Simulation of the Occupational Radiation Dose in Pressurized Water Reactors

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- The starting point: available data and methods
- The model: linking elements of the simulation chain
- Results and discussion
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Introduction and motivation

Occupational doses are determined by a number of parameters, including:

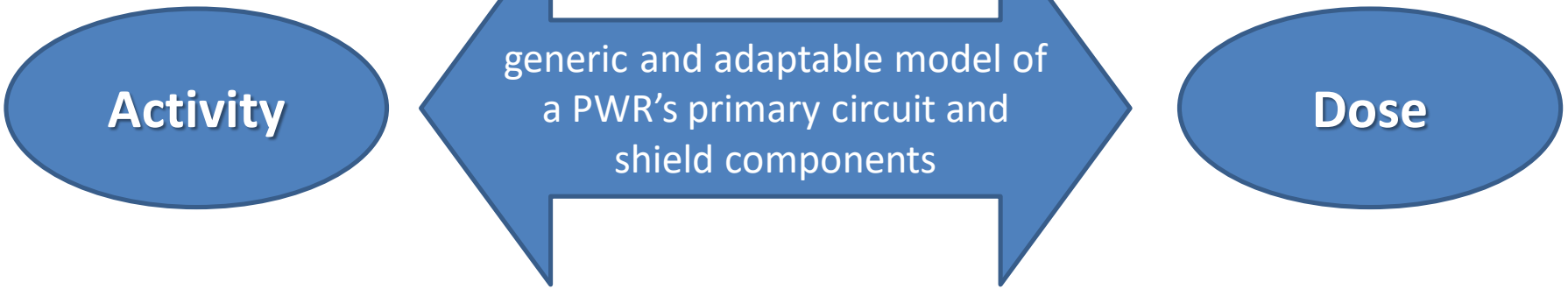
- activation → shielding only
- contamination → chemical operating mode; (F)SD
- geometry of shielding
- self-shielding of components
- deposits of radionuclides; hot-spots
- planning of tasks
- behaviour of workers

