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

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

## Introduction and motivation

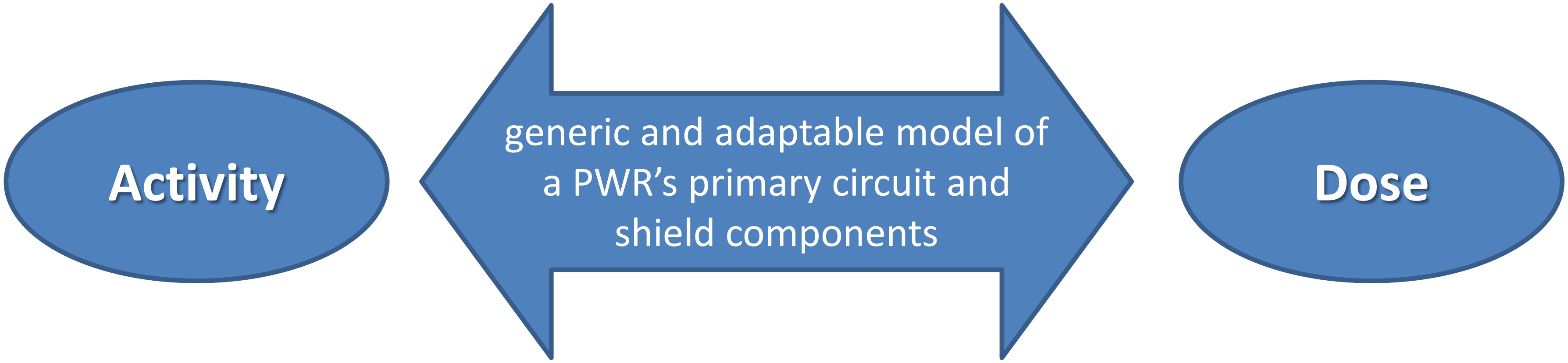
- Occupational doses are determined by a number of parameters, including:
  - activation → shielding only
  - contamination → chemical operation mode; (F)SD
  - geometry of shielding
  - self-shielding of components
  - deposits of radionuclides; hot-spots
  - planning of tasks
  - behaviour of workers

**The blue coloured items are addressed by our model**

# Introduction and motivation

Numerous parameters influencing radiation exposure – complex problem

Complexity reduction by simplification



# 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

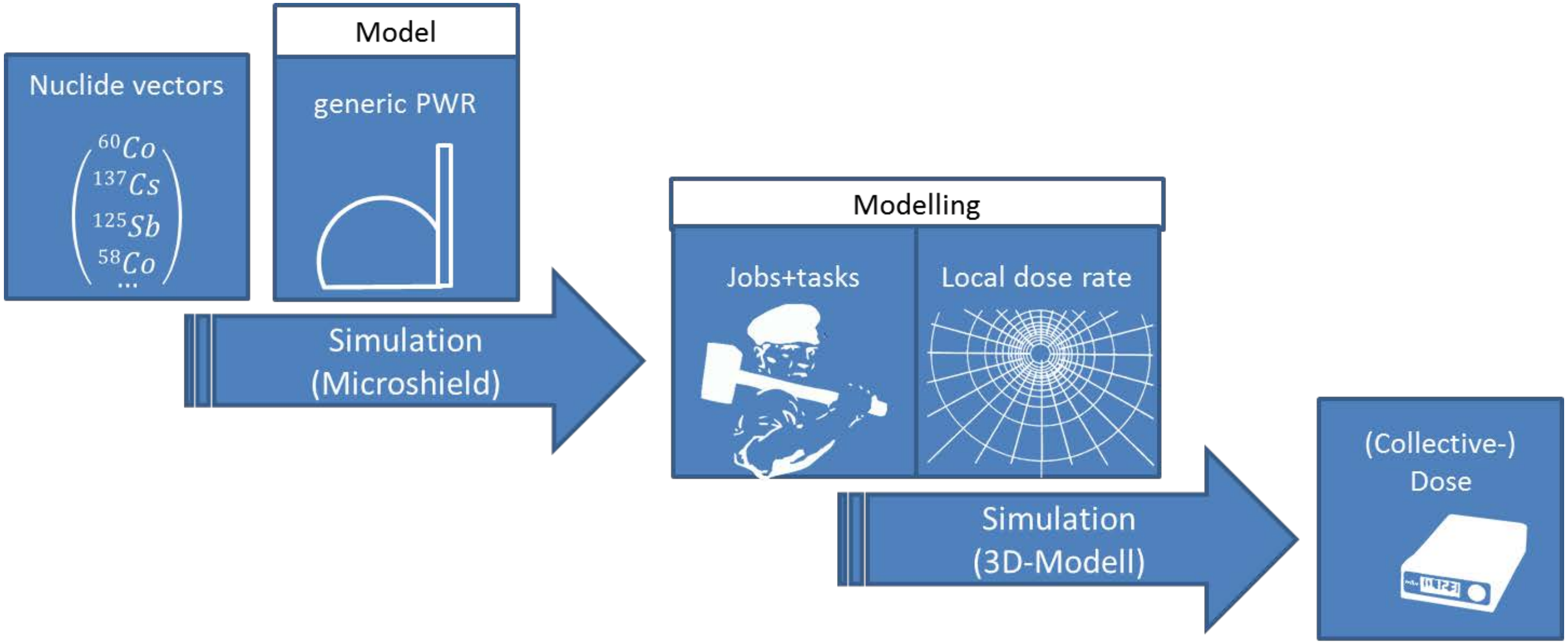
- Engineering drawings and technical documentation for German PWR reactors

