Calculation of dose rate, decay heat and criticality for verifying compliance with transport limits for steel packages

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outline

• introduction: HDB
• motivation for calculations
• transport package
• nuclide inventory & calculation examples
  – application of Nuclides.net
• conclusion
introduction: HDB

HDB - Hauptabteilung Dekontaminationsbetriebe

Central Decontamination Department

ITU - Institute for Transuranium Elements

Karlsruhe Research Center
HDB activities

- safe utilization
  - decontamination
  - release measures

- infrastructure
  - entrance store
  - intermediate store
  - documentation

- conditioning of radioactive waste
  - incineration
  - evaporation
  - compaction
  - cementation

Important information for transport:
  - declaration of nuclides
  - activity
60% of the German 'Federal' nuclear waste
- from laboratories and decommissioned nuclear reactors
- from the Karlsruhe Reprocessing Plant WAK
- from the European Institute for Transuranium Elements (ITU)
- from various institutions and industries

Baden-Württemberg state collection center

65000 drums in 5500 container
55000 m³ storage volume
motivation for calculations

- transport of conditioned radioactive waste to
  - a nuclear waste repository
  - the originator

BUT
- declaration of nuclides
- safety considerations
  - dose rate
  - criticality
  - decay heat

- transport in EU regulated by ADR / RID 2005

NEED

⇒ approved transport package
transport package

- steel container
  - Typ IV (Konrad)
- volume approx. 7 m³
- load max. 20 Mg

conditioned radioactive waste
- e.g. 200 l drums

intermediate store

• steel container
  – Typ IV (Konrad)
• volume approx. 7 m³
• load max. 20 Mg
packaging of a steel container

- steel container contains (e.g.)
  - 14 drums with conditioned radioactive waste
  - mixed radioactive inventory
- activity max. 1 TBq
- encapsulation in inactive cement

⇒ conditioned radioactive waste within a transport package
transport safety

⇒ required information
  – activity
  – criticality
  – decay heat
  – half-life

⇒ transport limits
  – radiation protection ordinance
    • HDB regulations (indirect)
    • KONRAD regulations (indirect)
  – ADR / RID 2005

! verifying compliance with transport limits before transportation

⇒ calculations with computer program e.g. Scale 4.4a
⇒ specific activity, decay heat, half-life etc. from databases e.g. Nuclides.net

✓ approved transport package
nuclide inventory

- known 116 elements
  approx. 2770 nuclides
- KADABRA 299 nuclides
  (HDB nuclide database)
- ADR / RID 2005 240 nuclides
  - limiting values for transport
  - key nuclides
    - (e.g. Co-60, Cs-137, Am-241...)
  - mother/daughter equilibrium
    - (e.g. U-232/Th-228, U-238/Th-234 & Pa-234m, Sr-90/I-90 & Y-90)
nuclide vector

- in practice 240 nuclides
  - minus half-life < 100 d
  - minus activities < 1E-15 Bq
- approx. 100 nuclides define a ‘nuclide vector’
- creating a virtual package with 14 drums based on KADABRA data
- conservative approach
  - creating special nuclide vectors
    - highest loads for dose rate
    - highest loads for decay heat
transport package approval

- dose rate
  - at 1 m from surface < 2 mSv h\(^{-1}\)
  - computer program Micro-Shield 5.5
  - dose rate constants in 1 m distance from surface

- criticality
  - no chain reaction (criticality coefficient \(k_{\text{eff}} < 1\))
  - computer program Scale 4.4a
  - Monte-Carlo simulation of the neutron flux

- heat
  - no temperature problem for the package
  - sun & decay heat
  - computer program Heating
  - finite element method
## Dose Rate

- 2 mSv·h⁻¹ at 1 m from surface
- Calculations before packing

### Dose Rate Constant (1 m)

<table>
<thead>
<tr>
<th>Nuclide*</th>
<th>Number of Drums</th>
<th>Total Activity / Bq</th>
<th>Proportion / %</th>
<th>Dose Rate Constant (1 m) / Bq μSv⁻¹h⁻¹</th>
<th>Theoretical Max. Activity / Bq / Drum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs-137  β</td>
<td>32339</td>
<td>1.75E+13</td>
<td>58.32</td>
<td>7.19E+07</td>
<td>2.10E+04</td>
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<tr>
<td>Co-60 β</td>
<td>31964</td>
<td>1.39E+12</td>
<td>22.19</td>
<td>1.50E+07</td>
<td>1.67E+03</td>
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<tr>
<td>Cs-134 β</td>
<td>31344</td>
<td>4.75E+11</td>
<td>4.40</td>
<td>2.58E+07</td>
<td>5.68E+02</td>
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<tr>
<td>Rh-106 β</td>
<td>31425</td>
<td>3.26E+12</td>
<td>3.92</td>
<td>1.99E+08</td>
<td>3.90E+03</td>
</tr>
<tr>
<td>Sb-125 β</td>
<td>30905</td>
<td>1.14E+12</td>
<td>2.63</td>
<td>1.04E+08</td>
<td>1.37E+03</td>
</tr>
</tbody>
</table>