The items blue coloured are addressed by our model

Introduction and motivation

Numerous parameters influencing radiation exposure – complex problem

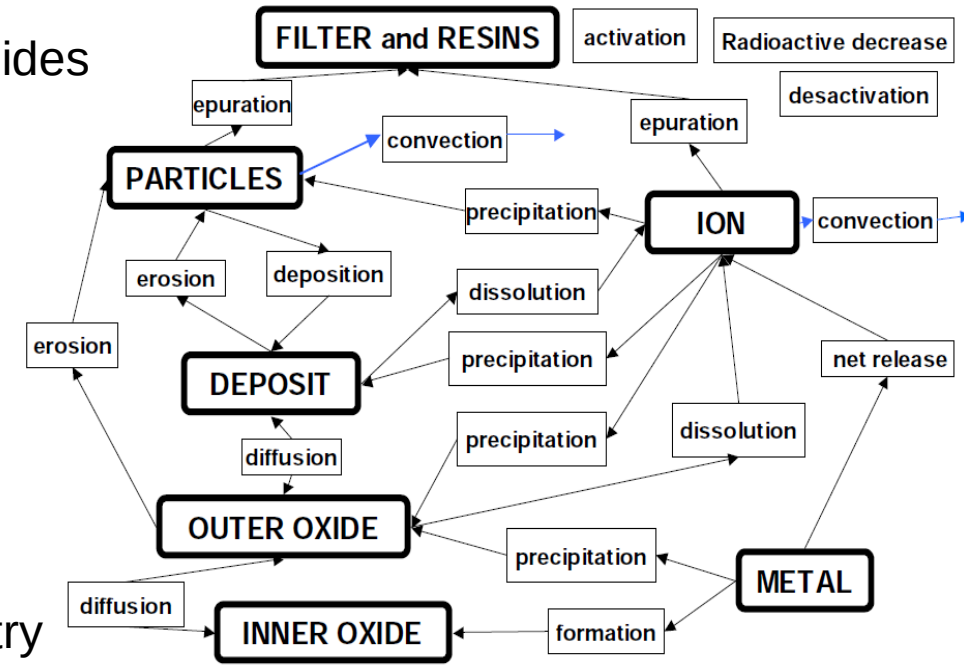
Complexity reduction by simplification



Nuclide vectors - 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

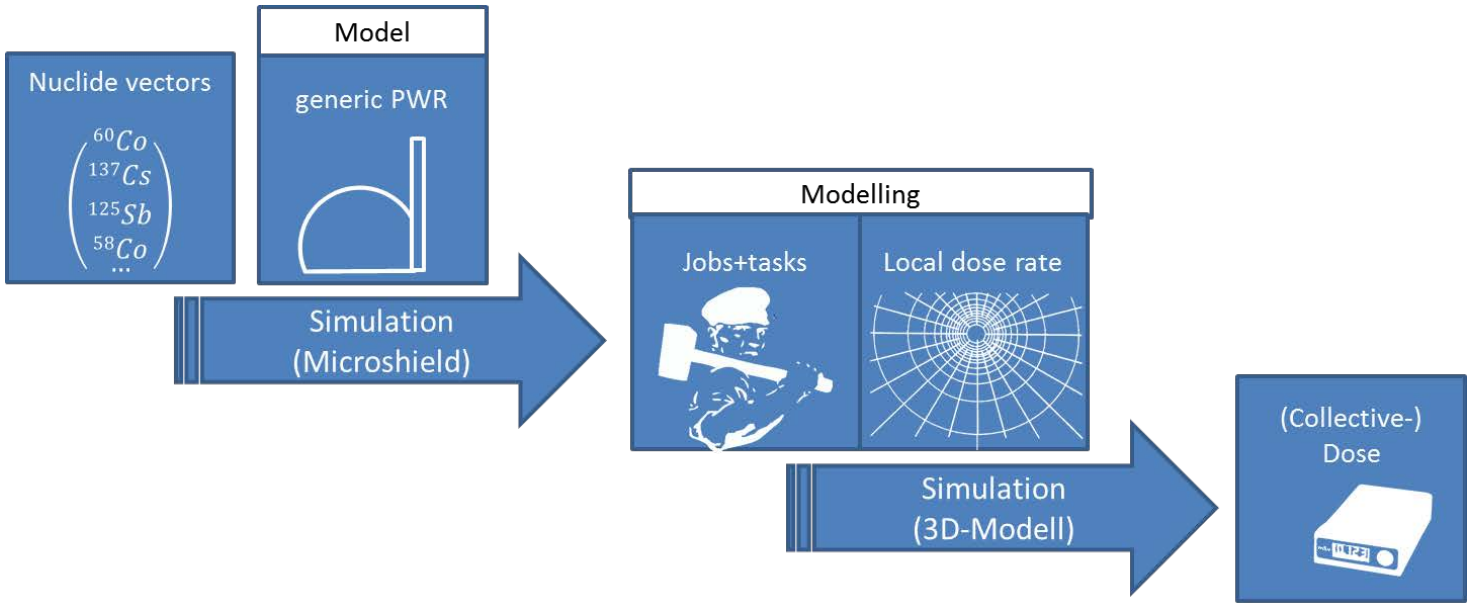
Basic information

- Data on radionuclide concentrations 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 based on:

- analysis of dissolved radionuclides within the primary coolant
- radiological impact of each nuclide
- physical / chemical / geometrical considerations, material behaviour, information based on literature

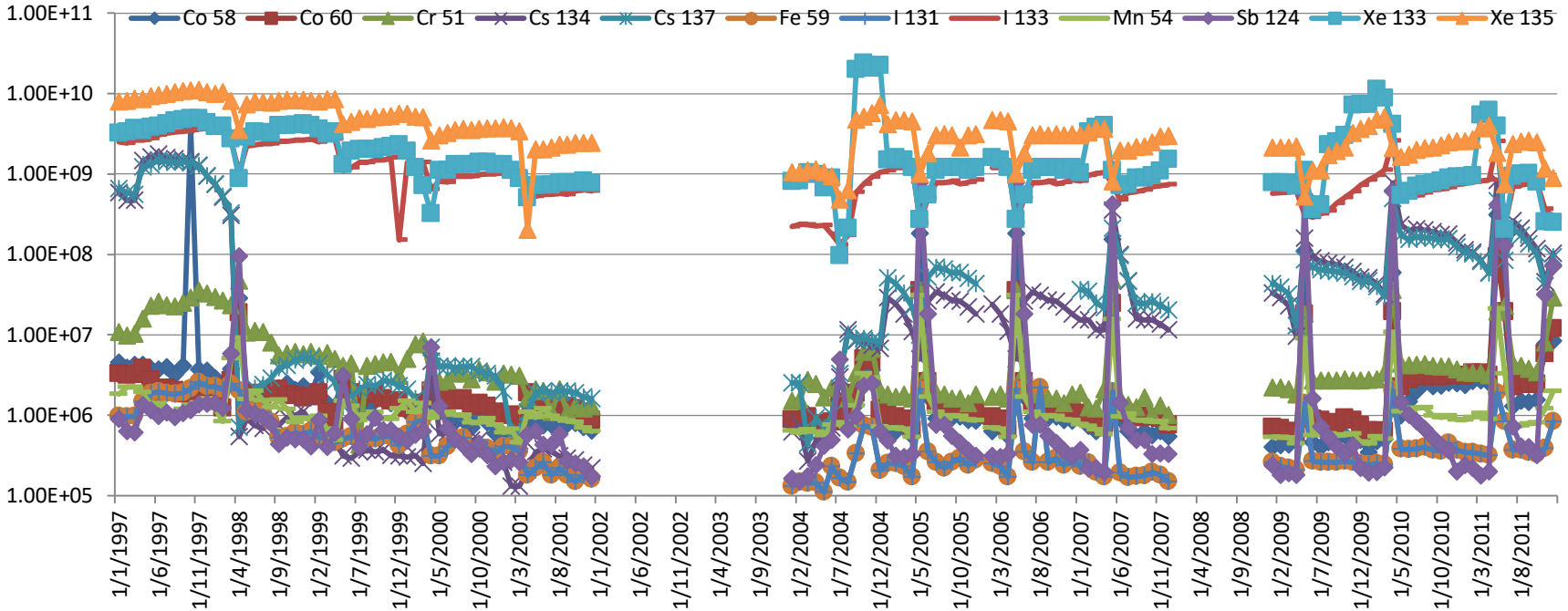
The *quantitative* determination of the nuclide vectors is based on:

