Accident Progression and Consequence Calculations for Low Power and Shutdown PSA Level 2 of Mühleberg NPP

10TH EUROPEAN MELCOR USER GROUP MEETING (EMUG)

UNIVERSITY OF ZAGREB - FACULTY OF ELECTRICAL ENGINEERING AND COMPUTING (FER)
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BKW

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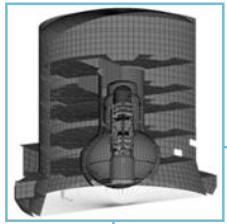
BKW Engineering
Our services at a glance

Safety Analysis and Risk Management

As operator of a nuclear power plant for 45 years, we are experts in safety and thermal hydraulic analysis, structural mechanical calculations and the material ageing phenomena. Handling technical and economic risks is our strength.

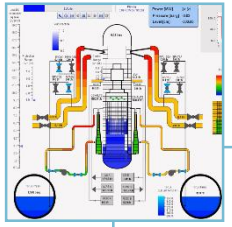
- Safety and system analysis of nuclear facilities
- Power operation, shutdown, decommissioning
- Deterministic safety analyses
- Thermo-hydraulic analyses (RELAP, TRACE, ATHLET, MELCOR)
- Coupled thermo-hydraulic/neutronkinetic analyses (Relap5/S3K, TRACE/PARCS)
- Radiological safety analysis
- Probabilistic safety analysis
    - Levels 1 and 2
    - Risk of core damage and potential radioactive releases
    - Data analysis, component reliability analysis, risk monitoring
    - Human reliability analysis
- Severe Accident Management Guidance (SAMG) development and training
- Licensing support

BKW Engineering
Collaboration between BKW and PSI



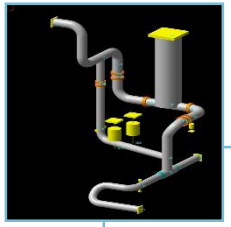
Safety

- Project management of nuclear engineering projects
- Probabilistic, deterministic, and radiological safety analysis for operation, shutdown, and decommissioning of plants
  - Analyses of earthquake, flood, fire events, etc.
  - Human reliability analysis
  - Statistical data analysis
  - Risk management
- Severe accident management guidance (SAMG)
- Licensing support



Multi Physics

- Coupled multi physics analysis
- Thermal hydraulics analysis of BWR and PWR (RELAP, TRACE, ATHLET)
- Computational fluid dynamics (application)
- Subchannel and DNB/CPR analysis
- Core analysis
- Neutron transport / activation
- Fuel cycle physics and criticality safety analysis
- Fuel behavior
- Severe accident analysis (MELCOR)
- Containment thermal hydraulics



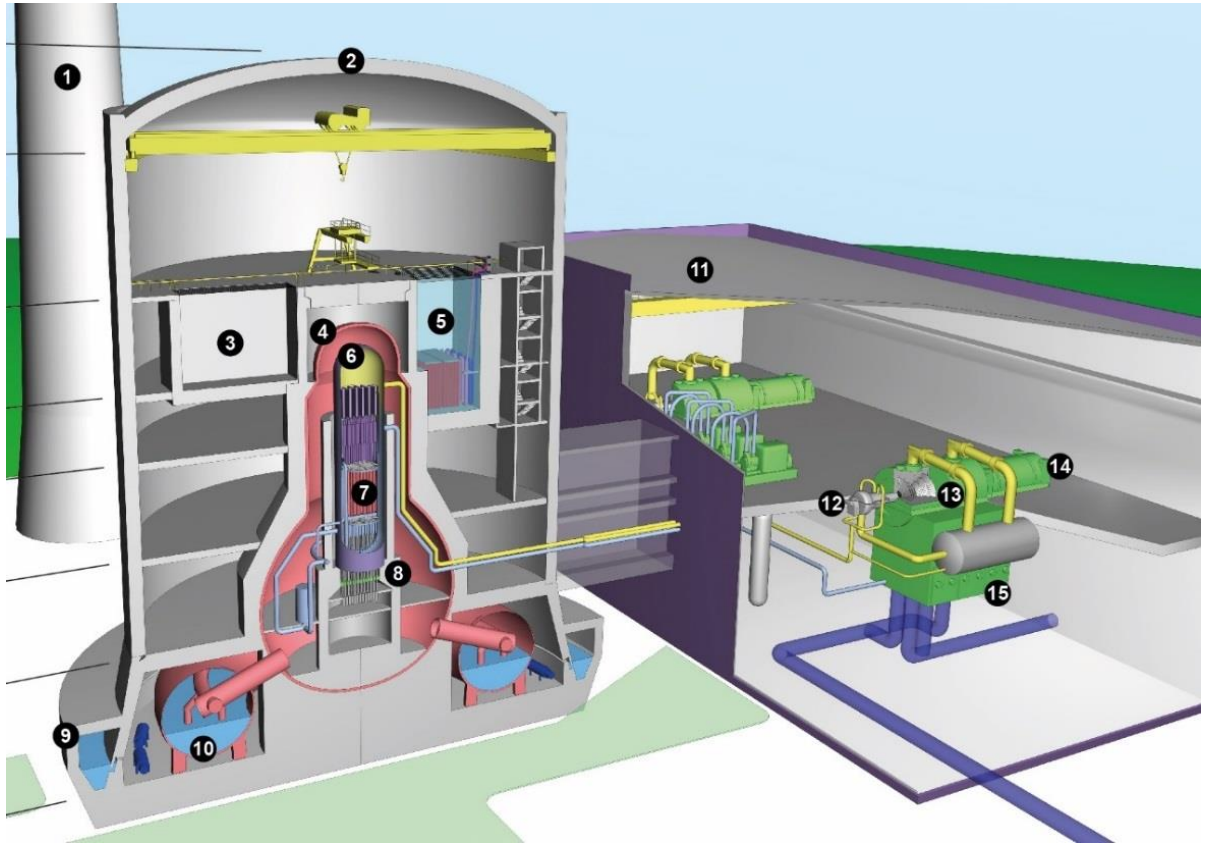
Mechanics

- Structure mechanics
- Structure dynamics
- Finite element analysis
- Piping analysis
- Fracture mechanics
- Ageing management

https://www.bkw.ch/en/about-us/media-relations/detail/news/detail/News/bkw-und-psi-bieten-gemeinsam-dienstleistungen-fuer-sicherheitsanalysen-an/

