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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

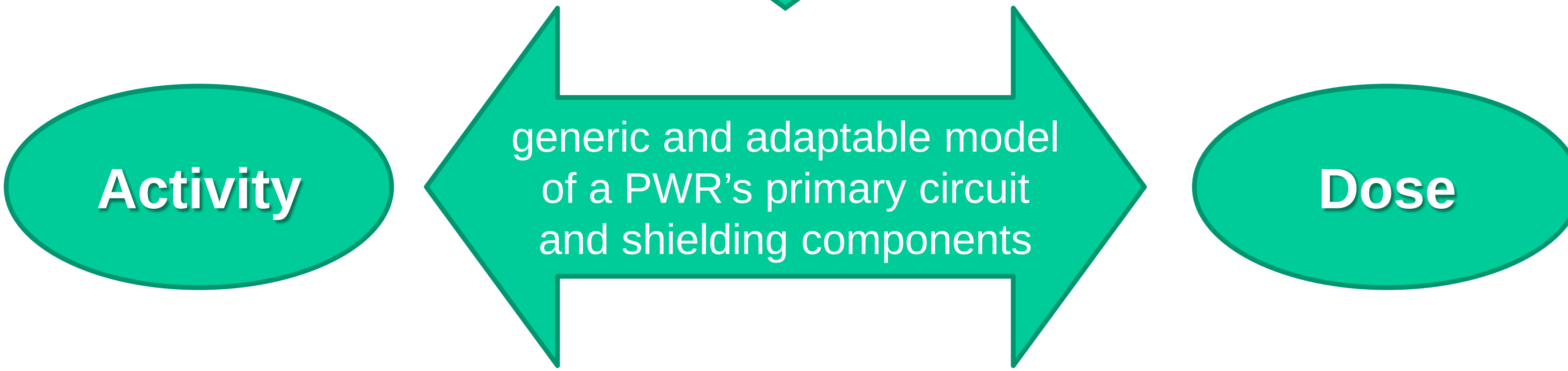
- Occupational doses are determined by a number of parameters, including:
  - activation → shielding only
  - contamination → chemical operating mode; (F)SD
  - geometry of shielding
  - self-shielding of components
  - deposits of radionuclides; hot-spots
  - planning of working tasks
  - behaviour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

The items blue coloured are addressed by our model

Introduction and motivation

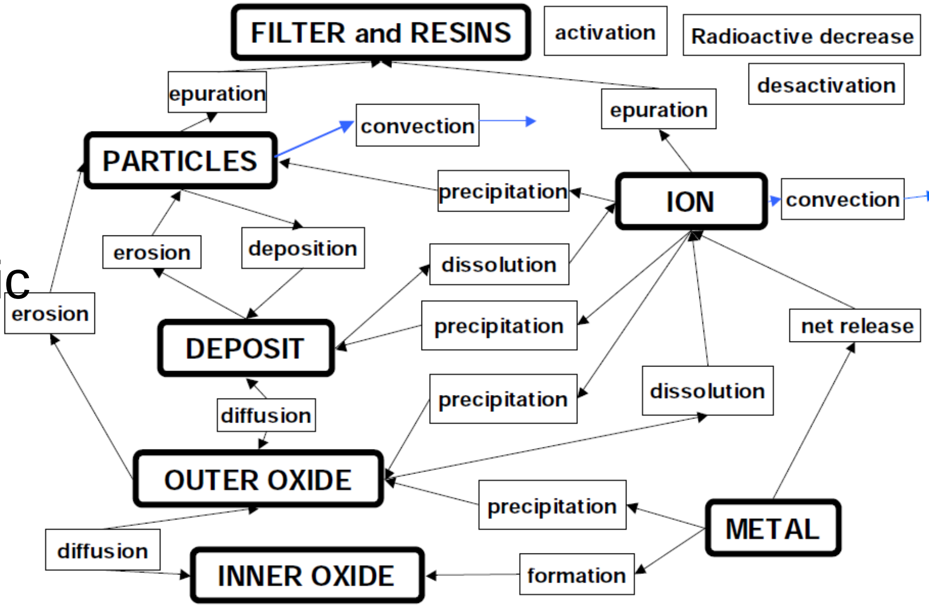
- Numerous parameters influencing radiation exposure – complex problem

