Current Activities at GRS Regarding the Application of the MELCOR Code

5th EMUG Meeting 2013
May 2 - 3, 2013
KTH, Stockholm, Sweden

Th. Steinrötter, M. Kowalik, GRS

Content

- **Spent Fuel Pool Analyses for German PWR and BWR Plants**
- **Analyses of Shutdown Modes for both PWR and BWR Plants**
- **Assessment of the Improvement of SAM for German PWR**

Spent Fuel Pool Analyses for German PWR and BWR Plants

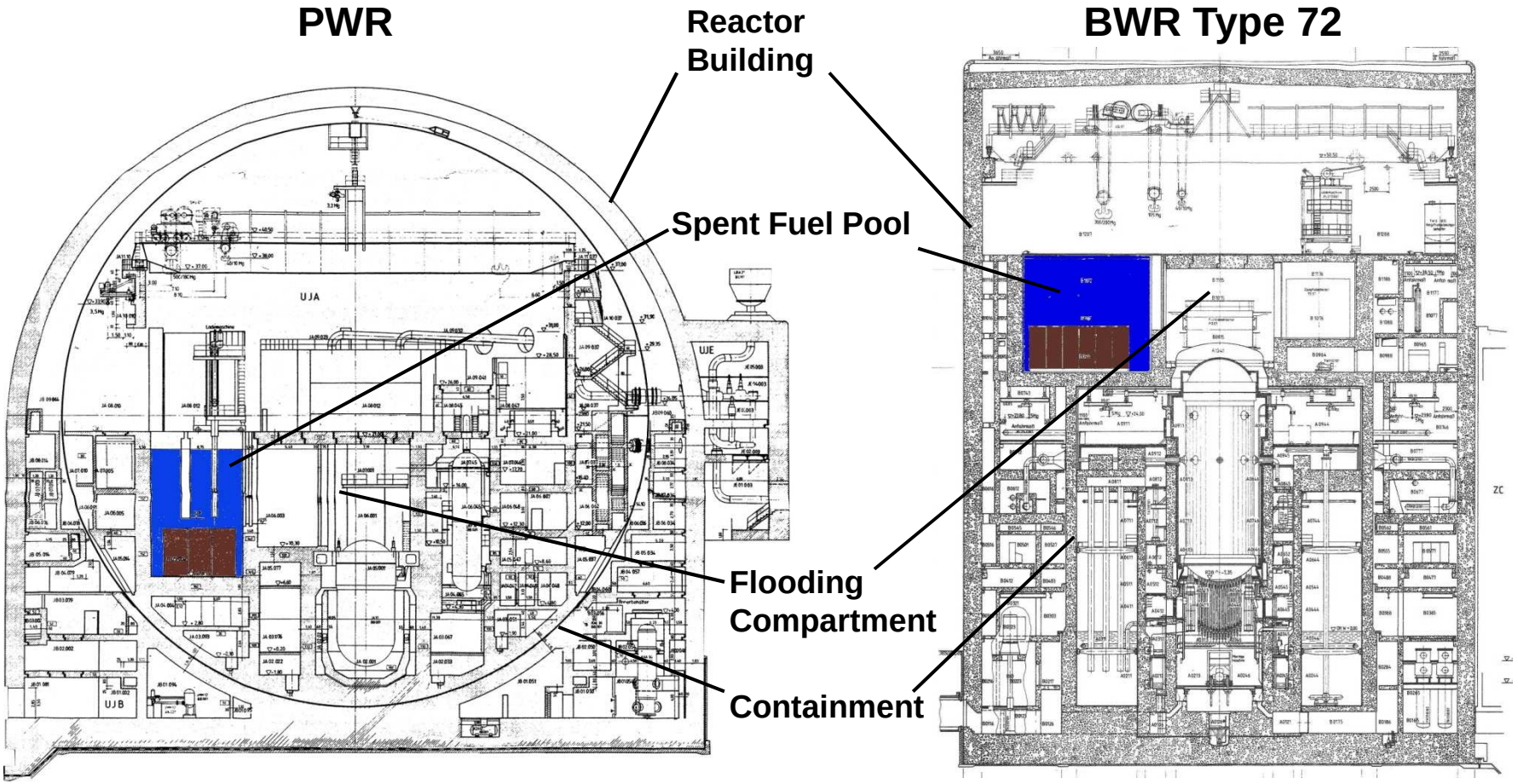
- Research project financially supported by the German Federal Ministry of Economics and Technology (BMWi) regarding the extension of probabilistic analyses for **s**pent **f**uel **p**ools (SFP).
- Supporting deterministic analyses of the accident progression inside spent fuel pool and plant are a main part of the project.
- The accident progression is being analyzed for both PWR and BWR pools by using the integral codes MELCOR.
- Outcome of these analyses:
  - thermal-hydraulic behavior inside SFP and plant under accident conditions,
  - the behavior of embedded structures, and the release of radionuclides.

⇨ Basic approach for consideration of SFP within Level 2 PSA, quantification of event trees and possible mitigative accident measures.

Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd)

- General boundary conditions of the MELCOR analyses:
  - the modeling also includes the containment and adjacent building compartments,
  - passive autocatalytic recombiners (PAR) are considered as realized in the plant,
  - station Black-out is assumed as initial event (outcome of the Fukushima accident),
  - different loadings of the pools:
    - partial loading during normal power operation (shortly after finishing in-service inspection ⇨ highest decay heat for that operating mode),
    - typical loading during in-service inspection (connection with filled flooding compartment), and
    - inclusion of the whole core from RPV into SFP; pool separated from flooding compartment (worst case).
- Conceptual differences between reactor types PWR and BWR have to be considered for the analyses.

Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd) – German PWR and BWR Plants



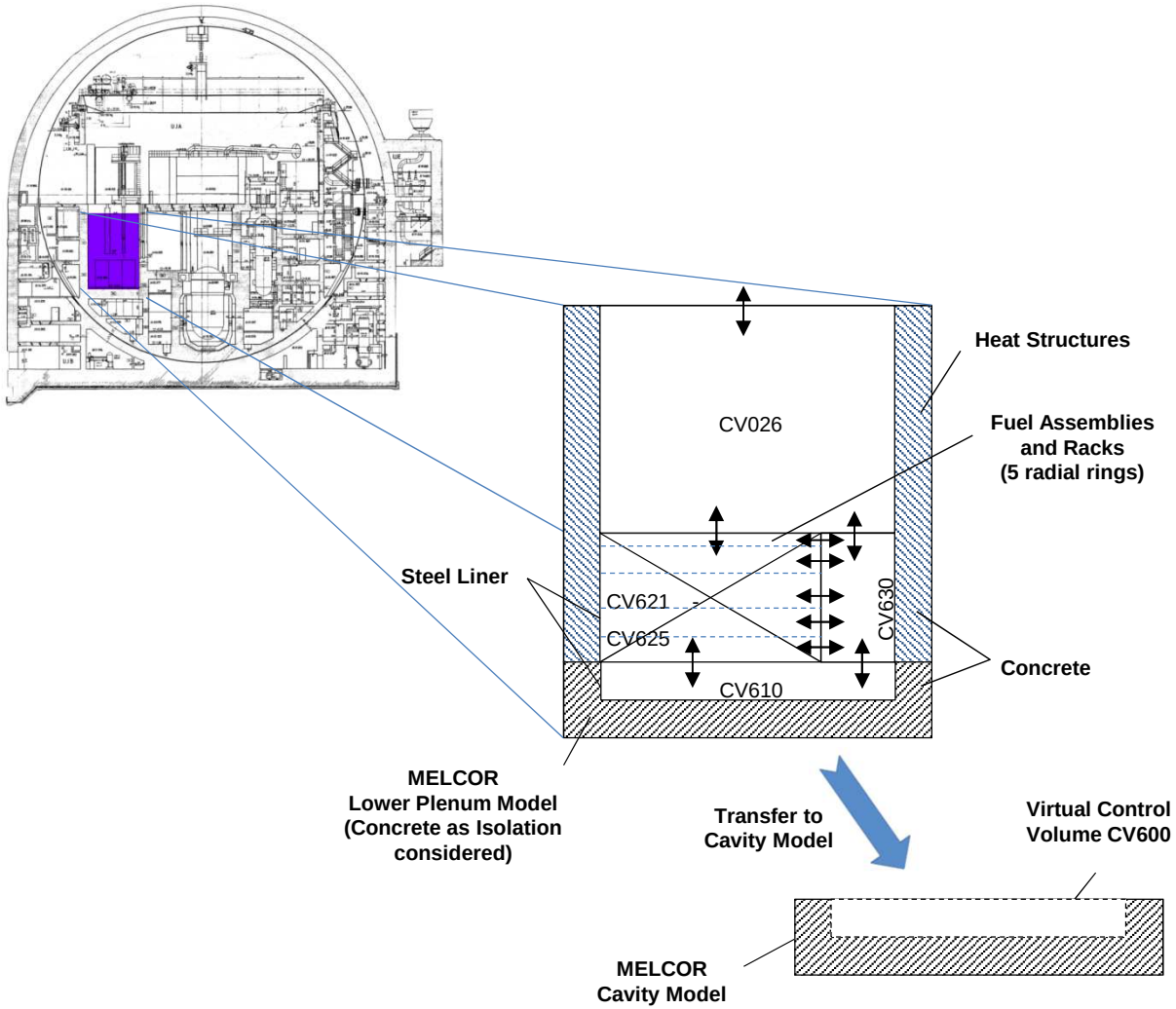
- SFP located inside containment
- PAR above SFP region