BKW Mühleberg Nuclear Power Plant
Overview

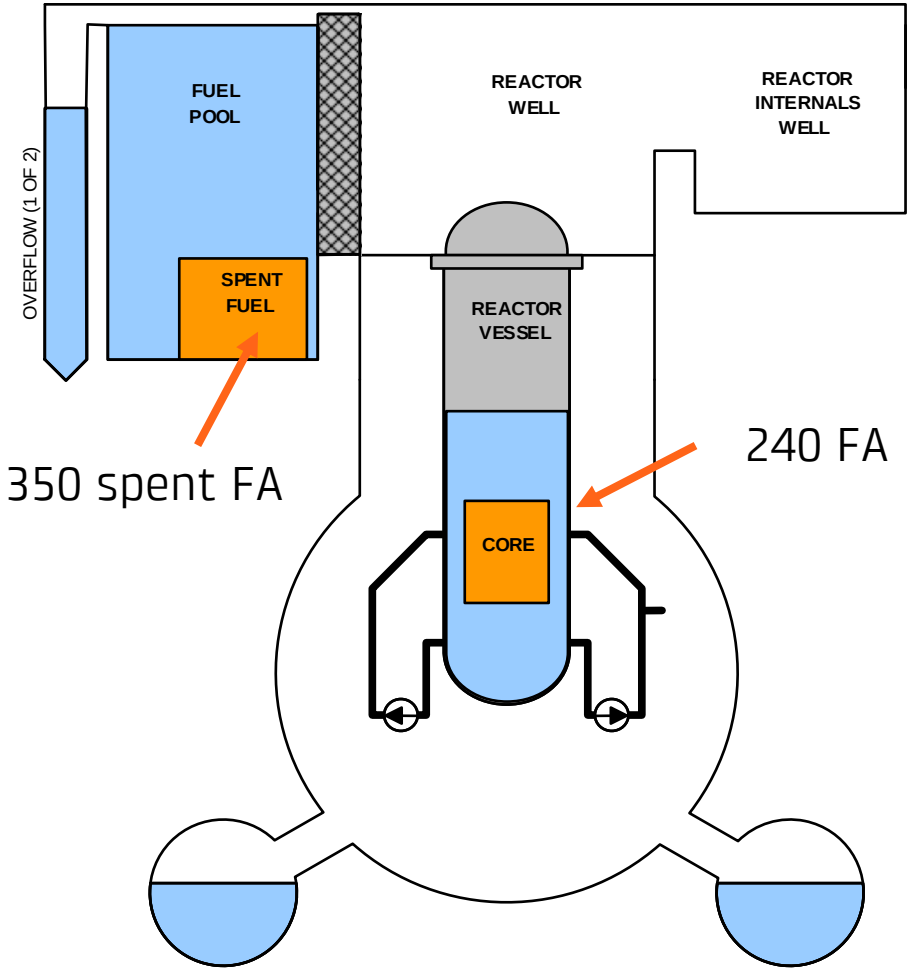
- Reactor: General Electric BWR 4
- Commissioning: 1972
- Final shutdown: December 2019
- Power: 373 MW el., 1097 MW th.
- Core: 240 fuel assemblies type 10x10 GNF2
- Containment: Mark 1
- Containment depressurization system with outer torus
- Secondary containment:
  Concrete Structure
- Bunkered building for emergency systems



