Simulation of the Occupational Radiation Dose Caused by Contamination of Primary Circuit Media in Pressurized Water Reactors

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Content

- Introduction & motivation
- Basic information: available data defining the starting point
- The model: combining the links of the simulation chain
- Results and discussion
- Summary
Introduction and motivation

- Occupational doses are determined by a number of parameters, including:
  - activation → shielding only
  - contamination → chemical operation mode; (F)SD
  - geometry of shielding
  - self-shielding of components
  - deposits of radionuclides; hot-spots
  - planning of tasks
  - behaviour of workers

The blue coloured items are addressed by our model
Introduction and motivation

Numerous parameters influencing radiation exposure – complex problem

Complexity reduction by simplification

generic and adaptable model of a PWR’s primary circuit and shield components

Activity  →  Dose
Basic information

- Water chemistry and transport of radionuclides
  - very complex
  - physico-chemical and thermodynamic process
  - large number of parameters
    - many degrees of freedom
    - few measured data

- Existing models considering water chemistry and transport tend to be facility-specific

- Our approach: step back to a simpler generic model
Basic information

- Data on radionuclide concentrations dissolved in the primary coolant are available

- Engineering drawings and technical documentation for German PWR reactors

- Measurement data on local dose rates at specific locations at the primary circuit
  - steam generator water chambers
  - hot/cold legs

- Data on occupational doses / dose rates / personnel / working time from the ISOE database
Modelling

- Combination of multiple simulation steps:
  - Definition of representative **nuclide vectors**
  - **3D-Model** of PWR primary circuit
  - Definition of **jobs** (locations, retention times within 3D model)
  - Dose rate **calculations** (MicroShield)
Modelling – nuclide vectors

- Nuclide vectors are defined based on:
  - analysis of dissolved radionuclides within the primary coolant
  - reverse simulation from known local dose rates
  - physical / chemical / geometrical considerations, material behaviour, information based on literature

- Defined for contamination (deposits)
- Component-specific
- NPP-generation-specific (mainly the Co-60 content is adjusted)
Modelling – nuclide vectors

Generation 2 of Siemens/KWU PWR
Modelling – 3D model
Modelling – considering jobs

- The following jobs are simulated
  - jobs related to the reactor coolant pumps
  - pressuriser maintenance and repair
  - steam generator eddy current testing
- Mean working time for each job/craft
- Pathways, breaks, changing clothes is simulated as one shielded point
- Characterisation of representative spatial points
  - about 3 points per job/craft
  - identify not negligible sources around each point
  - identify relevant shielding
  - calculate local dose rate at each point (several simulations, one for each source)
- Calculation of the job doses
  - retention times at the points – mean values extracted from ISOE database
Modelling – considering Jobs

Jobs at coolant pumps

Pressuriser maintenance and repair

ISOE-Symposium 2015, Rio de Janeiro, Brazil
Modelling – considering Jobs

Steam generator eddy current testing
Modelling – dose rate calculations using MicroShield

- Different coordinate systems and limitations of different software components require some adaptations:

  - Simplification of components
    - keep the **radiological impact** realistic
    - keep **outer dimensions** realistic (for realistic distances)
    - neglect details of the **inner structure**
    - modify the **outer shape** of structures to simple cylinders, neglect details

- Coordinate transformation
  - global coordinates in Sketchup
  - source-related coordinates in MicroShield

importance
Modelling – dose rate calculations using MicroShield

Steam generator

Source 1
+ Shielding

Sources 2 / 3
+ Shielding
## Results and discussion

**Jobs related to the reactor coolant pumps**

<table>
<thead>
<tr>
<th>Item</th>
<th>Simulation result</th>
<th>Range of plant mean values</th>
<th>Range of measured single values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual mean dose Gen 2</td>
<td>174 µSv</td>
<td>194 - 365 µSv</td>
<td>2 - 924 µSv</td>
</tr>
<tr>
<td>Collective dose Gen 2 per pump</td>
<td>8.7 man mSv</td>
<td>7 - 18 man mSv</td>
<td>7 - 56 man mSv</td>
</tr>
<tr>
<td>Individual mean dose Gen 3</td>
<td>73 µSv</td>
<td>85 - 301 µSv</td>
<td>2.5 - 637 µSv</td>
</tr>
<tr>
<td>Collective dose Gen 3 per pump</td>
<td>4.6 man mSv</td>
<td>1.8 - 16.8 man mSv</td>
<td>0.36 - 65 man mSv</td>
</tr>
</tbody>
</table>
### Results and discussion

#### Pressuriser maintenance and repair

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</thead>
<tbody>
<tr>
<td>Individual mean dose Gen 2</td>
<td>1075 µSv</td>
<td>241 - 400 µSv</td>
<td>2 - 830 µSv</td>
</tr>
<tr>
<td>Collective dose Gen 2</td>
<td>86 man mSv</td>
<td>7-60 man mSv</td>
<td>0.1-270 man mSv</td>
</tr>
<tr>
<td>Individual mean dose Gen 3</td>
<td>528 µSv</td>
<td>90 - 260 µSv</td>
<td>23 - 367 µSv</td>
</tr>
<tr>
<td>Collective dose Gen 3</td>
<td>42 man mSv</td>
<td>5 - 128 man mSv</td>
<td>0.8 - 981 man mSv</td>
</tr>
</tbody>
</table>

- The confidence interval of the simulations is given by a factor of about 2, mainly caused by uncertainties concerning the time shares in the different radiation fields.
Summary

- The generic model allows the prediction of expected individual and collective doses

- Our model is based on empirical data from German NPPs, but can easily be adapted to other 4-loop PWR reactor types

- Adaptation can easily be carried out by:
  - changing nuclide vectors
  - changing material composition and thickness of shielding
  - changing the job situation (time-shares and retention times)
  - creation of new jobs

Perspective:

- Simulation of "steam generator eddy current testing"
- Simulate the influence of full system decontaminations on the jobs:
  - Changed nuclide vectors, lowered differences of component’s activities