- SFP located outside containment
- No PAR at SFP region

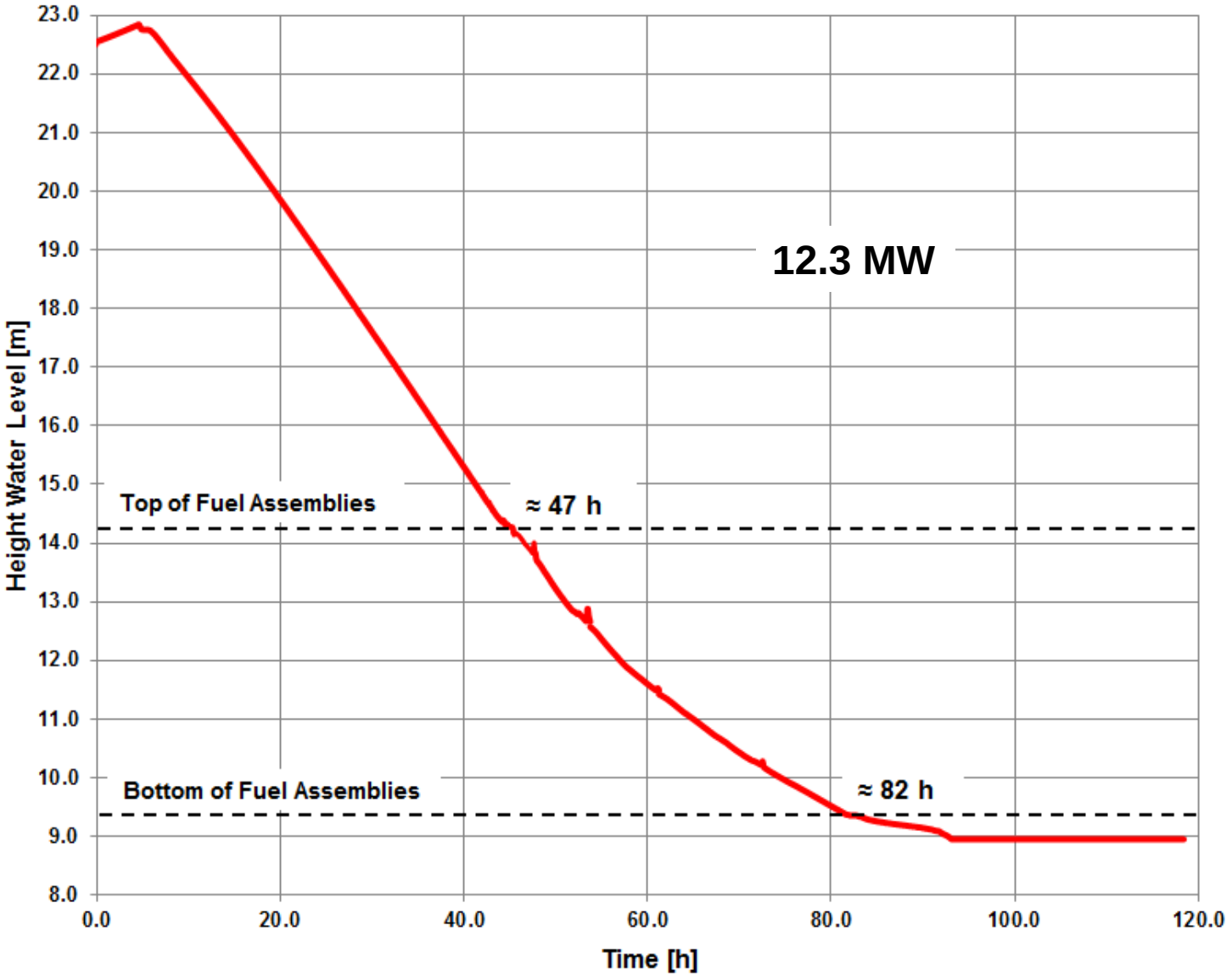
Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd)

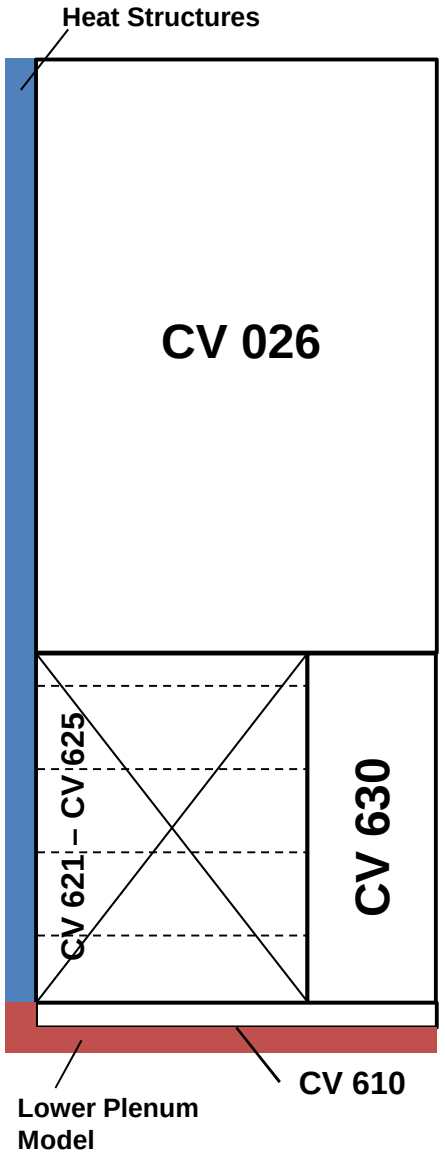
- Preliminary results of a MELCOR 1.8.6 analysis of a "Station Black-out" event for PWR .
- Characteristics of the modeling:
  - typical dimensions of a PWR spent fuel pool (A = 98.2 m^2, height water column = 13.55 m),
  - water volume (≈ 1330 m^3) is being depicted by eight control volumes,
  - wall structures of the pool are modeled as heat structures (oxidation and melting possible),
  - bottom area of the pool is modeled by the MELCOR Lower Plenum Model (flat bottom),
  - one core inside the pool (≈ 12.3 MW), pool separated from flooding compartment,
  - inventory of radionuclides like power operation mode, time offset for decay heat of 124 h,
  - 5 radial rings with fuel assemblies, 6^{th} ring as water gap,
  - 3 axial meshes for lower region including supporting plate of the racks, 12 axial meshes for the fuel assemblies, top plate of the racks in the upper axial mesh (COR Package),
  - temperature criterion for the failure of the steel liner at the bottom of the pool, six penetrations, cavity model is switched on with the failure of the liner, and
  - detailed modeling of the containment including recombiners.

Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd) – Nodalisation PWR

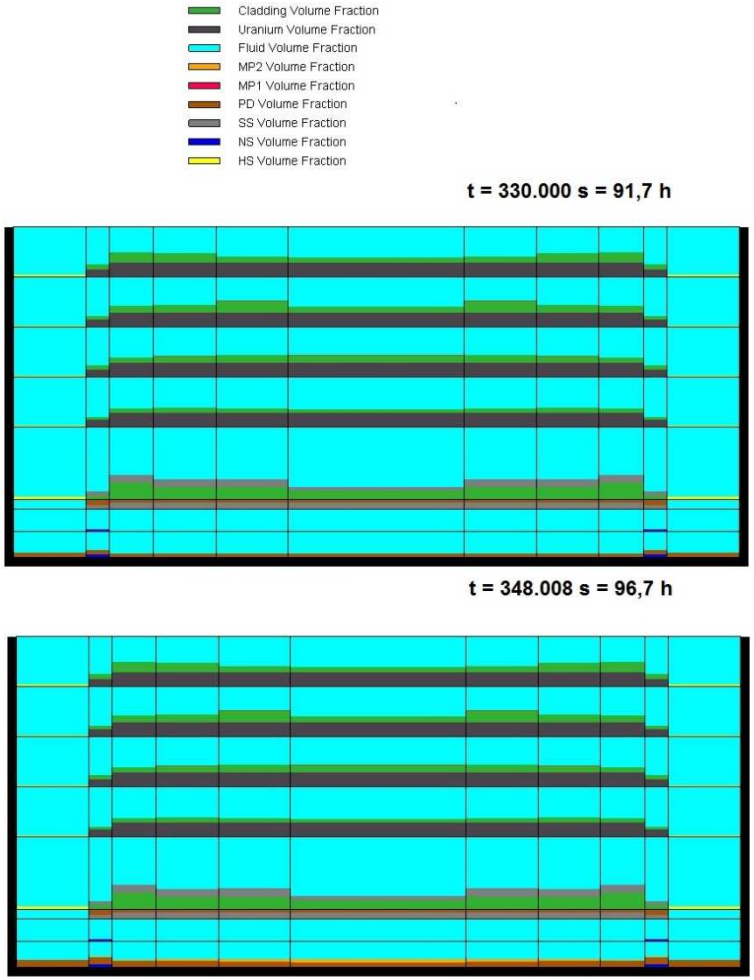


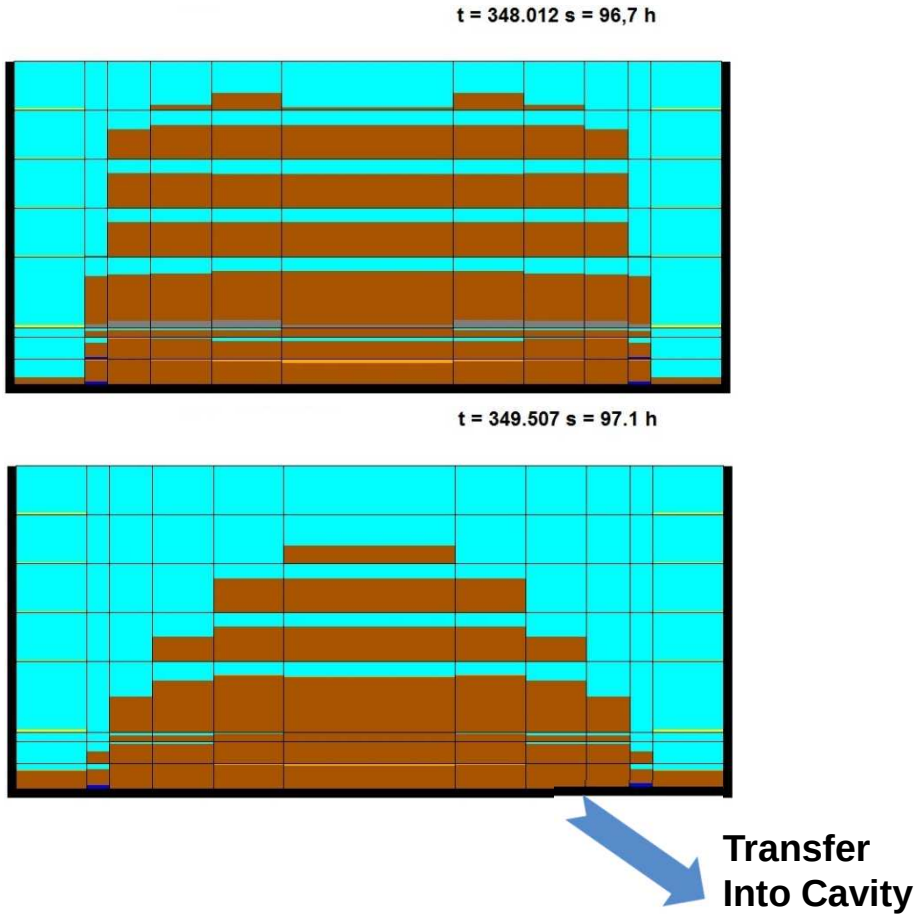
Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd) – Calculated Water Level inside SFP for PWR