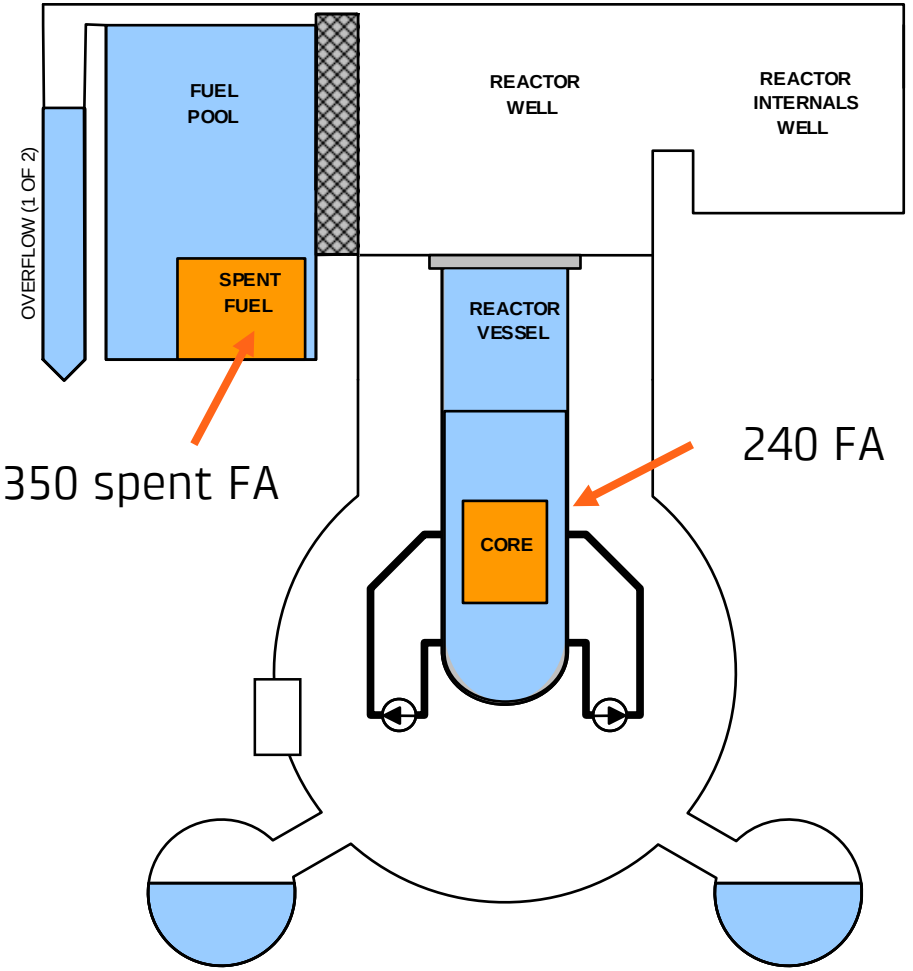
BKW Mühleberg Nuclear Power Plant

Low Power and Shutdown Conditions

Phase 1A: Preparation of RPV head removal



Phase 1B: Removal of RPV internals



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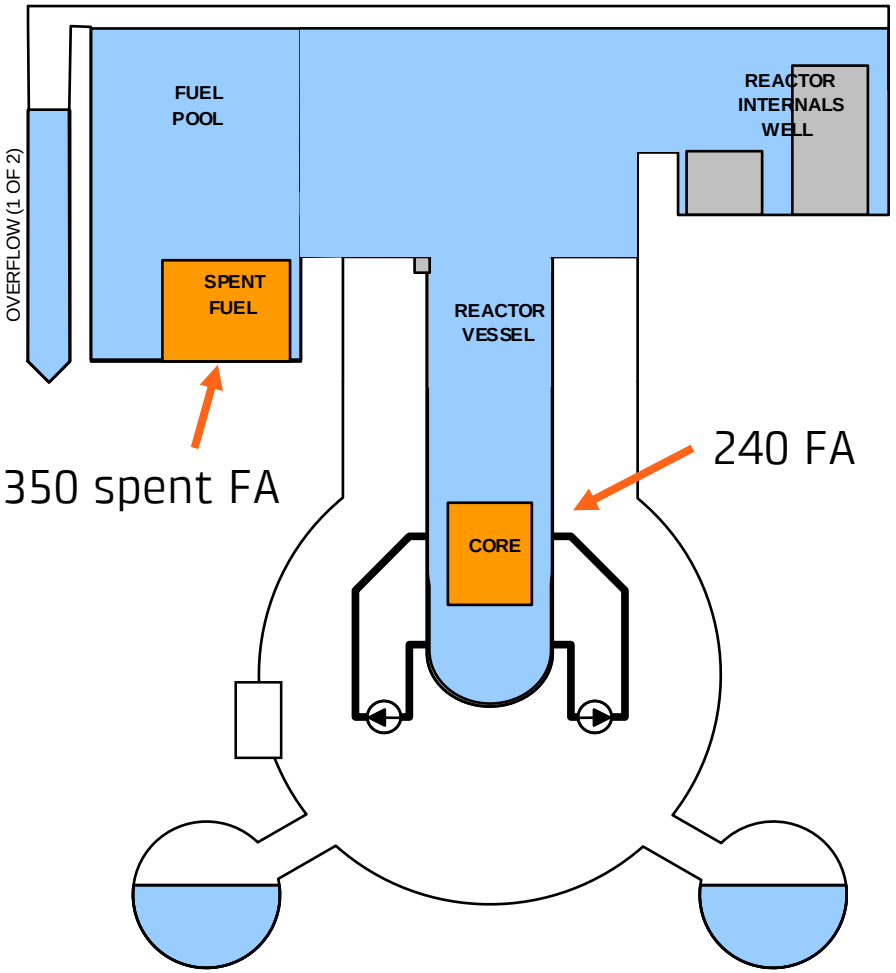
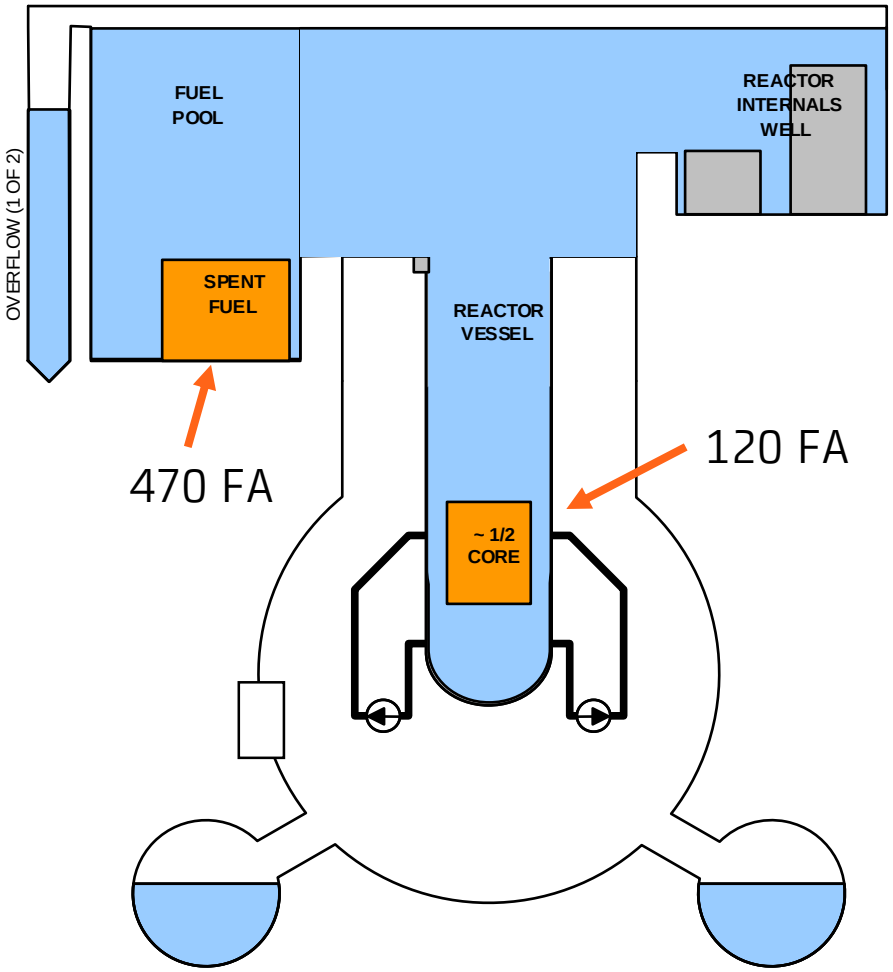
Low Power and Shutdown Conditions