- Complexity reduction by simplification



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

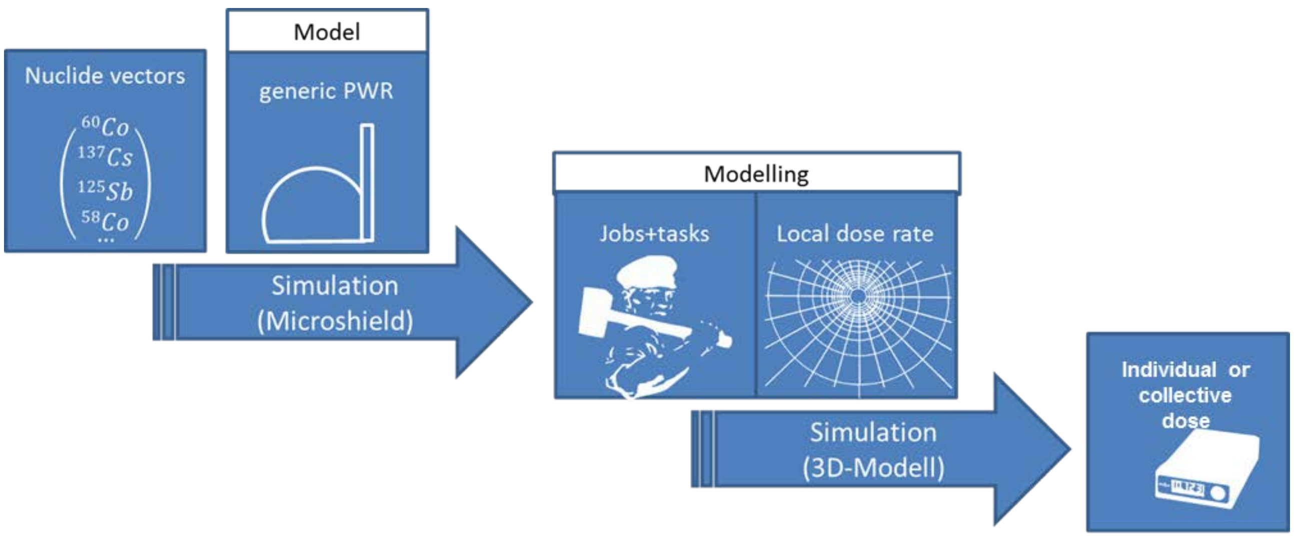
- Our approach: step back to a simpler generic model

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

Modelling

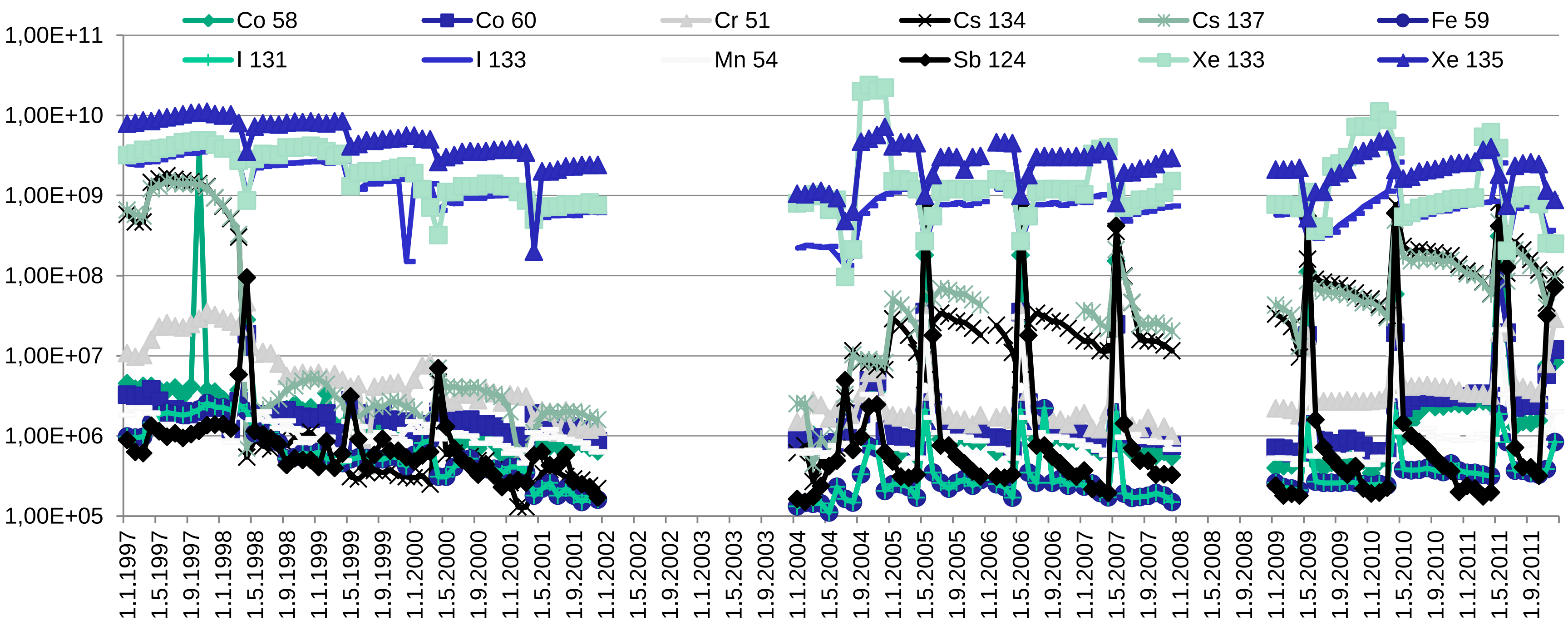
- Combination of multiple simulation steps:
  - Determination of representative **nuclide vectors**
  - **3D model** of PWR primary circuit
  - Definition of **jobs** (locations, retention times within 3D model)
  - Dose rate **calculations** (MicroShield)