- 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)



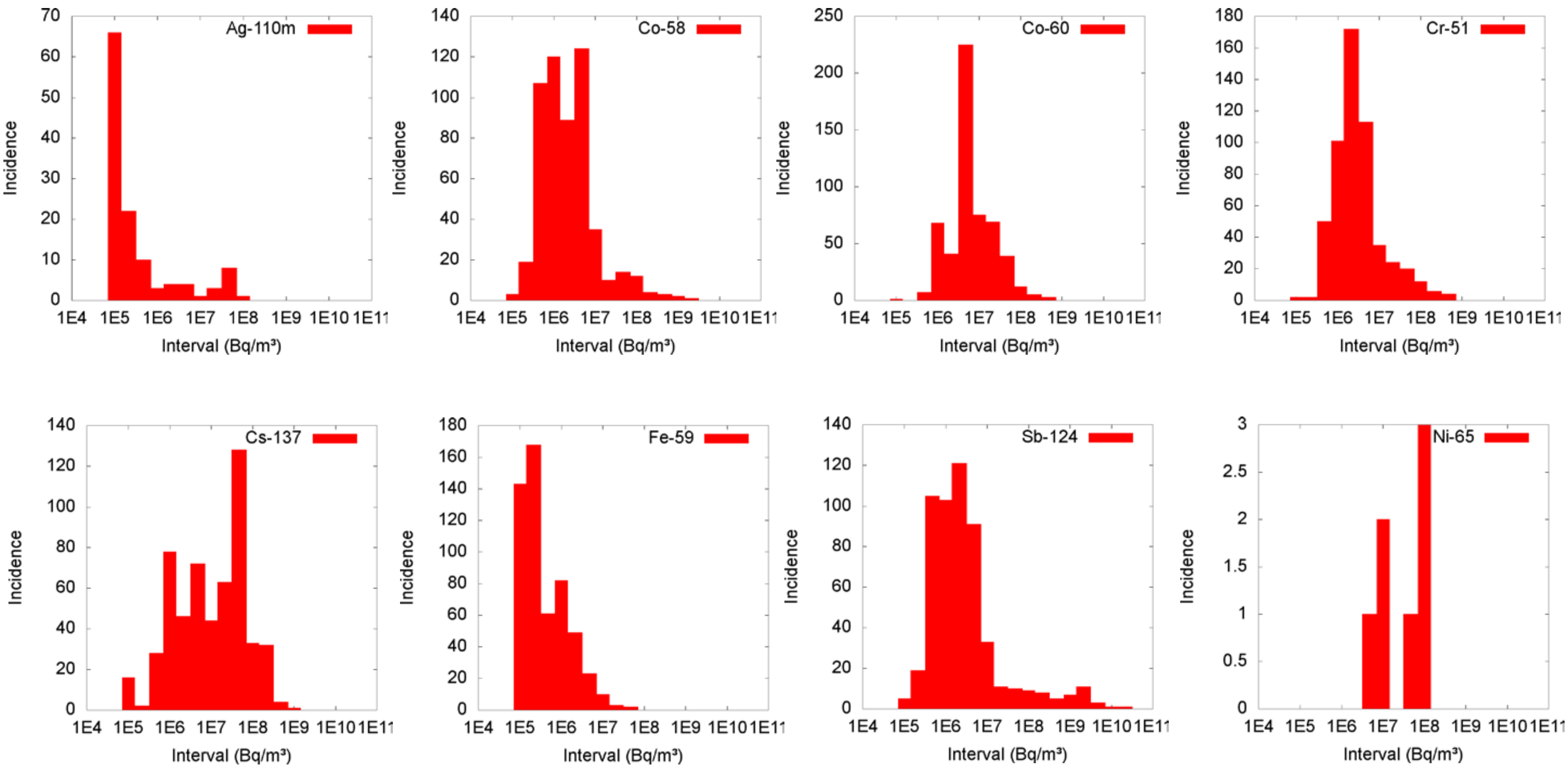
## Modelling – nuclide vectors

- 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