- analysis of the activity concentration within the primary coolant
- reverse simulation from known local dose rates (from site visits)

adherent contamination (deposits) for specific components

NPP-generation-specific (mainly the Co-60 content is adjusted)

Modelling – nuclide vectors



Operation: ^{16}N

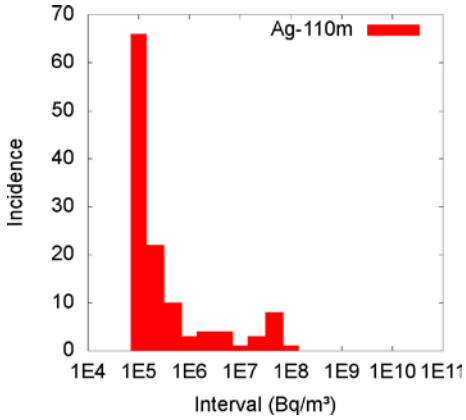
Overall maintenance and refuelling outages and decommissioning: ^{51}Cr ^{54}Mn ^{59}Fe $^{58,60}Co$

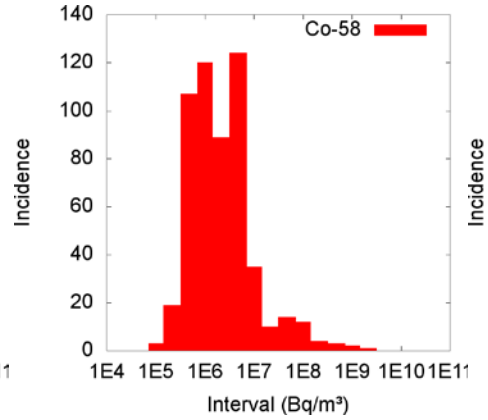
^{110m}Ag and ^{124}Sb are only relevant for specific plants

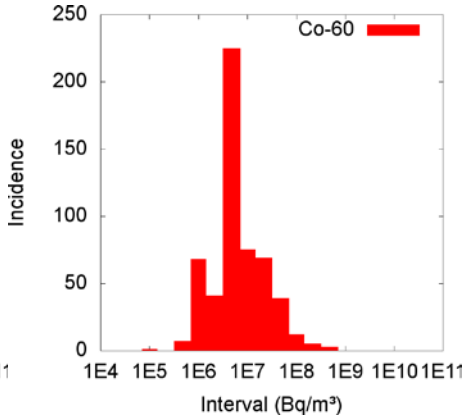
=> thus not considered in *generic* model