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)

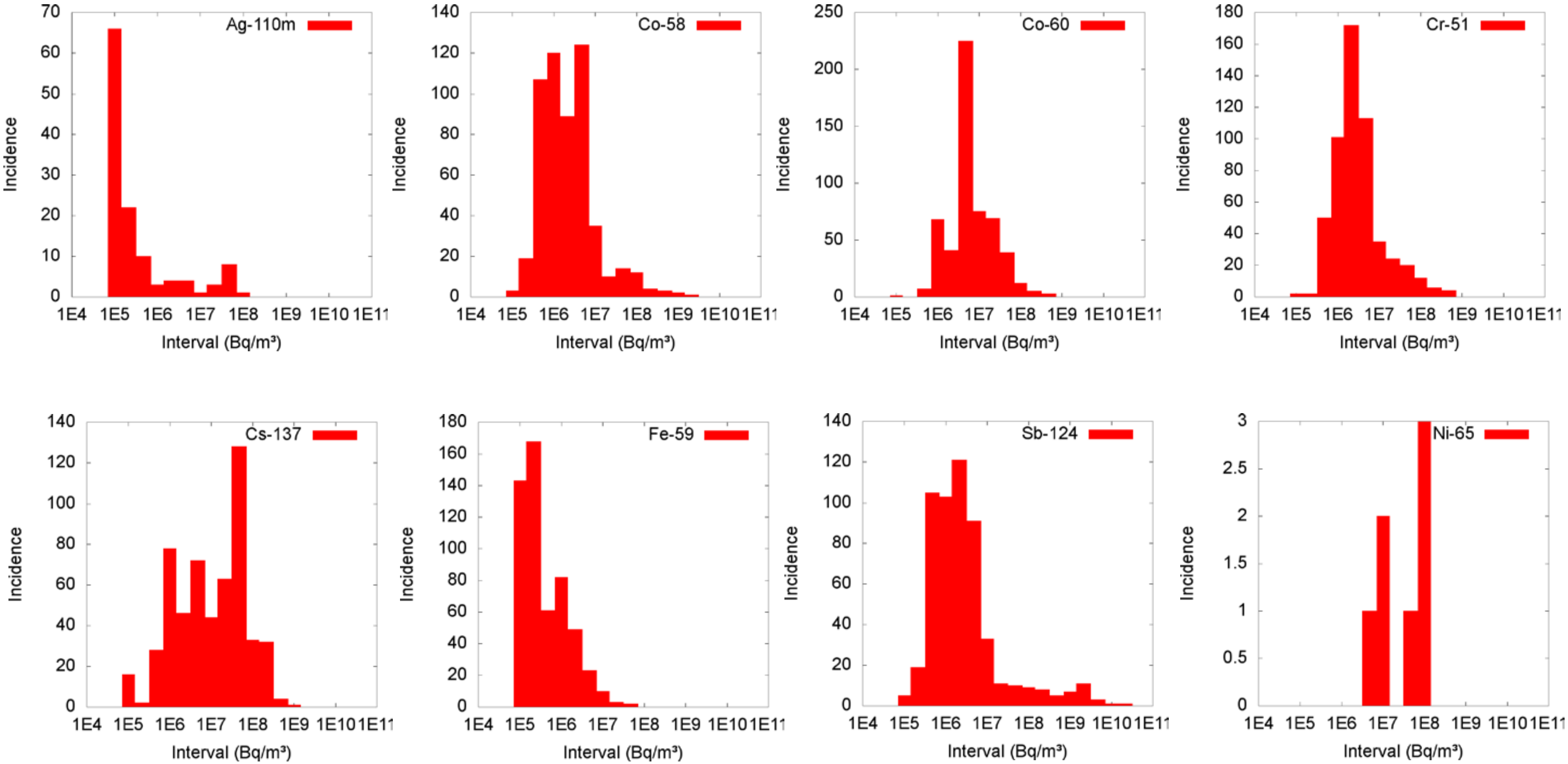
Modelling – nuclide vectors



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

Modelling – nuclide vectors

- Generation 2 of Siemens/KWU PWR



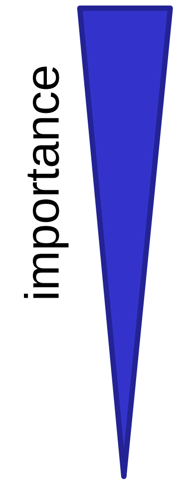
Modelling – 3D model

- 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

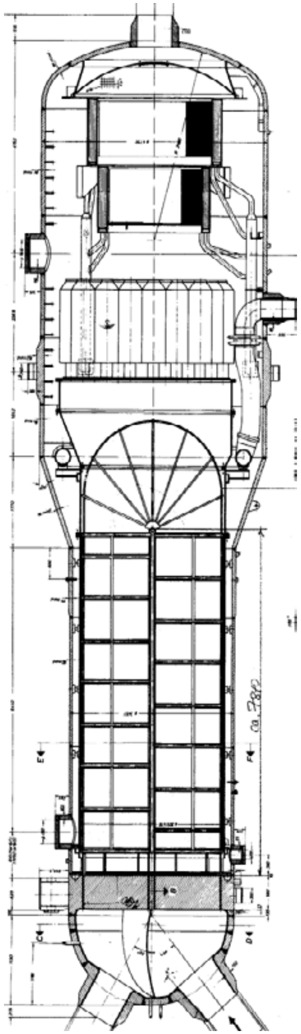
Modelling – dose rate calculations using MicroShield