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*KADABRA KADABRA Micro-Shield*

*Excerpt from nuclide vector*

Maximum possible activity inventory in 1 drum
example: accident conditions

- load of 4 packages (ADR)
  ⇒ limited by KONRAD regulations up to 50 g/100 l of fissile material
  ⇒ concentrated in a sphere, no cement, no shielding material
  ⇒ surrounded by water as reflector material

⇒ no sustainable chain reaction \( (k_{\text{eff}} < 1) \)
Scale 4.4a calculation

- input values Scale 4.4a

<table>
<thead>
<tr>
<th>nuclide*</th>
<th>total activity / Bq</th>
<th>specific activity / Bq g(^{-1})</th>
<th>total mass / g</th>
<th>proportion / %</th>
<th>mass fraction / g \cdot (50 g)^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-233 β</td>
<td>1.21E+07</td>
<td>3.56E+08</td>
<td>5.53E+02</td>
<td>0.004</td>
<td>0.002</td>
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<tr>
<td>U-235 β</td>
<td>2.82E+04</td>
<td>7.78E+04</td>
<td>5.76E+06</td>
<td>36.9</td>
<td>18.4</td>
</tr>
<tr>
<td>Pu-239 β</td>
<td>1.04E+13</td>
<td>4.54E+03</td>
<td>4.54E+03</td>
<td>0.03</td>
<td>0.015</td>
</tr>
<tr>
<td>Pu-241 β</td>
<td>9.18E+14</td>
<td>9.85E+06</td>
<td>9.85E+06</td>
<td>63.1</td>
<td>31.6</td>
</tr>
</tbody>
</table>

KADABRA  Nuclides.net  for Scale 4.4a

* excerpt from nuclide vector

- assuming U and Pu as UO\(_2\) and PuO\(_2\) in the sphere

\( k_{\text{eff}} < 0.60 \Rightarrow \text{no chain reaction} \)
transport conditions

- 1 drum in the center of the package contains all nuclide inventory (ADR)
  - ambient temperature 38 °C
  - 12 h exposure to the sun & decay heat

⇒ no significant (dangerous) increase in temperature
Heating calculation

- input values for Heating

<table>
<thead>
<tr>
<th>nuclide*</th>
<th>total activity / Bq</th>
<th>specific activity / Bq g⁻¹</th>
<th>isotopic power / W g⁻¹</th>
<th>proportion / %</th>
<th>decay heat / W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241  α</td>
<td>1.27E+07</td>
<td>1.27E+11</td>
<td>1.14E-01</td>
<td>77.3</td>
<td>167</td>
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<tr>
<td>Pu-238 α</td>
<td>2.82E+04</td>
<td>6.34E+11</td>
<td>5.67E-01</td>
<td>11.1</td>
<td>24</td>
</tr>
<tr>
<td>Pu-240 α</td>
<td>1.04E+13</td>
<td>8.40E+09</td>
<td>7.03E-03</td>
<td>4.2</td>
<td>9.09</td>
</tr>
<tr>
<td>Pu-239 α</td>
<td>1.04E+13</td>
<td>2.29E+09</td>
<td>1.93E-03</td>
<td>4.0</td>
<td>8.73</td>
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<tr>
<td>Y-90 β</td>
<td>9.18E+14</td>
<td>2.02E+16</td>
<td>3.01E+03</td>
<td>0.8</td>
<td>1.79</td>
</tr>
</tbody>
</table>

KADABRA Nuclides.net Nuclides.net 210.61

* excerpt from nuclide vector

- heat generated
  - by sun: 9344 W
  - by decay: 211 W

- temperature
  - at the top 72 °C
  - in the center 60 °C
conclusion

• nuclide declaration is important
  – conservative assumptions
• different (virtual) nuclide inventories for each case
  – dose rate
  – criticality
  – decay heat
• reliable data source needed

⇒ input values for the computer programs
  - e.g. Micro-Shield, Scale, Heating

✓ approved transport package
HDB, Karlsruhe, Germany:
- Luis Valencia
- Heike Merx
- Ralf Steiner

NFCC, Zürich, Switzerland:
- Bengt Tveiten

Thank you!