Phase 2A: Fuel offloading



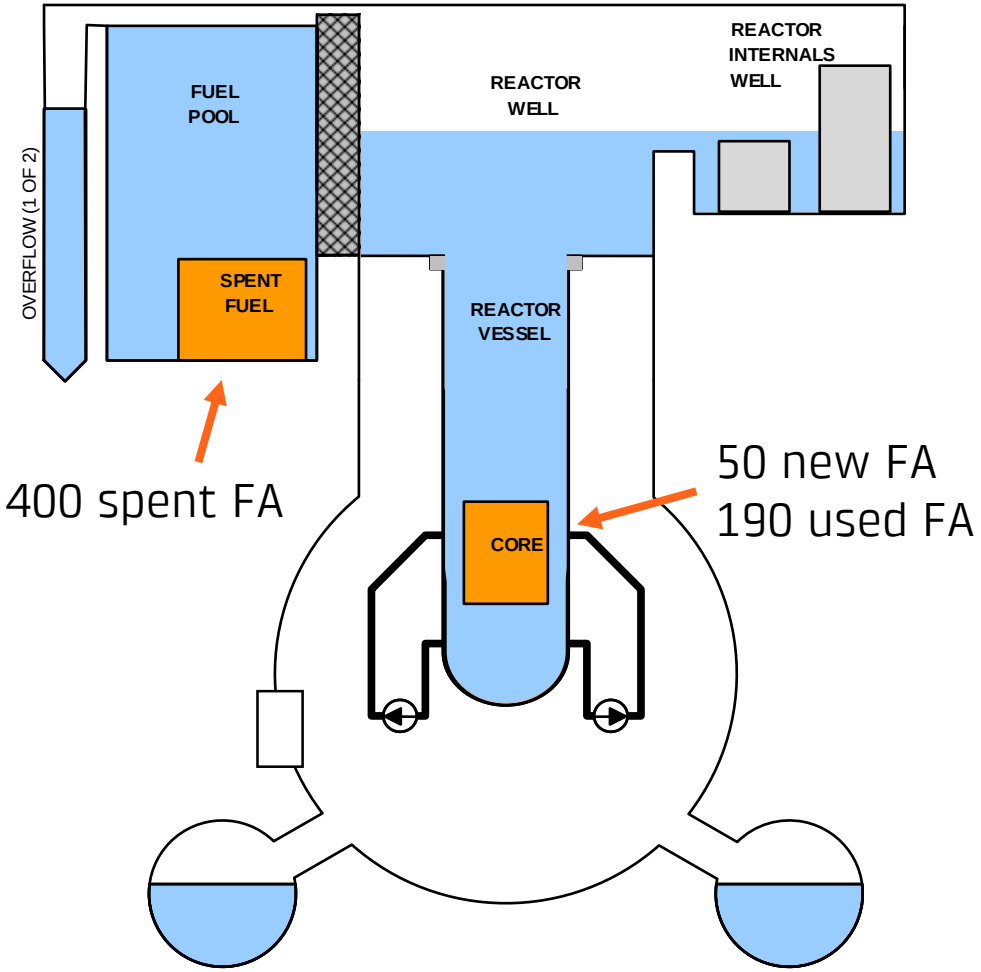
Phase 2B: Fuel reloading



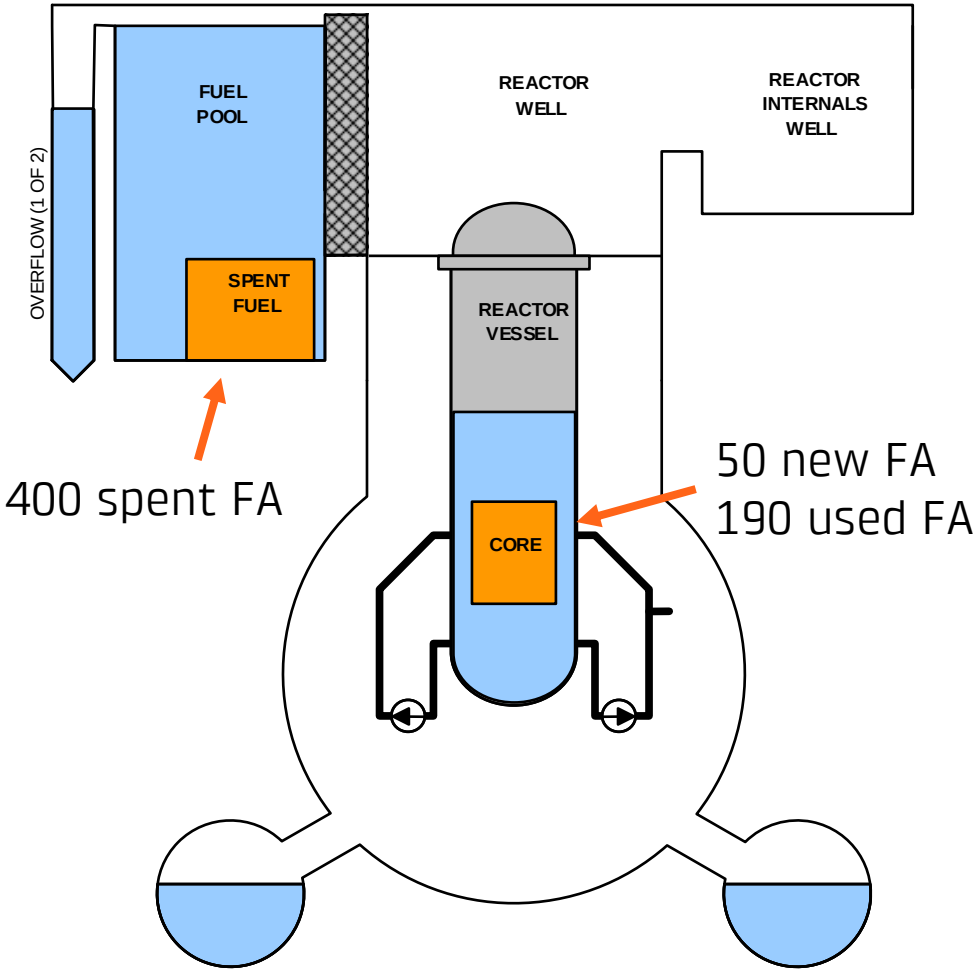
BKW Mühleberg Nuclear Power Plant

Low Power and Shutdown Conditions

Phase 3A: Placing back RPV internals



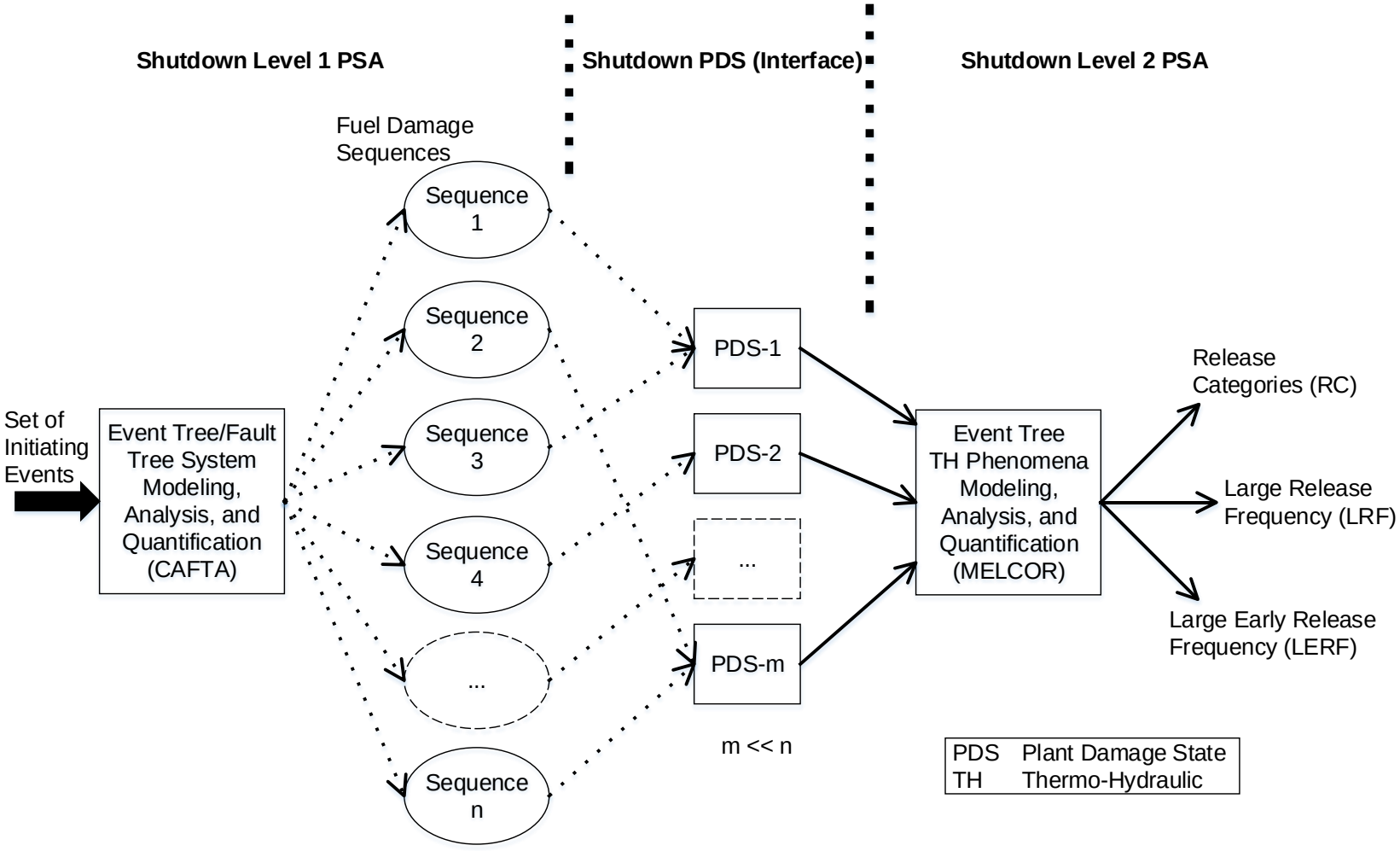
Phase 3B: Preparation for startup



Probabilistic Safety Analysis 2017

Mühleberg NPP: Integrated Level 1 – Level 2 PSA Model

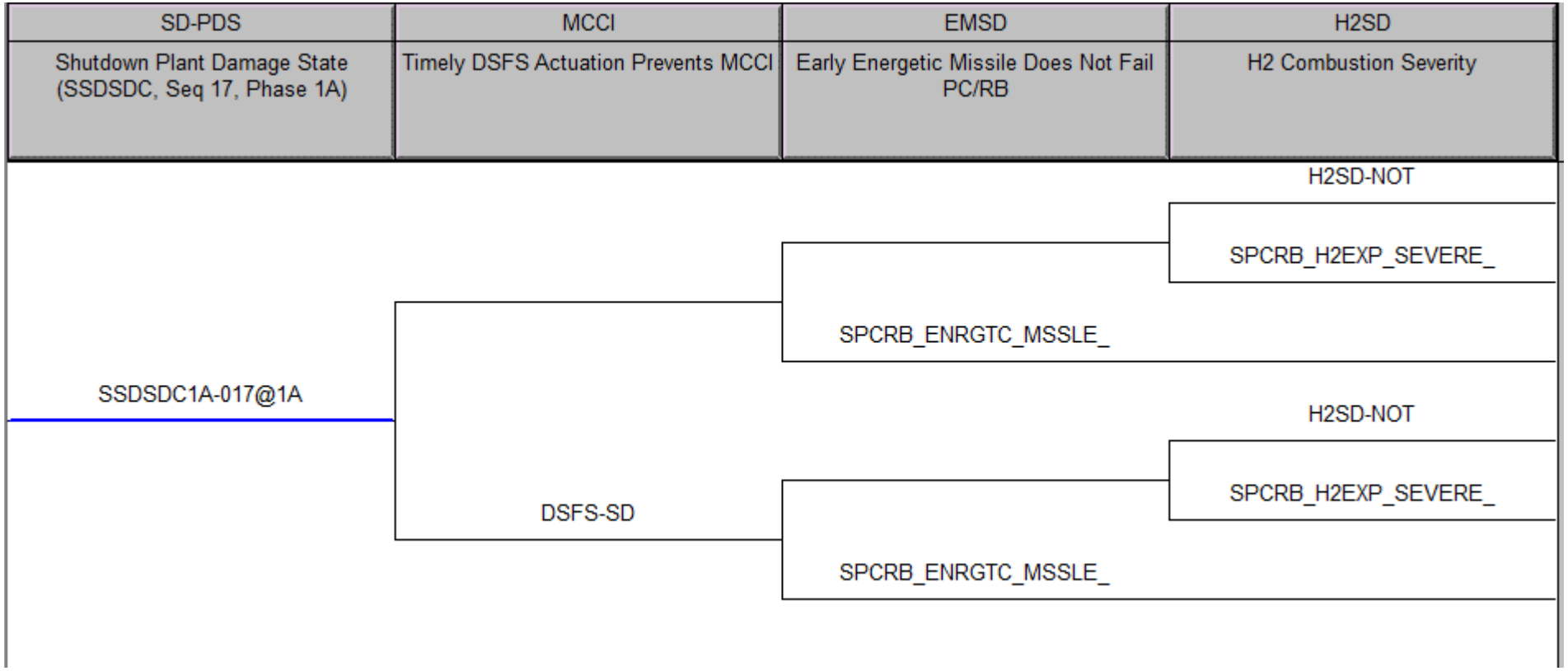