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

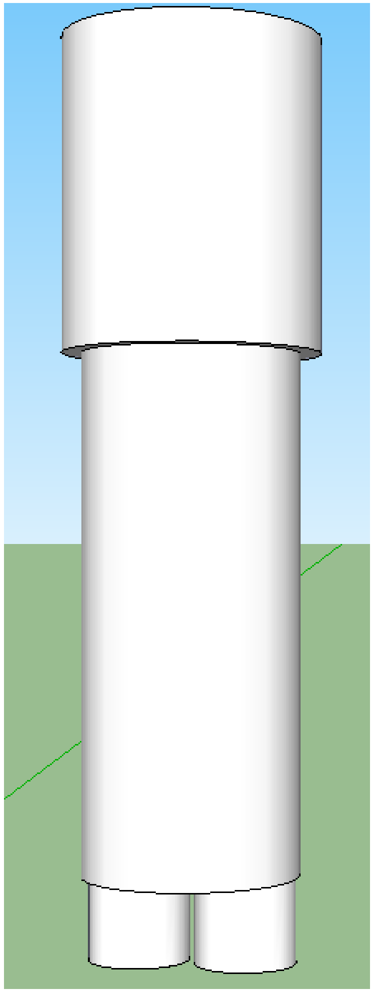
  - Simplification of components
    - Keep the **radiological impact** realistic
    - Keep **outer dimensions** realistic (for realistic distances)
    - Neglect details of the *inner structure*
    - Modify the *outer shape* of structures to simple cylinders, neglect details
  - Coordinate transformation
    - Global coordinates in Sketchup
    - Source-related coordinates in MicroShield