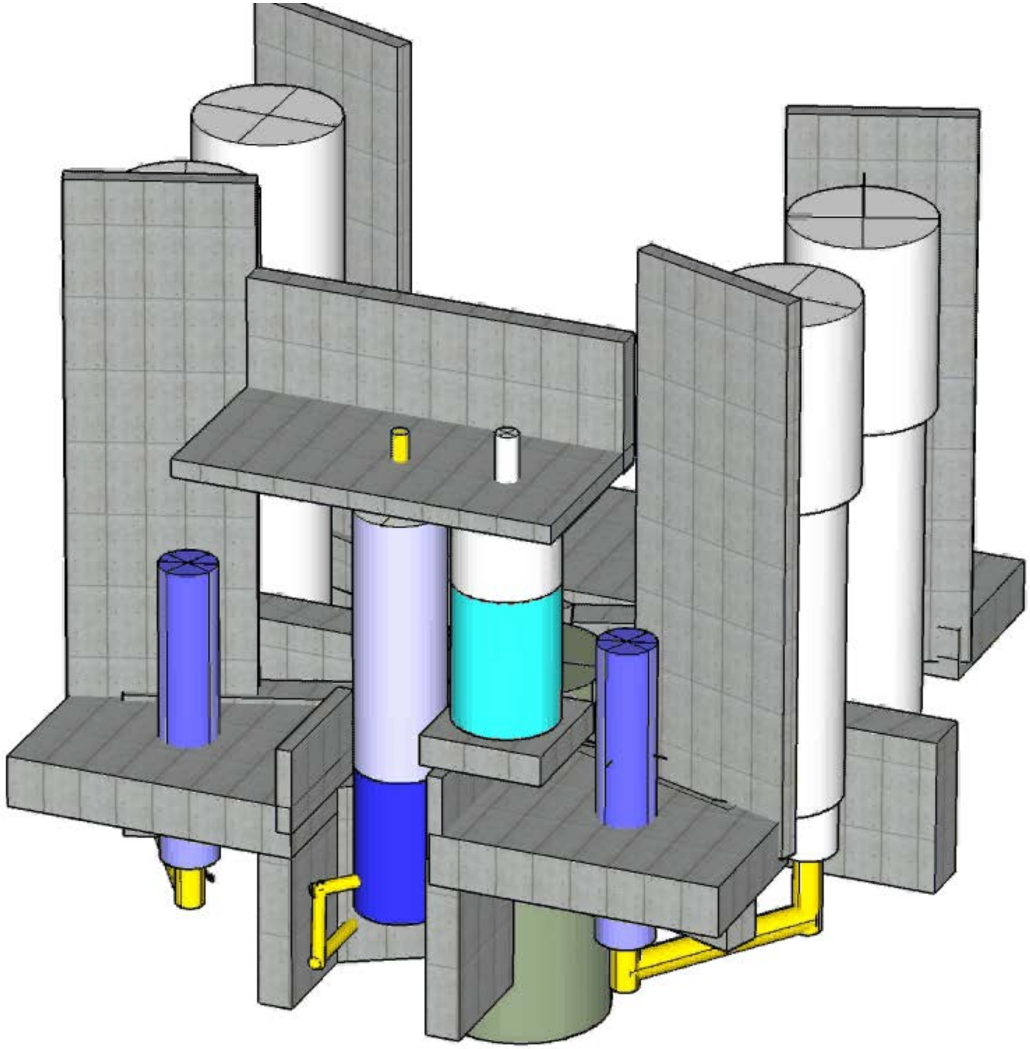
- Defined for contamination (deposits)
- Component-specific
- NPP-generation-specific (mainly the Co-60 content is adjusted)