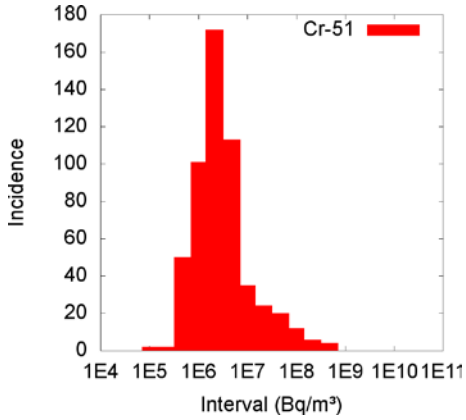
Modelling – nuclide vectors

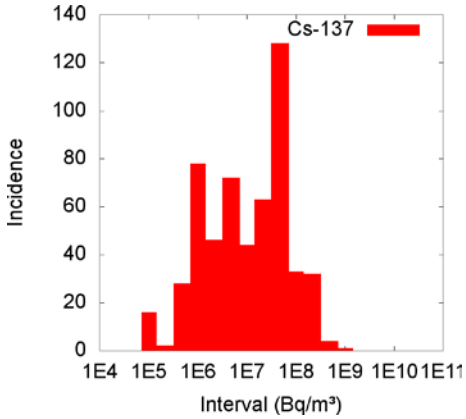
Generation 2 of Siemens/KWU PWR

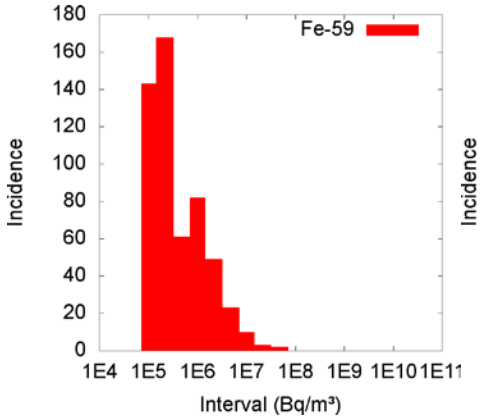


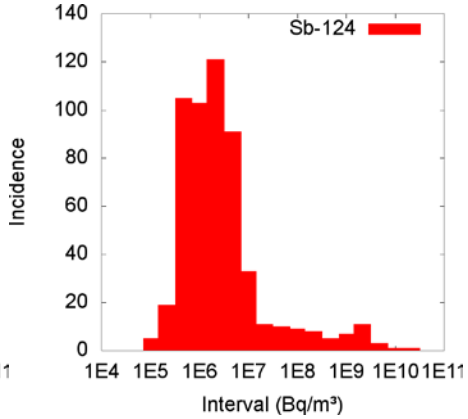


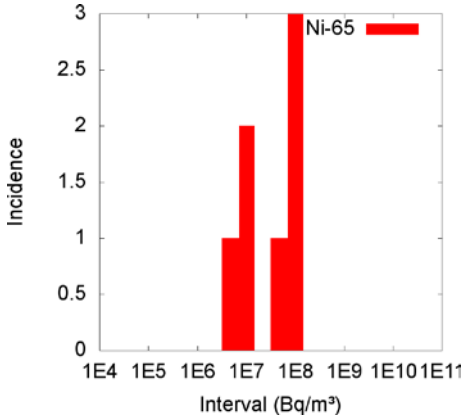












Modelling – 3D model

Description of the geometric situation

- Arrangement of sources and shieldings, locations and distances
- Dimensions of sources and shieldings
- Determine distances and angles

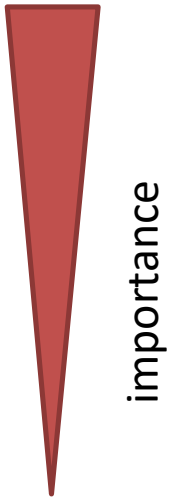
Model helps to decide

- 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

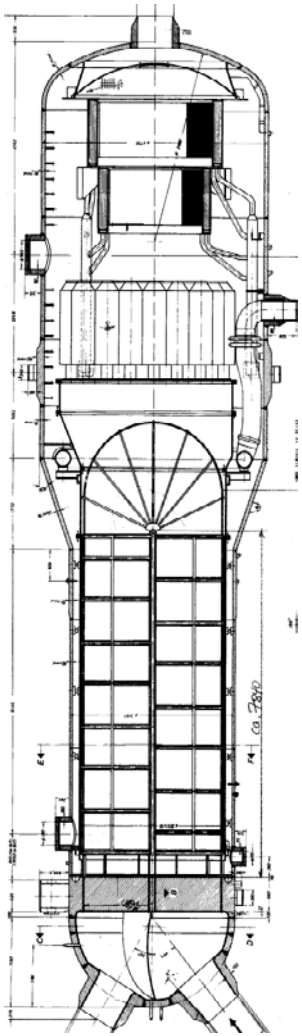
Different coordinate systems and limitations of different software components require some adaptations:

- 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

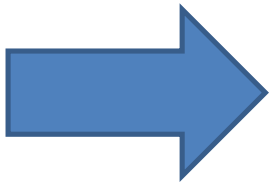


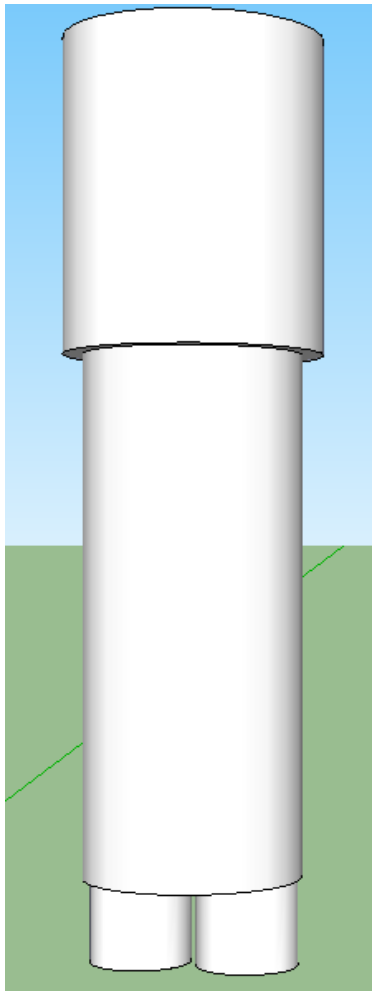
- Coordinate transformation
  - Global coordinates in Sketchup
  - Source-related coordinates in MicroShield

