Simulation of the Occupational Radiation Dose Caused by Contamination of Primary Circuit Media in Pressurized Water Reactors
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 operating mode; (F)SD
  - geometry of shielding
  - self-shielding of components
  - deposits of radionuclides; hot-spots
  - planning of working tasks
  - behaviour of workers

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

- Numerous parameters influencing radiation exposure – complex problem

- Complexity reduction by simplification

Activity

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

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 PWRs
- 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
Combination of multiple simulation steps:
- Determination 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

- The qualitative determination of the nuclide vectors is based on:
  - analysis of dissolved radionuclides within the primary coolant
  - ranking order of the radiological impact of each nuclide
  - physical / chemical / geometrical considerations, material behaviour, information based on literature

- The quantitative determination of the nuclide vectors is based on:
  - analysis of the activity concentration within the primary coolant
  - reverse simulation from known local dose rates

- adherent contamination (deposits) for specific components

- NPP-generation-specific (mainly the Co-60 content is adjusted)
**Modelling – nuclide vectors**

- **Operation:** $^{16}\text{N}$
- **Overall maintenance and refuelling outages:** $^{51}\text{Cr}$, $^{54}\text{Mn}$, $^{59}\text{Fe}$, $^{58,60}\text{Co}$, $^{124}\text{Sb}$ (131,133$I$, 133$\text{Xe}$, 134,137$\text{Cs}$)
- **Decommissioning:** $^{60}\text{Co}$, $^{110m}\text{Ag}$, $^{124}\text{Sb}$
Modelling – nuclide vectors

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

- Description of the geometrical situation
  - Arrangement of sources and shielding, locations and distances
  - Dimensions of sources and shielding
  - Determine distances and angles
- Helps to decide
  - whether a source or shielding element is relevant or negligible for geometrical reasons
  - which sources can be assumed to be significant at a specific location
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
Modelling – dose rate calculations using MicroShield

Steam generator

Shielding only

Source 1
+ Shielding

Sources 2 / 3
+ Shielding
Modelling – 3D model
Modelling – considering Jobs

Jobs at coolant pumps

Pressurizer maintenance and repair
Modelling – considering jobs

- The following working tasks (jobs) are simulated
  - jobs, related to the reactor coolant pumps
  - pressurizer maintenance and repair
  - steam generator eddy current testing
Modelling – considering jobs

- mean working time for each job/working task/craft
- pathways, breaks, changing clothes considered as a shielded point
- Characterisation of representative spatial points
  - about 3 points per job/working task/craft
  - identify not negligible sources around each point
  - identify relevant shielding
  - calculate local dose rates 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
Results (example 1)

Jobs related to the reactor coolant pumps (pre-Konvoi plants)

<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 per 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</td>
</tr>
<tr>
<td>Collective dose per 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 (example 2)

Data from ISOE database and simulation for specific jobs (pre-Konvoi plants)

- ISOE Database:
  - Maximum
  - Minimum
  - Simulation

- Dose rate [µSv/h]
- PC Pump Gen. 2
- PC Pump Gen. 3
- Pressurizer Gen. 2
- Pressurizer Gen. 3
- SG Gen. 2
- SG Gen. 3
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 be easily 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