Modelling – dose rate calculations using MicroShield



Steam generator

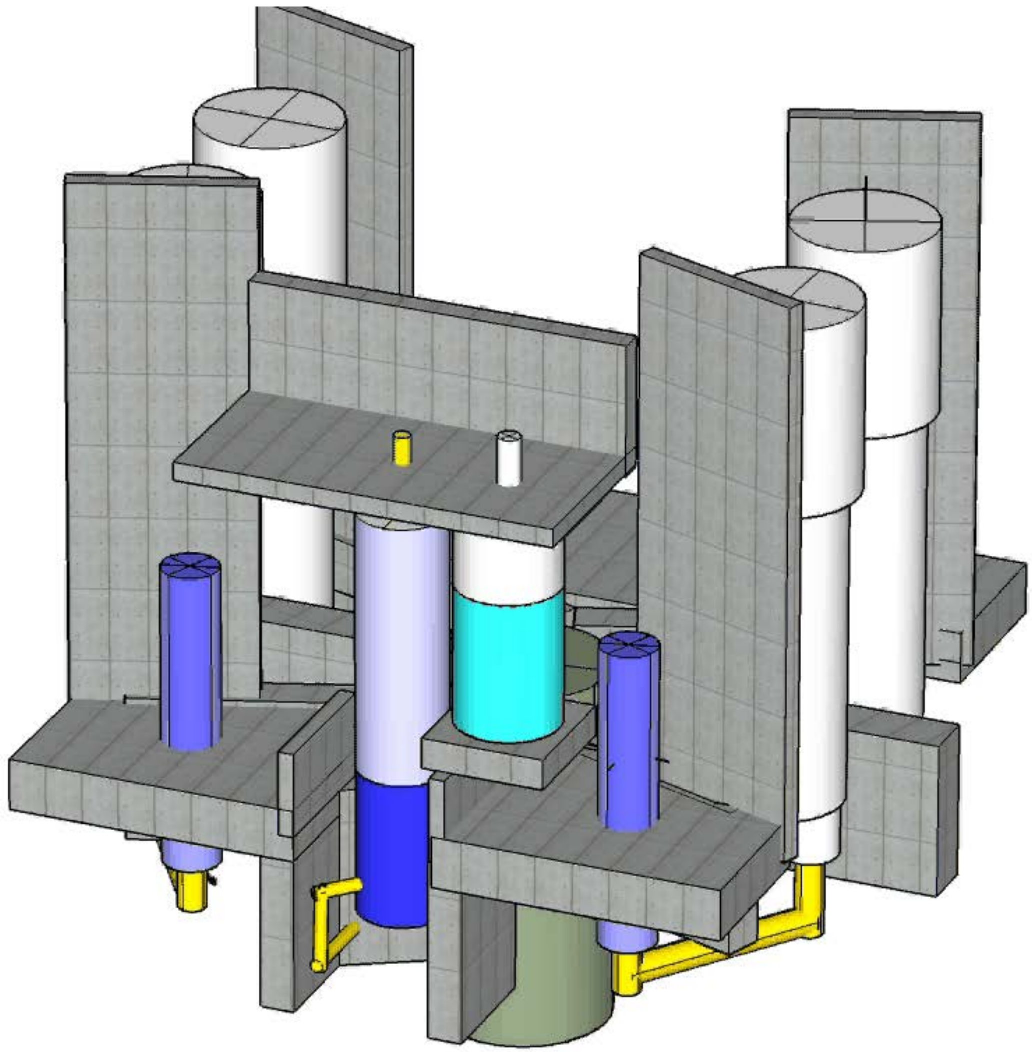


Shielding only

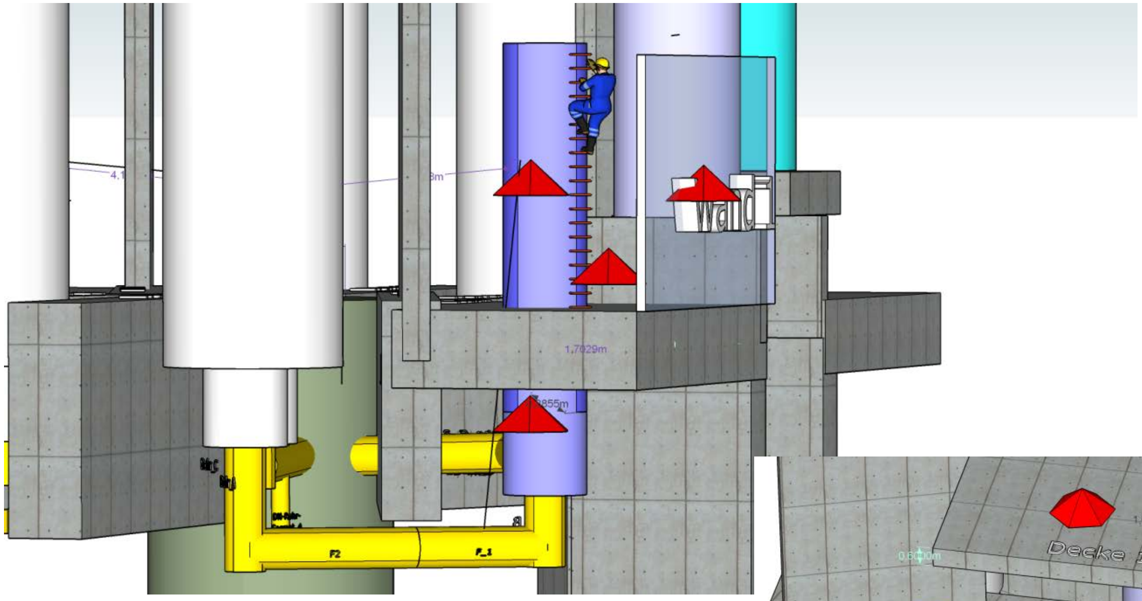
Source 1
+ Shielding

Sources 2 / 3
+ Shielding

Modelling – 3D model

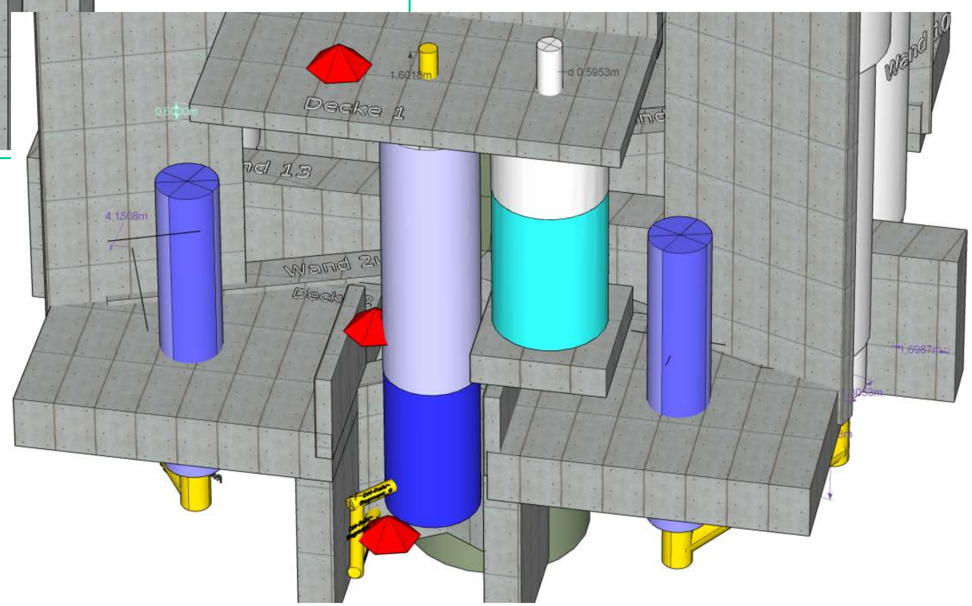


Modelling – considering Jobs



Jobs at coolant pumps

