Hazard Categorization for Tritium Facilities: Updates

40th Tritium Focus Group Meeting
Albuquerque, NM
October 23, 2018

Chandra Savage Marsden
Gas Transfer Systems Group
(Q-7)
DOE-STD-1027-92 defines Nuclear Facility Categories and therefore the graded regulatory approach for facilities.

- **Category 1**  Potential for significant **off-site** consequences

- **Category 2**  Potential for significant **on-site** consequences
  
  (1 rem @ 300 meters)

- **Category 3**  Potential for significant **localized** consequences
  
  (10 rem @ 30 meters)

- **Radiological**  (less than Category 3 consequences)

**All but Category 1 based on amounts of radionuclides in the**
Threshold Quantity (TQ) Calculation for Tritium

\[
TQ = \frac{Dose \ (rem)}{RF \cdot SA \cdot \chi/Q \cdot CEDE \cdot RR}
\]

TQ = Quantity of material used as threshold (grams)

Dose = 1 rem for Category 2, 10 rem for Category 3

RF = Release fraction (unitless)

SA = Specific activity of radionuclide released (Ci/g)

\[
\chi/Q = \frac{\chi}{Q}
\]

= Expression accounting for dilution of release at a point under given meteorological conditions (sec/m³) – different at 30 and 300 meters

CEDE = Committed effective dose equivalent for a given radionuclide (rem/Ci)

RR = Respiration rate (m³/sec)
<table>
<thead>
<tr>
<th>Source</th>
<th>Category 3</th>
<th>Category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>EPA RQ calculation</td>
<td>NUREG-1140 (NRC) with modifications</td>
</tr>
<tr>
<td>RF (dimensionless)</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>SA (Ci/g)</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>$\chi/Q$ (s/m$^3$)</td>
<td>7.2 x10$^{-2}$</td>
<td>1.0 x10$^{-4}$</td>
</tr>
<tr>
<td>CEDE (rem/Ci)</td>
<td>62</td>
<td>92.5</td>
</tr>
<tr>
<td>RR (m$^3$/s)</td>
<td>2.7 x10$^{-4}$</td>
<td>3.5 x10$^{-4}$</td>
</tr>
<tr>
<td>TQ (grams)</td>
<td>1.67</td>
<td>30.89</td>
</tr>
<tr>
<td>Rounded TQ (grams)</td>
<td>1.6</td>
<td>30</td>
</tr>
</tbody>
</table>

- DOE uses RF = 1.0 for tritium in the Cat 2 calculation, NRC uses 0.5
- DOE/NRC model calculates dose from all available pathways
- EPA model calculates dose based on the most significant pathway
- NRC and EPA use NRC “average” RR, DOE uses “active” RR
- Rounded values proposed by TFG and incorporated into STD-1027 in 199
### 2011 NNSA Calculated New Tritium TQs (SD G 1027)

<table>
<thead>
<tr>
<th></th>
<th>Category 3</th>
<th>Category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF (dimensionless)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SA (Ci/g)</td>
<td>9619</td>
<td>9619</td>
</tr>
<tr>
<td>$\chi/Q$ (s/m^3)</td>
<td>7.2 x10^{-2}</td>
<td>1.0 x10^{-4}</td>
</tr>
<tr>
<td>CEDE (rem/Ci)</td>
<td>99.9</td>
<td>99.9</td>
</tr>
<tr>
<td>RR (m^3/s)</td>
<td>3.33 x10^{-4}</td>
<td>3.33 x10^{-4}</td>
</tr>
<tr>
<td>TQ (grams)</td>
<td>0.87</td>
<td>62.44</td>
</tr>
<tr>
<td>Pu-239 TQ (grams)</td>
<td>38</td>
<td>2600</td>
</tr>
</tbody>
</table>

- Uses same RF for both categories
-Uses updated ICRP dose coefficients (66.6 vs. 62 rem/Ci)
- RR based on ICRP “light work” definition
- Same CEDE (with skin absorption factor) used in both cases
-In 2013, LANL proposed that TFG accept the NNSA values
- Proposal was defeated by a vote of 7-2
2018 LANL Calculated Tritium TQs (Spring TFG Meeting)

<table>
<thead>
<tr>
<th></th>
<th>Category 3</th>
<th>Category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF (dimensionless)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SA (Ci/g)</td>
<td>9619</td>
<td>9619</td>
</tr>
<tr>
<td>$\chi/Q$ (s/m$^3$)</td>
<td>7.2 x10^{-2}</td>
<td>1.0 x10^{-4}</td>
</tr>
<tr>
<td>CEDE (rem/Ci)</td>
<td>66.6</td>
<td>66.6</td>
</tr>
<tr>
<td>RR (m$^3$/s)</td>
<td>3.33 x10^{-4}</td>
<td>3.33 x10^{-4}</td>
</tr>
<tr>
<td>TQ (grams)</td>
<td>1.30</td>
<td>93.66</td>
</tr>
</tbody>
</table>