Modelling – dose rate calculations using MicroShield



Steam generator



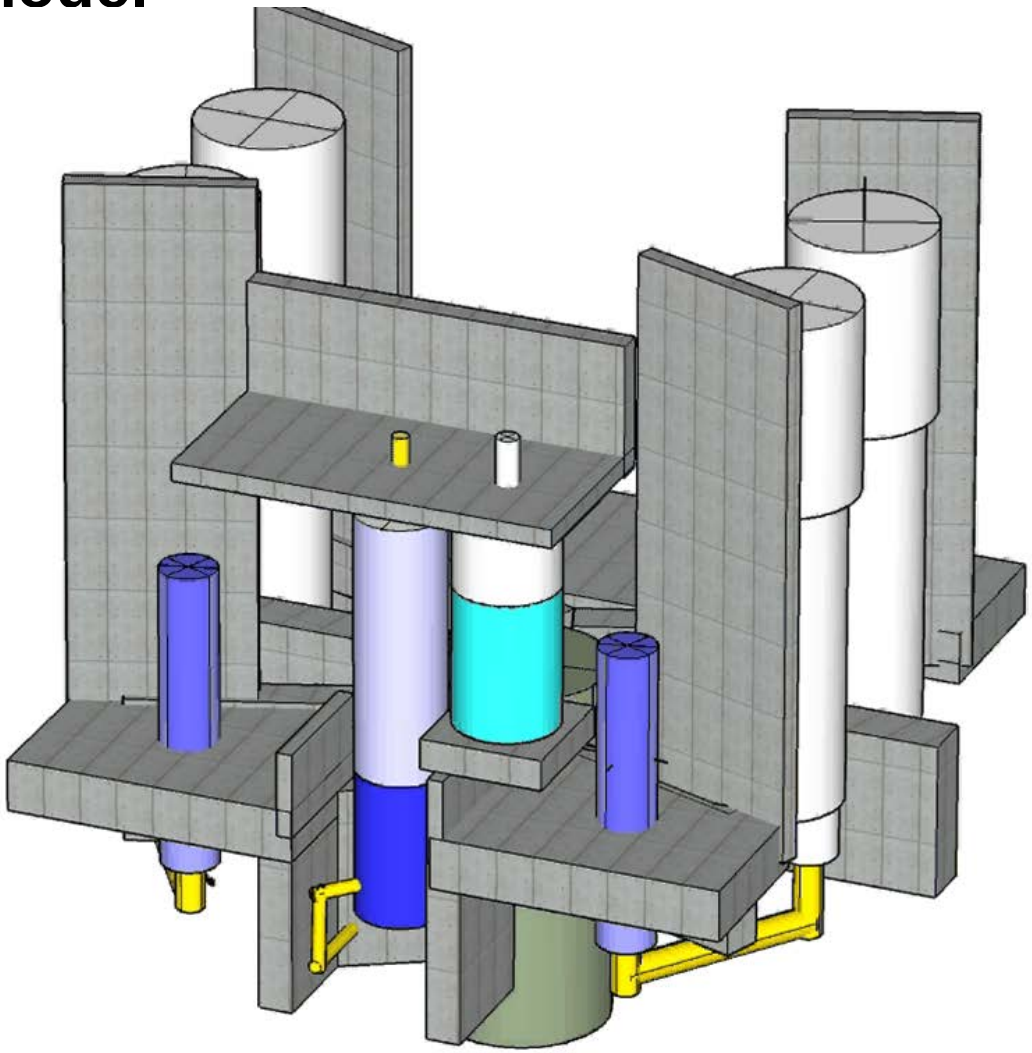


Shielding only

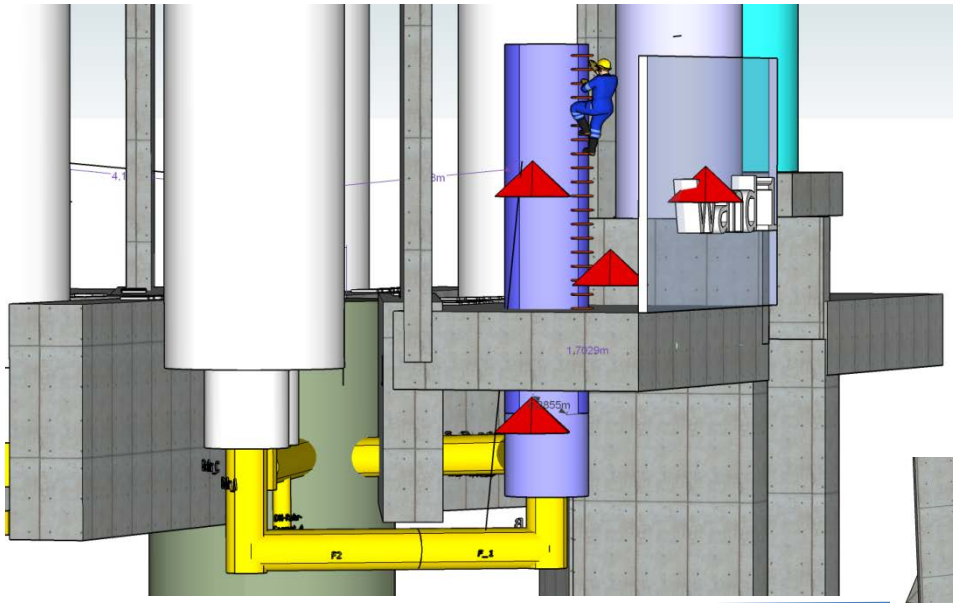
Source 1
+ Shielding

Sources 2 / 3
+ Shielding

Modelling – 3D model