# Modelling – nuclide vectors

## Generation 2 of Siemens/KWU PWR



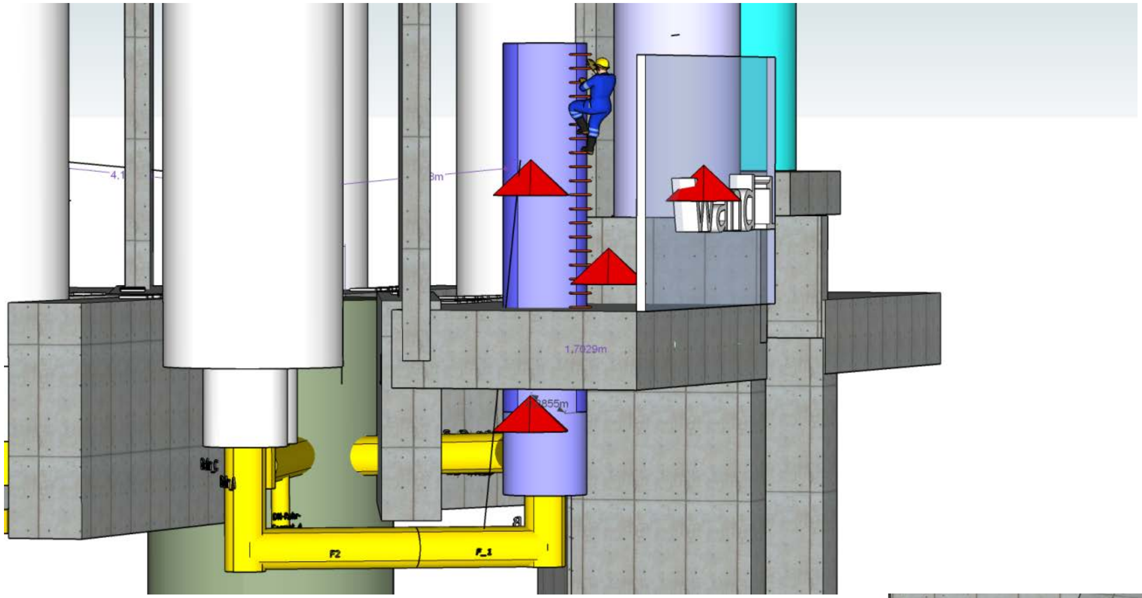
# Modelling – 3D model



# Modelling – considering jobs

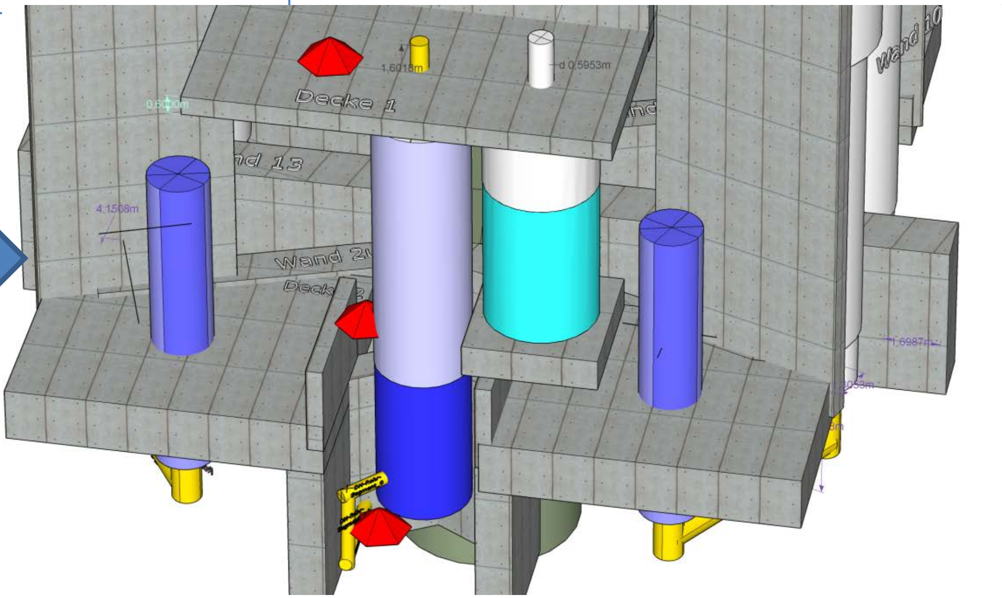

- The following jobs are simulated
  - jobs related to the reactor coolant pumps
  - pressuriser maintenance and repair
  - steam generator eddy current testing
- Mean working time for each job/craft
- Pathways, breaks, changing clothes is simulated as one shielded point
- Characterisation of representative 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