- Level 1 and Level 2 Models are joined together
- One combined Fault Tree
- One database
- One quantification Process
- Easy and quick calculations with one mouse click
- Very useful for many sensitivity studies
- The effect is directly present for shutdown FDF, LERF and LRF
- Well suited for Living PSA, outage planning and risk analysis



Probabilistic Safety Analysis 2017

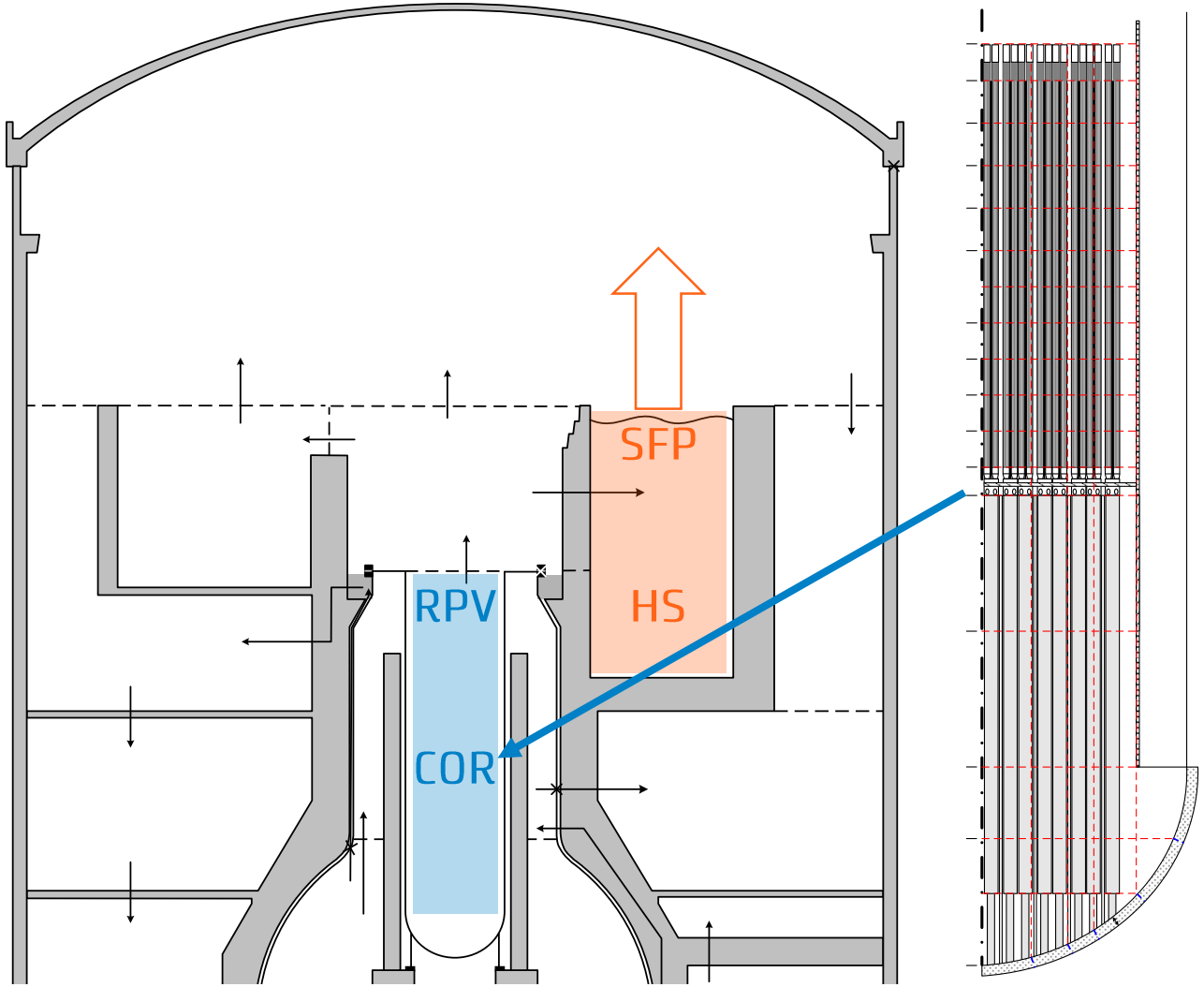
Mühleberg NPP: Level 2 Accident Progression Event Tree