Pressurizer maintanance 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

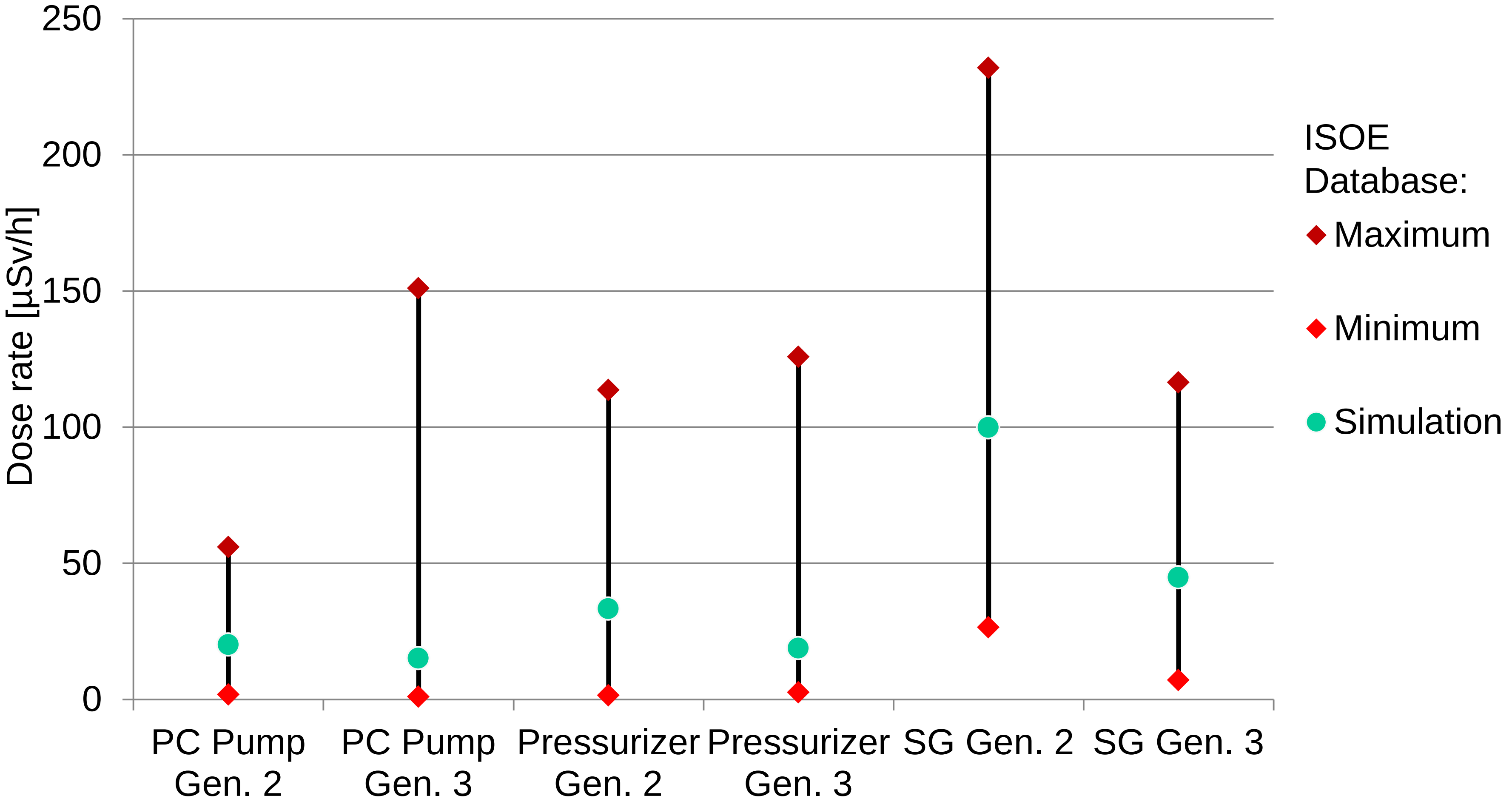
Results (example 1)

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

Item	Simulation result	Range of plant mean values	Range of measured single values
Individual mean dose Gen 2	174 µSv	194-365 µSv	2-924 µSv
Collective dose per Gen 2 per pump	8.7 man mSv	7-18 man mSv	7-56 man mSv
Individual mean dose Gen 3	73 µSv	85-301 µSv	2.5-637
Collective dose per Gen 3 per pump	4.6 man mSv	1.8-16.8 man mSv	0.36-65 man mSv

Results (example 2)

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



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