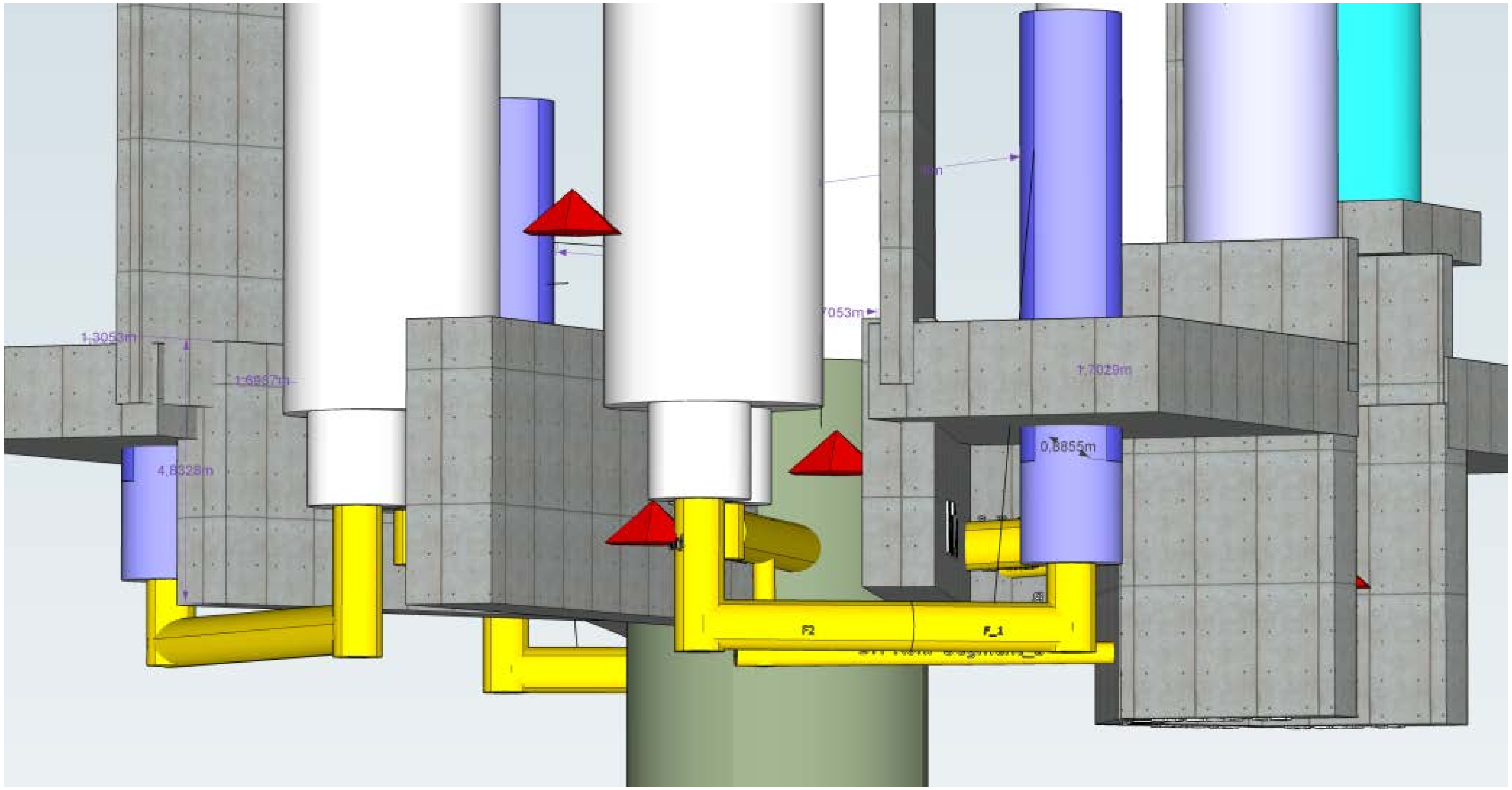

Jobs at coolant pumps

Pressuriser maintenance and repair



# Modelling – considering Jobs

Steam generator eddy current testing

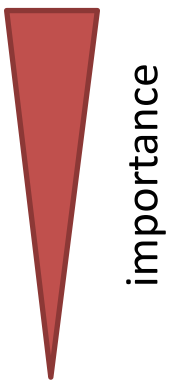


# Modelling – dose rate calculations using MicroShield

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

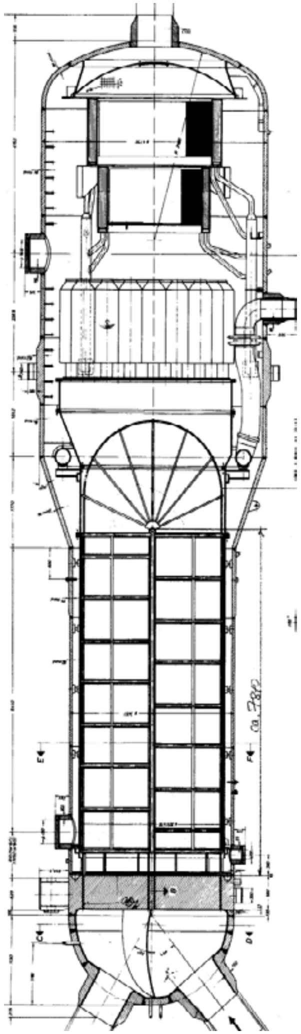
  - Simplification of components

    - 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

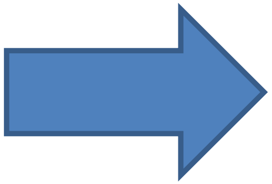


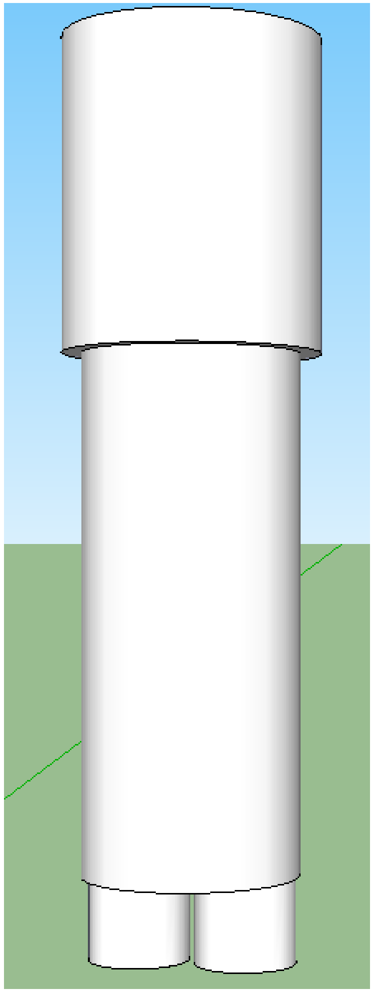

  - Coordinate transformation
    - global coordinates in Sketchup
    - source-related coordinates in MicroShield

# Modelling – dose rate calculations using MicroShield



**Steam generator**





Shielding only

Source 1
+ Shielding

Sources 2 / 3
+ Shielding

# Results and discussion

**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 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 µSv |
| Collective dose Gen 3 per pump | 4.6 man mSv | 1.8 - 16.8 man mSv | 0.36 - 65 man mSv |

## Results and discussion

### Pressuriser maintenance and repair

| Item | Simulation result | Range of plant mean values | Range of measured single values |
|---|---|---|---|
| Individual mean dose Gen 2 | 1075 µSv | 241 - 400 µSv | 2 - 830 µSv |
| Collective dose Gen 2 | 86 man mSv | 7-60 man mSv | 0.1-270 man mSv |
| | | | |
| Individual mean dose Gen 3 | 528 µSv | 90 - 260 µSv | 23 - 367 µSv |
| Collective dose Gen 3 | 42 man mSv | 5 - 128 man mSv | 0.8 - 981 man mSv |

- 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