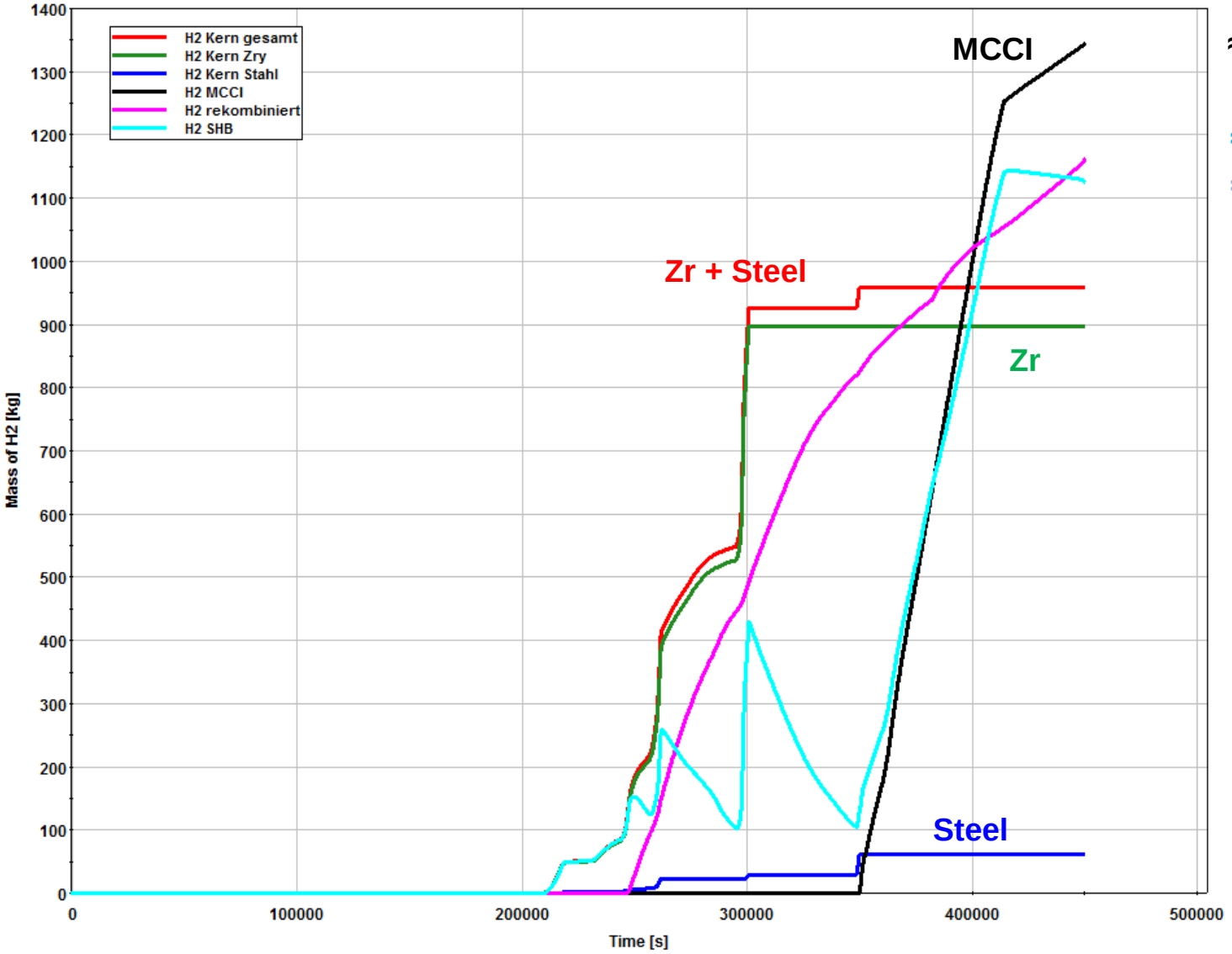
Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd) – Calculated Transfer into Cavity (lower eight meshes) PWR





- First relocation to pool bottom at 83 h,
- Failure of steel liner at 97.1 h ⇨ Start of transfer into cavity
- End of transfer into cavity at 97.9 h (about 192 tons)

Spent Fuel Pool Analyses for German PWR and BWR Plants (cont'd) – Calculated Hydrogen Masses PWR



≈ 1344 kg

≈ 1162 kg

≈ 1140 kg

≈ 960 kg

≈ 898 kg

≈ 62 kg

Analyses of Shutdown Modes for both PWR and BWR Plants

- The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) financially supports analyses of severe accident sequences during shutdown modes and external hazards (flooding, aircraft crash, earthquakes and explosions pressure wave).
- PSA Level 1 is obligatory to be managed in Germany including shutdown modes and external hazards. Currently, Level 2 analyses are not demanded for shutdown modes and external hazards. Thus, there is a lack of knowledge regarding PSA Level 2 of those events.
- Objective of the project is the analysis of phenomena in the shutdown modes and during external hazards events.
- Preliminary MELCOR results for two selected scenarios of a generic PWR.

Analyses of Shutdown Modes for both PWR and BWR Plants – Selected Scenarios for PWR

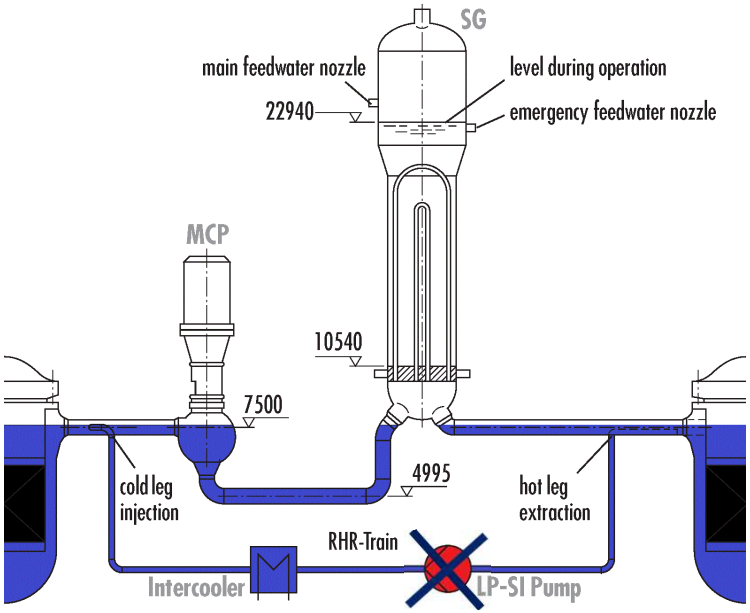
- For the shutdown modes of a PWR 11 relevant scenarios were identified. First preliminary results of two examples for PWR will be presented here:

SBO, mid-loop operation, RPV open (Scenario 1)	
Initial event:	Station Black-out (SBO)
Water level in primary circuit:	mid-loop
State of RPV lid:	removed
Time after shutdown (begin of operational mode):	40 hours

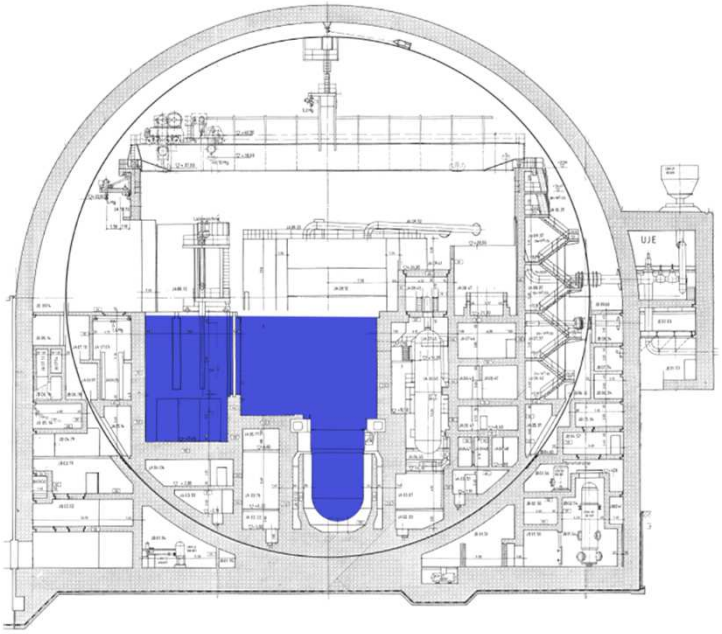
SBO, flooding compartment filled, RPV open (Scenario 2)	
Initial event:	Station Black-out (SBO)
Status of the refuelling slot gate:	closed
Water level in flooding compartment:	Level SFP
State of RPV lid:	removed
Time after shutdown (begin of operational mode):	58 hours

Analyses of Shutdown Modes for both PWR and BWR Plants – Selected Scenarios for PWR

Scenario 1



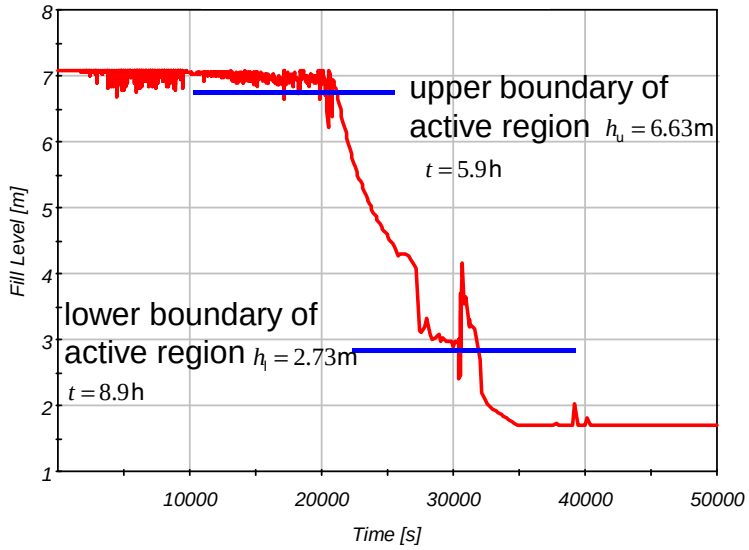
Scenario 2



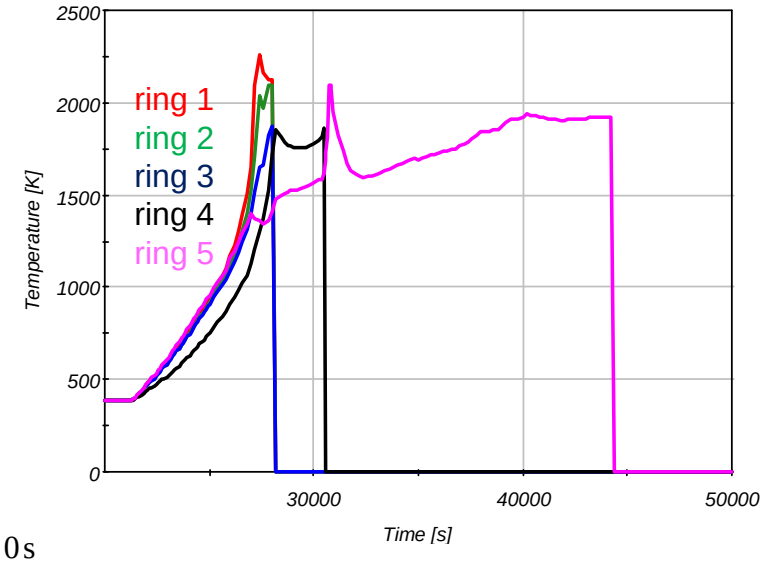
Event	Scenario 1	Scenario 2
Begin of Core Uncovery	≈ 6 hours	≈ 50 hours
Exposure of Core	≈ 9 hours	≈ 53 hours
Melt Ejection into Cavity	≈ 13 hours	≈ 58 hours

Analyses of Shutdown Modes for both PWR and BWR Plants – Preliminary Results of Scenario 1 for PWR