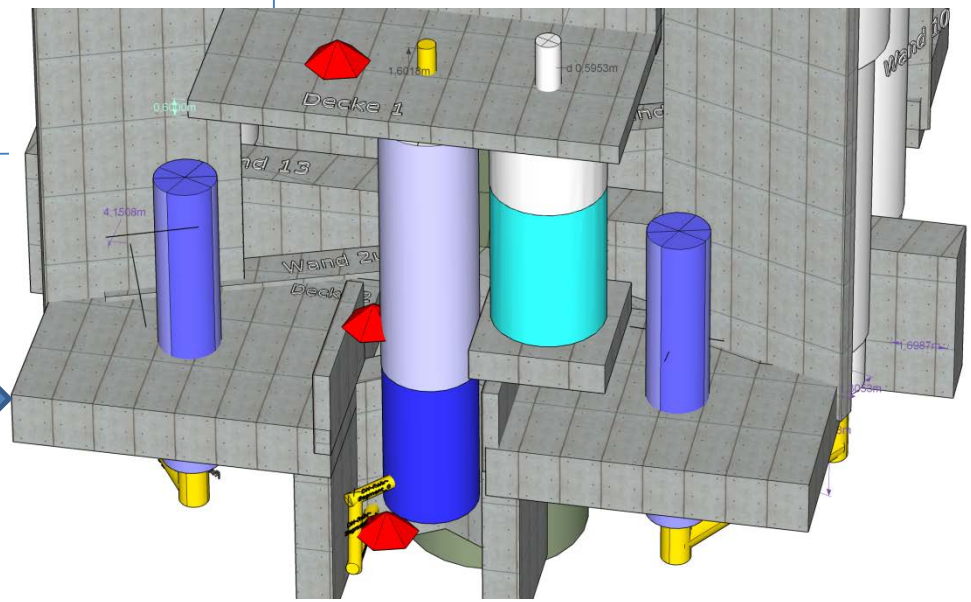


Modelling – considering Jobs



Jobs at coolant pumps

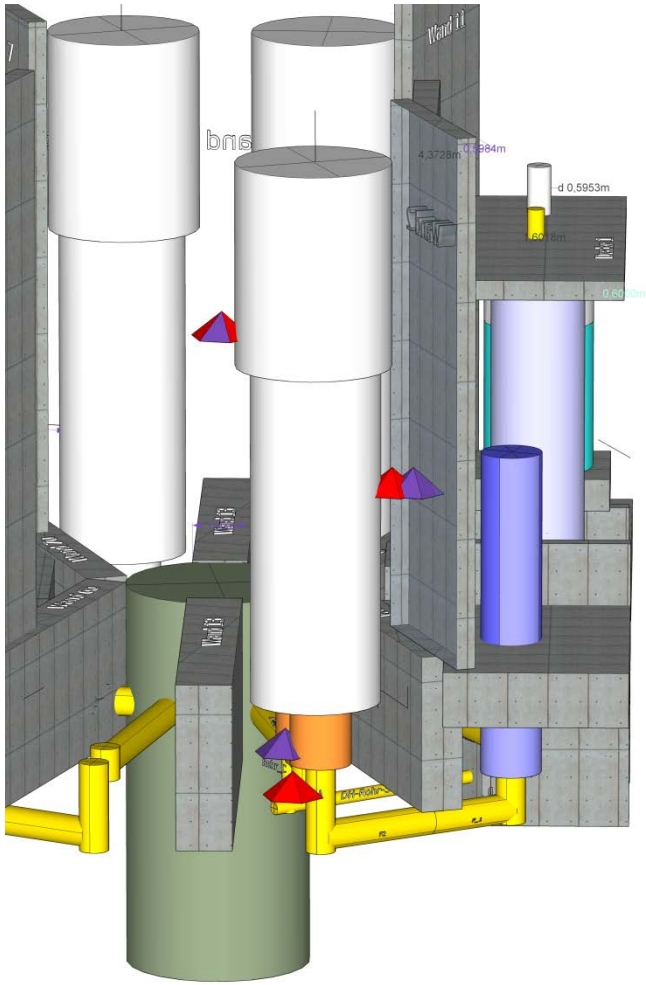
Pressurizer maintenance and repair



Modelling – considering Jobs

Dismantling of a steam generator (in 2 steps)