- ~50 different plant damage states
- 6 different shutdown phases
- In total, ~400 event tree end states
- Example: Event tree for one accident sequence in shutdown phase 1A



Mühleberg MELCOR Models

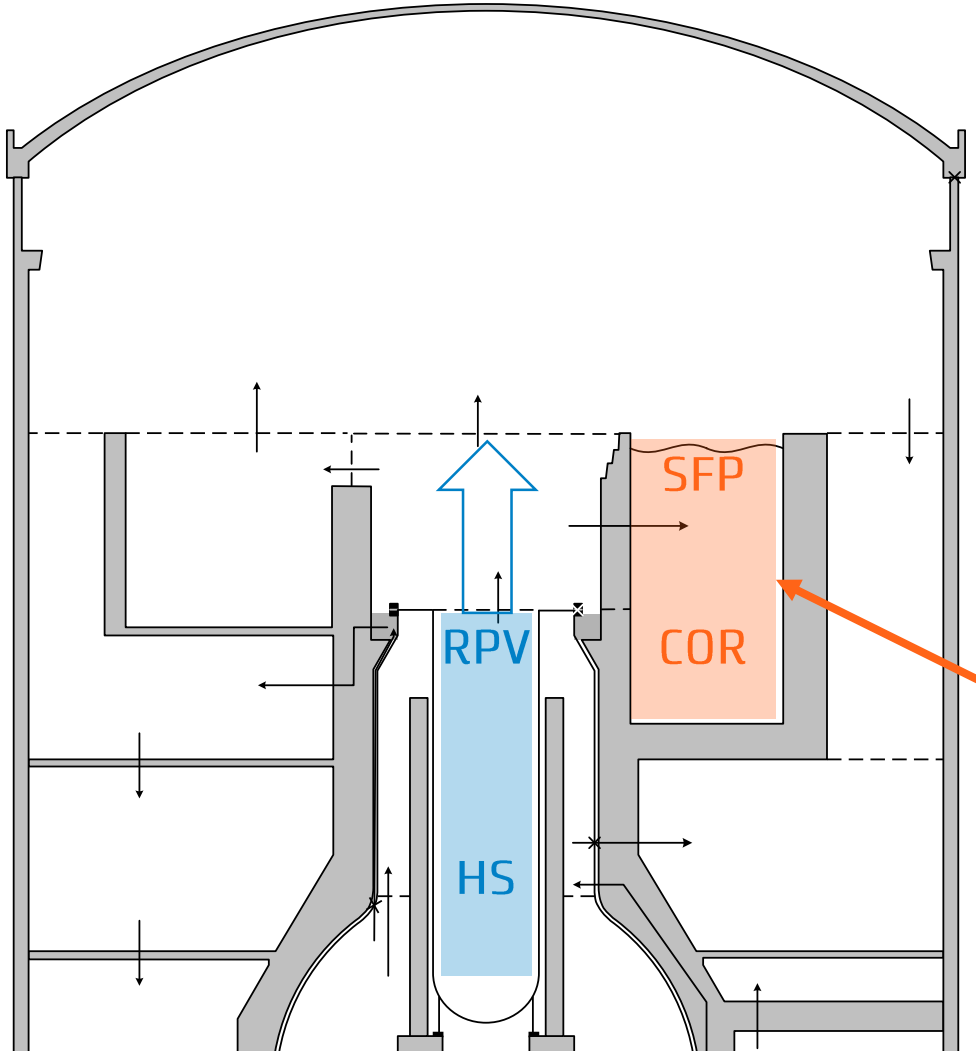
Reactor Models



- Purpose: calculate the progression of potential accidents in the reactor
- 3 different reactor models to represent different number of fuel assemblies, decay power, and hydraulic connections
- Core nodalization with 4 radial rings, 17 axial levels
- Accident progression in SFP represented by a heat and steam source