- Uses same RF and updated RR for both categories (same as NNSA)
- Uses updated ICRP dose coefficients (66.6 vs. 62 rem/Ci)
- Skin absorption not included in CEDE (consistent with EPA model)
- Category 3 TQ decrease is clearly unacceptable
- Need a methodology that increases both TQs
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Cat 2 Maximum</th>
<th>Cat 2 Recommended</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF (dimensionless)</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>SA (Ci/g)</td>
<td>9600</td>
<td>9600</td>
<td>9600</td>
</tr>
<tr>
<td>χ/Q (s/m³)</td>
<td>1.0 x10⁻⁴</td>
<td>1.0 x10⁻⁴</td>
<td>7.2 x10⁻²</td>
</tr>
<tr>
<td>CEDE (rem/Ci)</td>
<td>962</td>
<td>166.5</td>
<td>151.7</td>
</tr>
<tr>
<td>RR (m³/s)</td>
<td>3.33 x10⁻⁴</td>
<td>3.33 x10⁻⁴</td>
<td>3.33 x10⁻⁴</td>
</tr>
<tr>
<td>Q (grams)</td>
<td>3.25</td>
<td>18.77</td>
<td>0.57</td>
</tr>
<tr>
<td>CEDE source</td>
<td>ICRP 72 public dose coefficient for slow-absorption (Type S) particulates</td>
<td>ICRP 72 public dose coefficient for moderate-absorption (Type M) particulates</td>
<td>ICRP 68 worker dose coefficient for organically bound tritium</td>
</tr>
</tbody>
</table>

“While it is recognized that the use of the tritium HC-2 and HC-3 TQs is limited to the thresholds as recommended by the TFG, this report will calculate the HC-2 and HC-3 TQs using the methodology as specified in Sections 4.1 and 4.2, respectively, of this report. The calculation of tritium HC-2 and HC-3 thresholds is provided solely for reference purposes only with the understanding they cannot be used without the review and approval of the TFG.”
Where Is There Room to Adjust?

\[ TQ = \frac{Dose \ (rem)}{RF \cdot SA \cdot \chi/Q \cdot CEDE \cdot RR} \]

- **TQ**: Quantity of material used as threshold (grams)
- **Dose**: 1 rem for Category 2, 10 rem for Category 3
- **RF**: Release fraction (unitless)
- **SA**: Specific activity of radionuclide released (Ci/g)
- **\(\chi/Q\)**: Expression accounting for dilution of release at a point under given meteorological conditions (sec/m³)
- **CEDE**: Committed effective dose equivalent for a given radionuclide (rem/Ci)
- **RR**: Respiration rate (m³/sec)
Categorization Based on Chemical Form

- NNSA SD G 1027 allows for “Adjusted Release Fractions” (Airborne Release Fraction x Respirable Fraction), although not for tritium

- Tritium in different forms will have different release fractions
  - Elemental tritium would have a release fraction of 1.0
  - Tritium oxide as liquid would have a low release fraction (~10⁻³)
  - Tritium oxide on molecular sieve would have a low release fraction
  - Tritium as particulate metal hydride would have a very low release fraction
  - Different hydrides have different ARFs and RFs

- Could require complex inventory calculations and/or controls
  
  \[ Dose \ (\text{rem}) = SA \cdot \frac{\chi}{Q} \cdot RR \cdot \sum Q \cdot ARF \cdot RF \cdot CEDE \]

  - Use 1 rem for Category 2 and 10 rem for Category 3 and the appropriate \( \frac{\chi}{Q} \)

- Need to compile data and incorporate in revision of DOE-HDBK-3010
  - HDBK-3010 does not currently include any tritium data
  - SRNL has ARF and RF data for metal tritides
  - Data needed for spill, fire, and explosion scenarios
  - What other data is out there (OBTs, mole sieve, etc.)?
## Atmospheric Modeling Considerations (χ/Q)