- Neighboring SG already removed
- Secondary water inside for 1st step (preparation)
- Additional shielding at water chambers (orange)
- Secondary water removed for 2nd step (unmounting, dismantling)



Modelling – considering jobs

The following jobs are simulated

Overall Maintenance related:

- job-related to the reactor coolant pumps
- pressurizer maintenance and repair
- steam generator eddy current testing

Decommissioning related:

- Dismantling of steam generators
- Dismantling of reactor coolant pumps

Modelling – considering jobs

- Mean working time for each job/craft
- Pathways, breaks, changing clothes considered as a 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

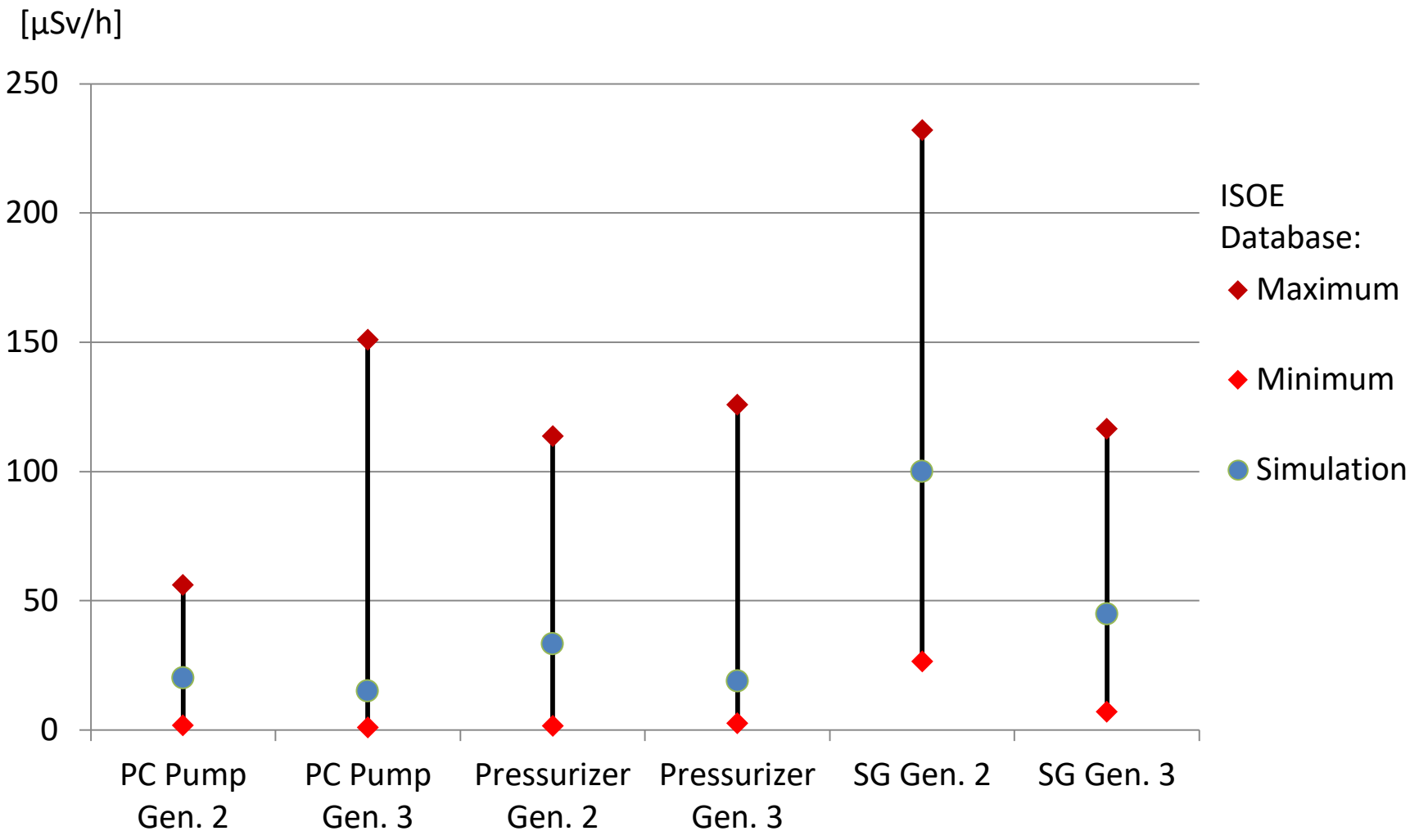
- Retention times at the points – mean values extracted from ISOE database

Results (tasks at reactor coolant pumps)