Water Level of Core

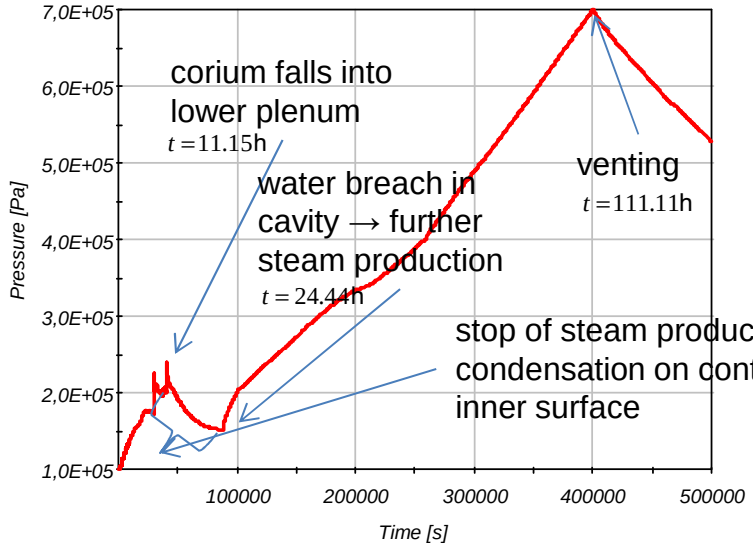


Cladding Temperatures

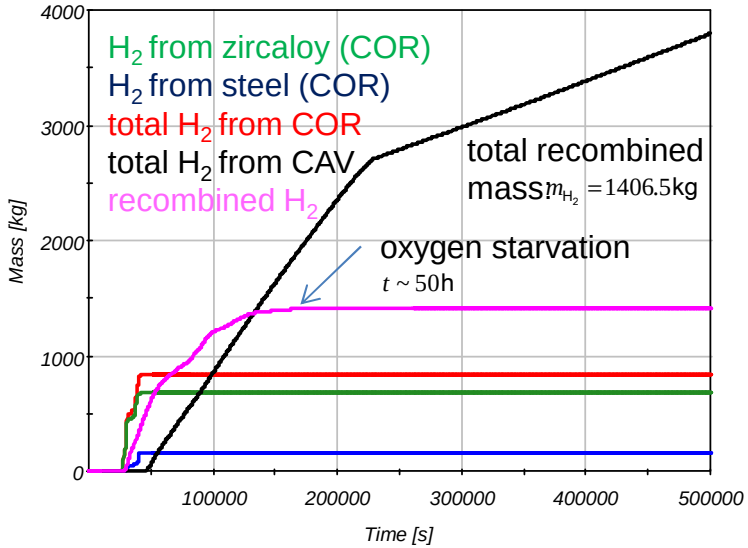


Begin of SBO: $t_0 = 0$ s

Pressure within Containment

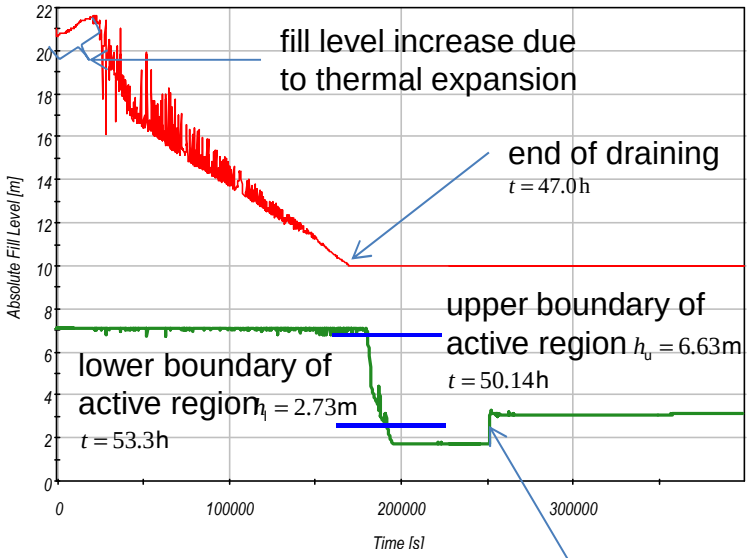


Hydrogen Generation

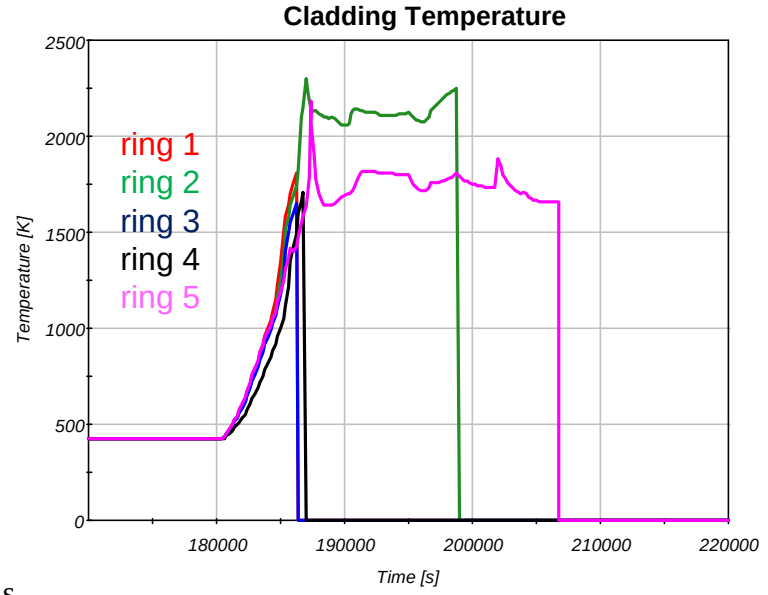


Analyses of Shutdown Modes for both PWR and BWR Plants – Preliminary Results of Scenario 2 for PWR

