved with DF = 1 for I-129