Overall maintenance and repair jobs related to the **reactor coolant pumps**

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

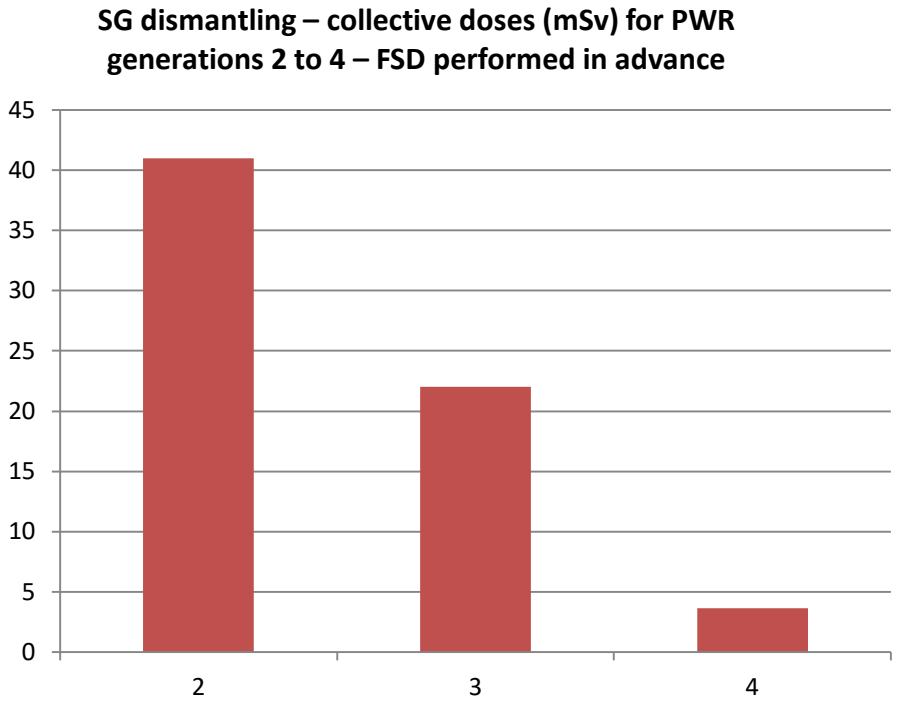
Results (overall maintenance related)

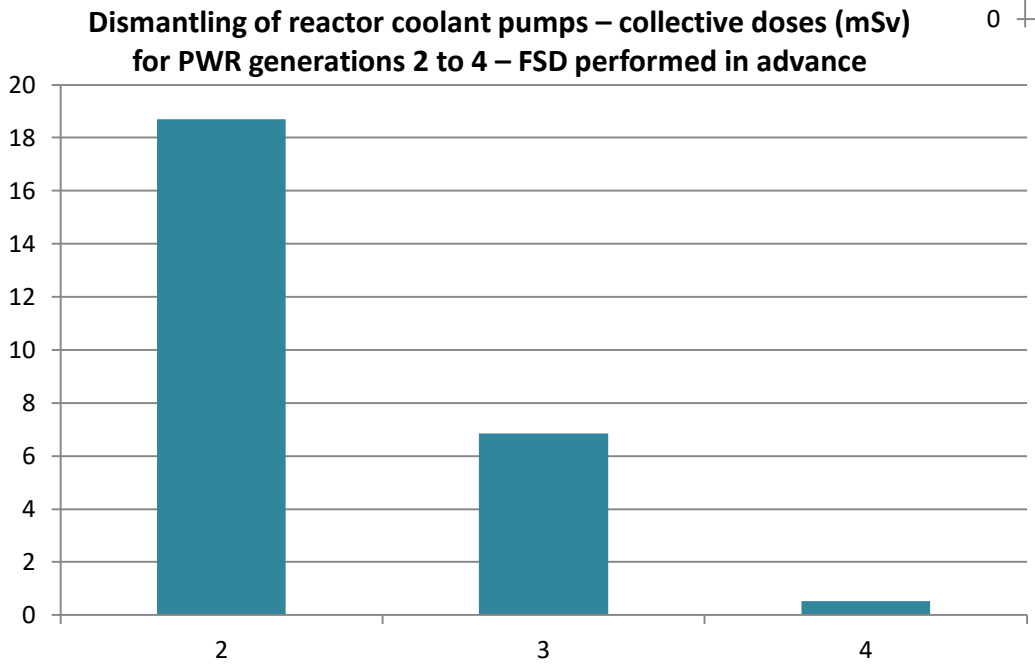


Results (decommissioning related)

Expected collective dose for dismantling of steam generators and reactor coolant pumps **decreases** for german PWR generations

(KWU/Siemens PWR generation 2 to 4)





No experimental data
for comparison available (yet)

Results (decommissioning related)

- Results of the simulation for decommissioning work are reasonable
- Collective dose of the personnel decreases for newer plant generations (as expected)
- Measured data from German PWR in decommissioning exist only for generation 1 plants, that are somewhat compareable to generation 2 plants
- Within the accuracy of the simulation, measured data (gen. 1) and the simulation (gen. 2) are in accord

Summary

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

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

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