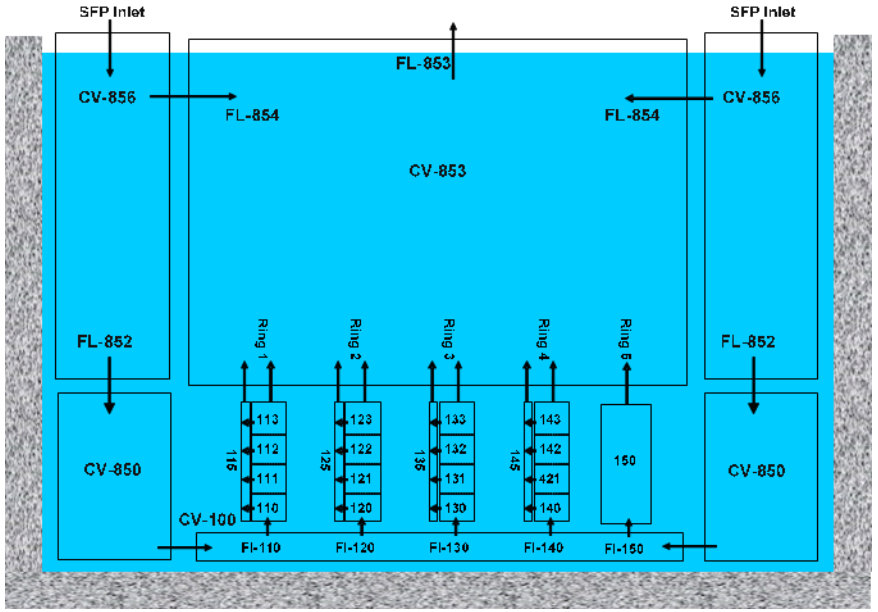
Mühleberg MELCOR Models

Spent Fuel Pool Models



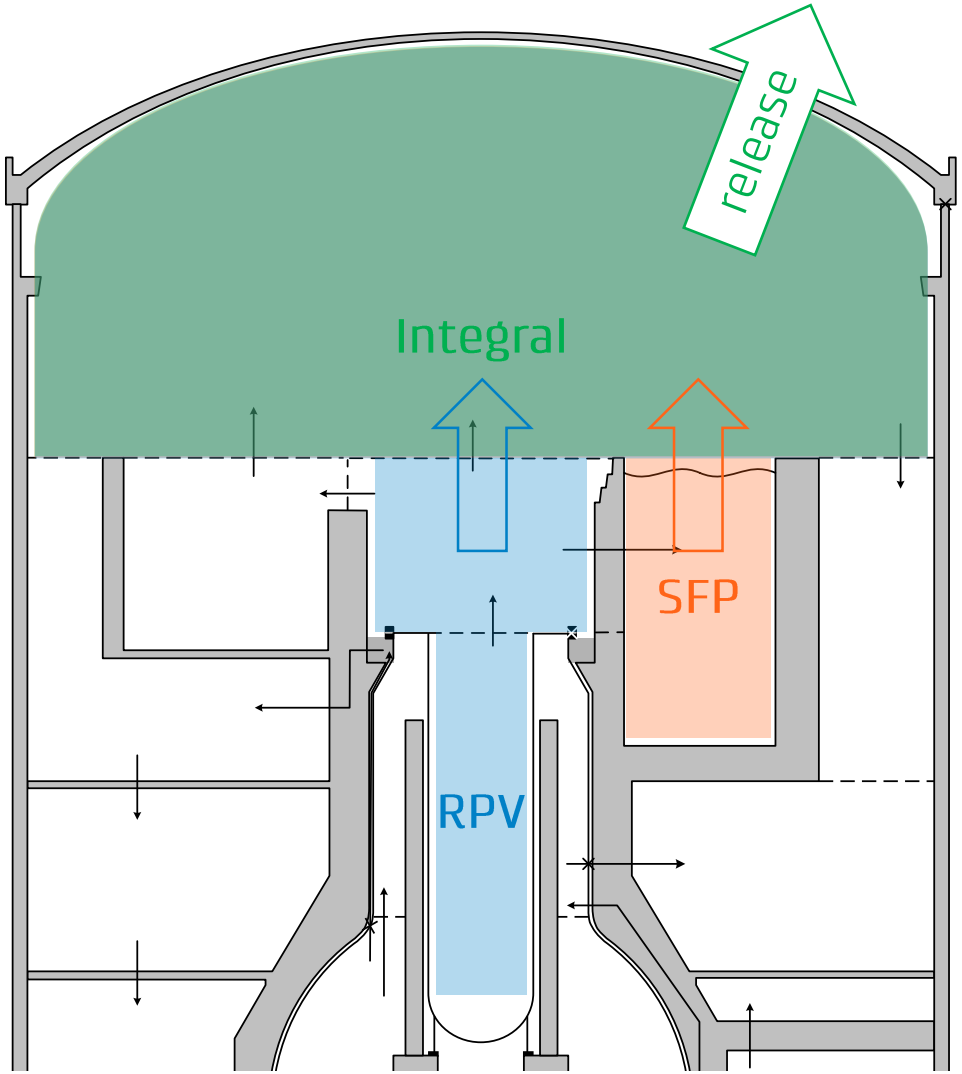
- Purpose: calculate progression of potential accidents in SFP
- 5 different SFP models to represent different number of fuel assemblies, decay power, and hydraulic connections
- SFP nodalization with 5 rings, 14 axial levels
- Peaking ratio for decay heat (DH):

$$\frac{maximum\ DH\ per\ assembly\ (ring\ 1)}{average\ DH\ per\ assembly\ (ring\ 3)} = 1.5$$



Mühleberg MELCOR Models

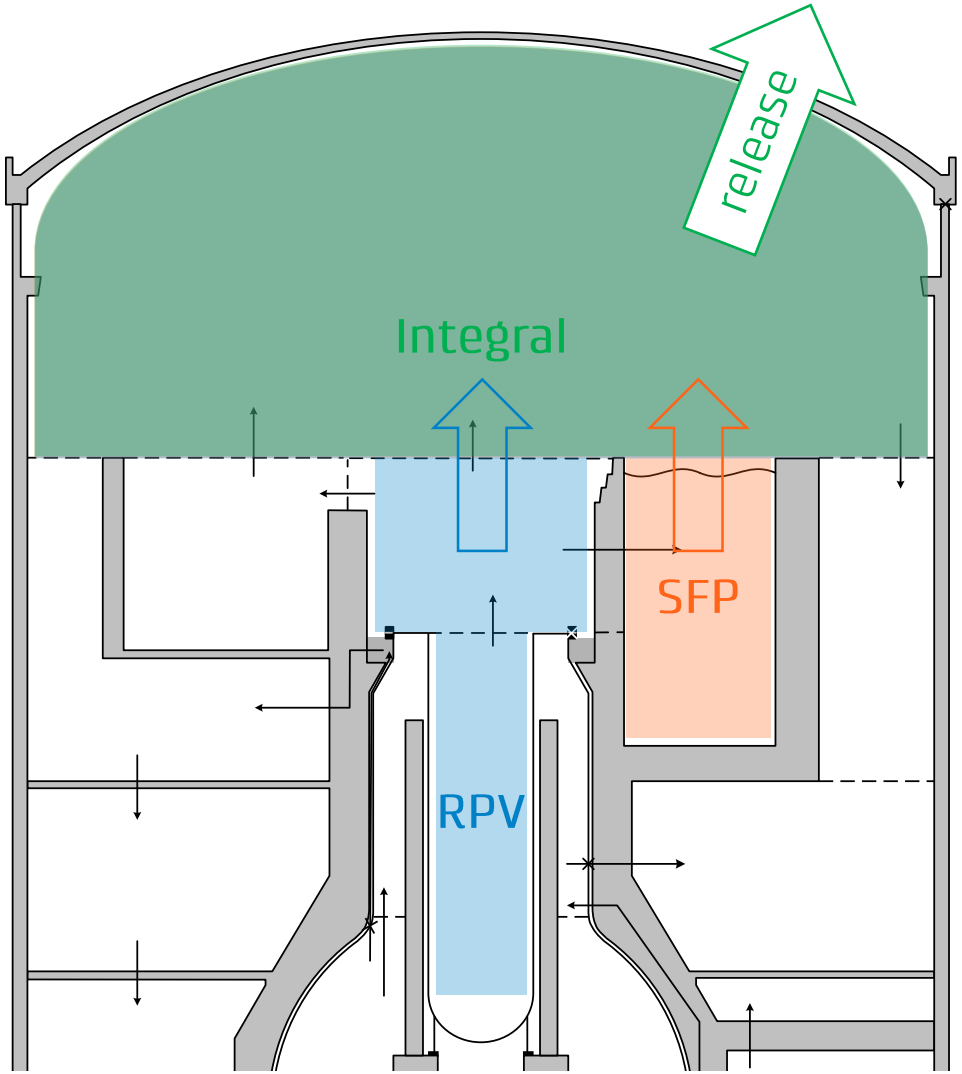
Reactor Building Model



- 1 reactor building model to combine:
  - All source terms from RPV
  - All source terms from SFP
- Integral release calculation
- Model only uses the packages for the following physics:
  - Thermodynamics
  - Fluid mechanics
  - Combustion
  - Heat transfer
  - Radionuclides
- Very fast running model
- Purposes:
  - Calculate potential radiological releases to environment
  - Calculate consequence measures for PSA (i.e., LER, LR, and total activity release)
  - Sensitivity studies on hydrogen combustion, etc.

MELCOR Severe Accident Calculations

Overview



- MELCOR accident progression and activity release calculations
- 35 RPV accident progression calculations
- 18 SFP accident progression calculations
- ~400 integral release calculations (prestudy)
  - Effect of reactor building failure vs. technical leakage
  - Effect of H_2 burn threshold 6% to 14%
  - Effect of H_2 autoignition conditions