<table>
<thead>
<tr>
<th>Physical model</th>
<th>NUREG-1140</th>
<th>DOE-STD-1027 (Cat 2)</th>
<th>EPA Model (Cat 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational method</td>
<td>CRAC2 (computer)</td>
<td>CRAC2 (computer)</td>
<td>Turner 1970</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(arithmetic)</td>
</tr>
<tr>
<td>Pasquill Stability Class</td>
<td>F</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>1 m/s</td>
<td>4.5 m/s</td>
<td>1 m/s</td>
</tr>
<tr>
<td>Dose pathway</td>
<td>Inhalation</td>
<td>Inhalation, cloud shine</td>
<td>Inhalation</td>
</tr>
<tr>
<td>Exposure distance</td>
<td>100 m</td>
<td>300 m</td>
<td>30 m</td>
</tr>
<tr>
<td>Model inputs</td>
<td>Building size, release height, CEDE, particle deposition velocity</td>
<td>Building size, release height, CEDE, particle deposition velocity</td>
<td>Release height, CEDE</td>
</tr>
</tbody>
</table>

- All assume point-source, ground-level release with no plume buoyancy
- NUREG-1140 model used buoyancy for UF₆ releases!
- CRAC2 model includes building wake effects – important at close distances
Comparison of Model Results

\[
\frac{\chi}{Q}(x, 0, 0; 0) = \frac{1}{\pi \cdot u \cdot \sigma_y \cdot \sigma_x}
\]

\[
\sigma_y = \frac{1000 \cdot x \cdot \tan(T)}{2.15}
\]

\[
\sigma_z = a \cdot x^b
\]

For Stability Class D:

\[
T = 8.3333 - 0.72382 \ln(x)
\]

At less than 300 m, \(a = 34.459\) \(b = 0.86974\)

NUREG-1140 model output
Are Gaussian Plume Models Even Applicable?

- Gaussian plume modeling is appropriate for time periods of “a few minutes”, regulatory models assume release periods of 30 minutes (NRC) or 24 hours (EPA).
- At shorter distances (< 100 m), building wake effects dominate

“Near the ground the increase of wind speed with height due to the surface friction is such that it is not possible to select a single wind speed which will be appropriate as a dilution speed. The turbulence is not homogeneous in the vertical due to the presence of the surface. Therefore Gaussian techniques are not appropriate” – Turner 1994, page 5-2
Options for Revised TFG Recommendations

- Same RF, CEDE, and breathing rates for both tritium TQs
  - RF of 0.5 unless other data are available (e.g. particulates)
  - Skin absorption factor?
  - Average breathing rate vs. “light work”?

- Use same atmospheric model to derive both TQs?
  - Turner method for 300 m (D, 4.5 m/s) gives $\chi/Q = 2.6 \times 10^{-4} \Rightarrow$ Cat 2 limit 36 g
  - CRAC2 model at 30 meters (D, 4.5 m/s) gives $\chi/Q \sim 4.5 \times 10^{-3} \Rightarrow$ Cat 3 limit 20.8 g

- Recalculate Cat 3 $\chi/Q$ value using the Turner method with wind @ 4.5 m/s
  - $\chi/Q = 1.6 \times 10^{-2} \Rightarrow$ Cat 3 limit 5.78 g

- New/better atmospheric models
  - K-theory approach
  - EPA CAP-88 program (still Gaussian plume)
  - Oak Ridge ACRA-TRIT (tritium-specific accidental release), others?
  - NRC MACCS (Briggs plume model), successor to CRAC2?
Revised LANL TQ Calculation – Short-term Solution?

<table>
<thead>
<tr>
<th></th>
<th>Category 2</th>
<th>Category 3</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF (dimensionless)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SA (Ci/g)</td>
<td>9619</td>
<td>9619</td>
<td>9619</td>
</tr>
<tr>
<td>Atmospheric model</td>
<td>CRAC2</td>
<td>CRAC2</td>
<td>Turner</td>
</tr>
<tr>
<td>$\chi/Q$ (s/m³)</td>
<td>1.0 x10^{-4}</td>
<td>4.5 x10^{-3}</td>
<td>1.6 x10^{-2}</td>
</tr>
<tr>
<td>CEDE (rem/Ci)</td>
<td>66.6</td>
<td>66.6</td>
<td>66.6</td>
</tr>
<tr>
<td>RR (m³/s)</td>
<td>3.33 x10^{-4}</td>
<td>3.33 x10^{-4}</td>
<td>3.33 x10^{-4}</td>
</tr>
<tr>
<td>TQ (grams)</td>
<td>93.66</td>
<td>20.81</td>
<td>5.78</td>
</tr>
<tr>
<td>Rounded TQ</td>
<td>93 grams</td>
<td>20 grams</td>
<td>5.7 grams</td>
</tr>
</tbody>
</table>

- Still retains many conservative assumptions
  - 100% oxide conversion
  - No plume buoyancy
  - Instantaneous Gaussian dispersion
- ARF x RF could reduce final categorization