Water Level Flooding Compartment and Core

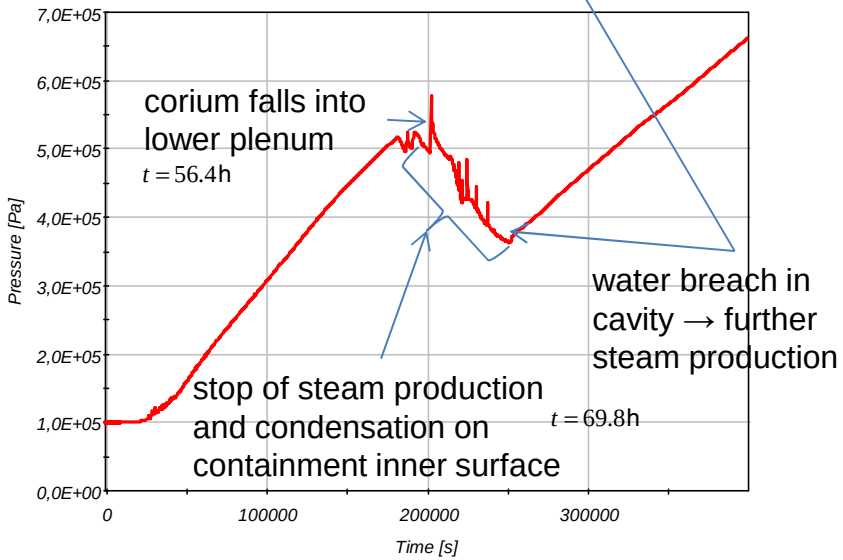


Cladding Temperature

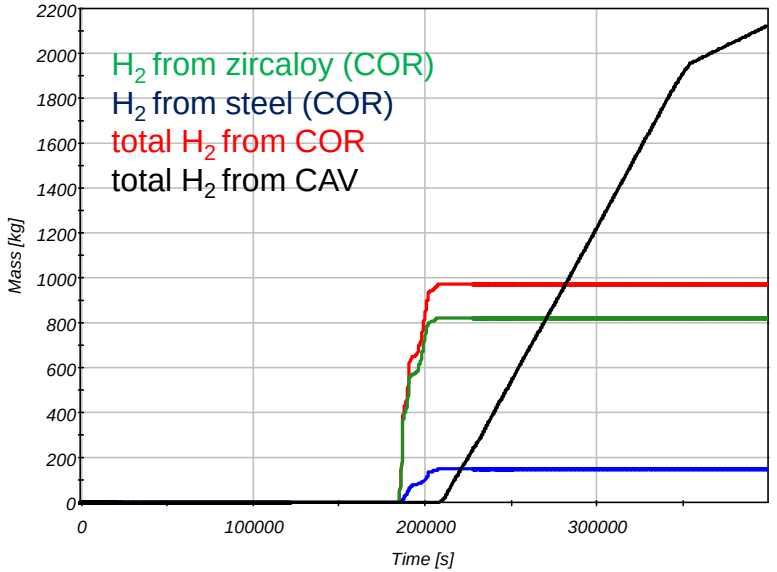


Begin of SBO $t_0 = 0\,\mathrm{s}$

Pressure within Containment



Hydrogen Generation



Assessment of EOPs and SAMG for German PWRs (project in preparation)

- National (Reactor Safety Commission) and European ‘Stress Test’ have been carried out. Assessment of the safety of the plants under Fukushima like conditions.
- An improvement (EOP) and extension (SAMG) of the German SAM program is currently under discussion.
- RSK recommendation for a need of improvement and extension concerning:
  - long-term energy supply (e.g. mobile generator, supply connections (partially realized)),
  - long-term heat removal from reactor core and spent fuel pool (ultimate heat sink ⇨ diverse heat sink like e.g water/air heat exchanger, groundwater well etc.),
  - long-term heat removal from wetwell of a BWR,
  - safe release of off-gases containing combustible gases by the filtered cont. venting system,
  - availability of the measures under conditions of long-term station black-out,
  - diverse feeding of the spent fuel pools, e.g. line connected to a fire system (partially realized),
  - SAM measures for the protection of the building structures surrounding SFP of a BWR against hydrogen combustions (e.g. recombiners (planned for the German BWR) etc.),
  - optimization of existing measures, and
  - development of a SAMG concept ⇨ On behalf of the utilities, AREVA is doing the development of SAMG for the German NPPs.

Assessment of EOPs and SAMG for German PWRs (project in preparation)

- Currently a new project on behalf of BMU is being prepared by GRS regarding the assessment of the improvement of existing SAM and the new SAMG for PWR by deterministic analyses using MELCOR:
  - Analyses of two events “Station Black-out” and “Small break LOCA with multiple failures” (significant contribution to core damage states or release categories of PSA Level 2),
  - Calculation of the SBO event with both the current status of the EOPs and the improved EOPs (e.g. increased capacity of batteries, mobile generators, etc.), comparable assessment of the analyses in order to show the benefit,
  - Severe accident analyses of both events under consideration of planned SAMG developed by AREVA,

⇨ Quantification and assessment of the benefit due to the improvement of SAM strategy of PWR.

Thanks for your attention!

Dr. Thomas Steinrötter

GRS mbH, Cologne

E-mail: thomas.steinroetter@grs.de

Tel: ++49 221 2068 942