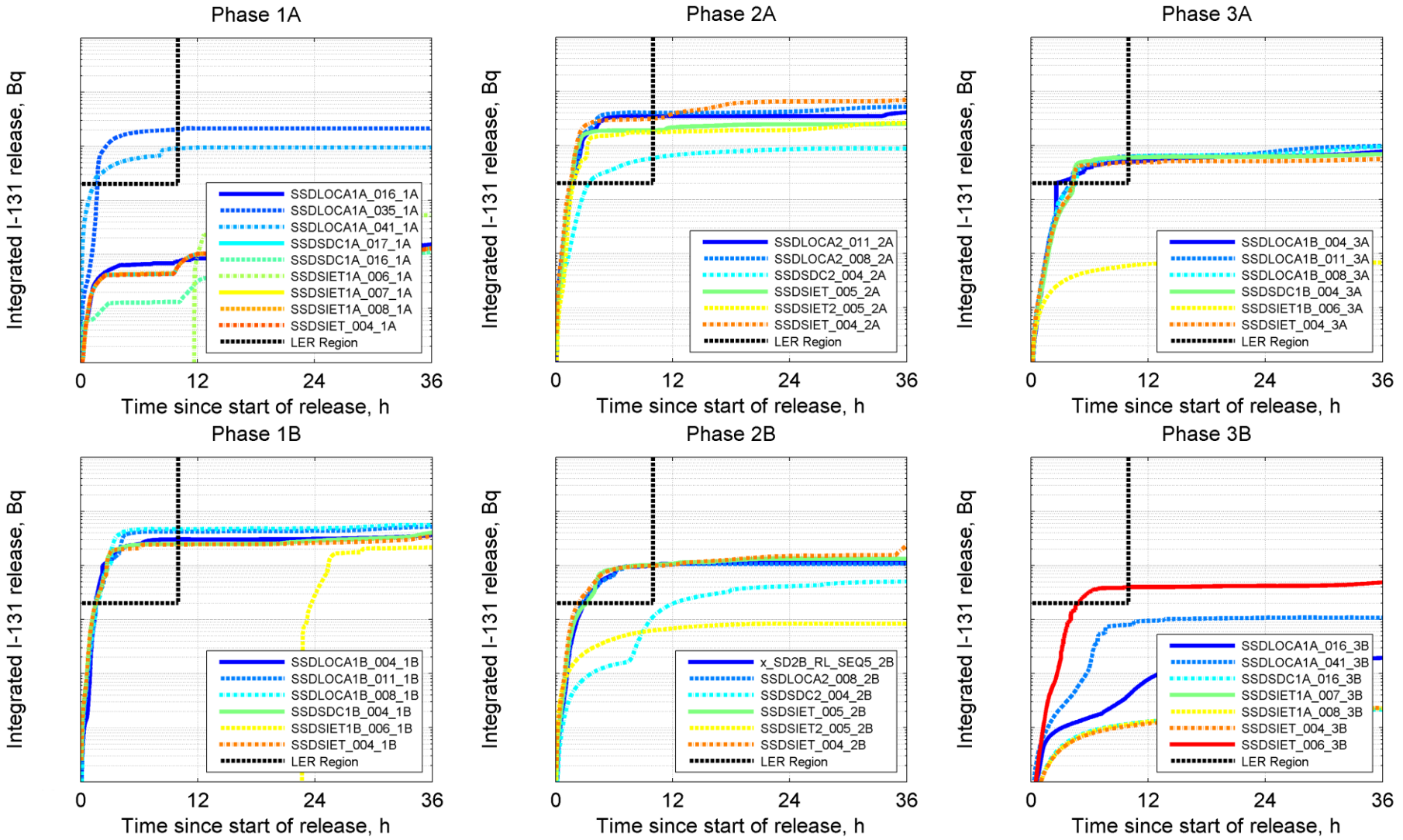
  → Definition of accident progression event tree
- ~200 integral release calculations (final study)
  - Characterize 405 event tree end states
  - Very detailed deterministic representation of releases
- Developed script for automatic:
  - Set-up of MELCOR calculations
  - Start of MELCOR calculations on server
  - Postprocessing → tables, diagrams

MELCOR Severe Accident Calculations

Results: Activity Release

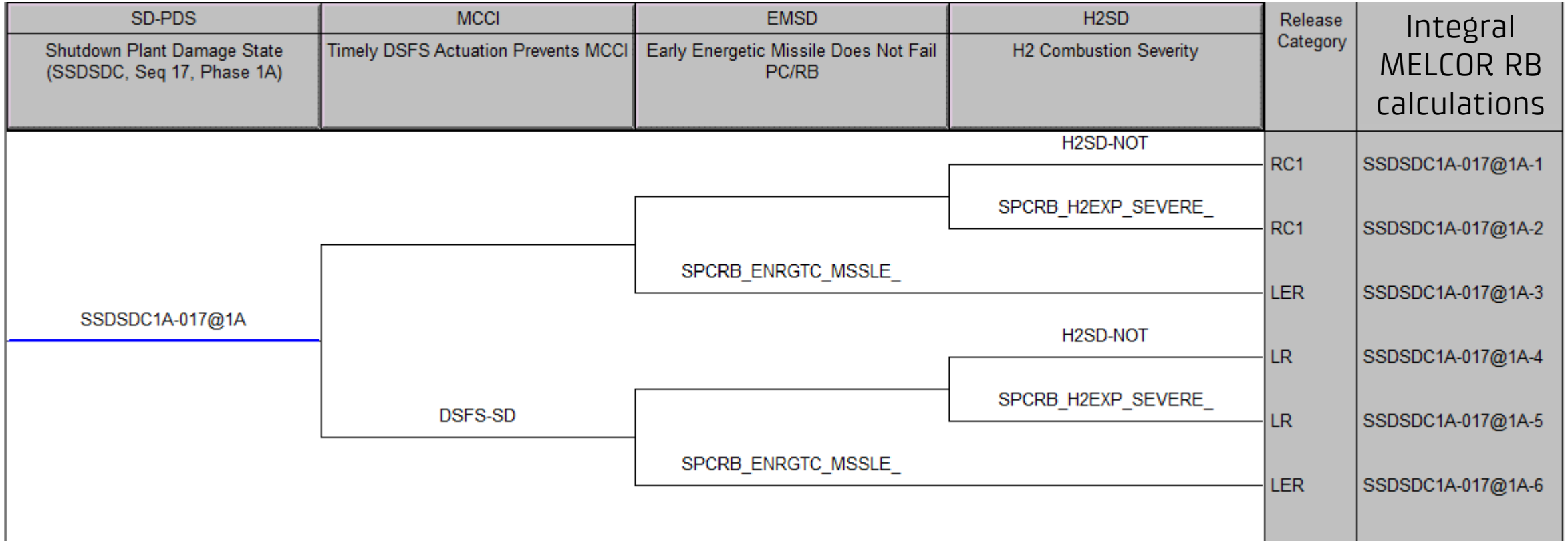
Example:

- I-131 activity release
- Within 36 hours
- Combustion at Low Hydrogen Concentration
- No MCCI



MELCOR Severe Accident Calculations

Results: End States in 90 Accident Progression Event Trees



Release categories:

"LER"	I-131	>	2.E +15 Bq	within 10 hr of the start of release
"LR"	Cs-137	>	2.E +14 Bq	
"RC1"	Aerosol	≥	1.E+15 Bq	
Etc.				

Summary and Conclusion

- BKW Engineering provides services to both Mühleberg Nuclear Power Plant and external customers
- We use MELCOR for PSA Level 1, 2, and SAMG
- Mühleberg NPP low power and shutdown conditions are characterized by 6 phases
- Updated the PSA Level 2 for low power and shutdown conditions
- 35 RPV accident progression calculations using the reactor models
- 18 SFP accident progression calculations using the SFP models
- ~400 integral release calculations using the reactor building model supported development of event tree
- ~400 event tree end states are characterized by ~200 integral release calculations that accurately describe the state of the plant
- Detailed deterministic basis for the probabilistic consequence measures

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Contact:
Dr. Tobias Szabó
tobias.szabo@bkw.ch
Tel. +41 58 477 40 93