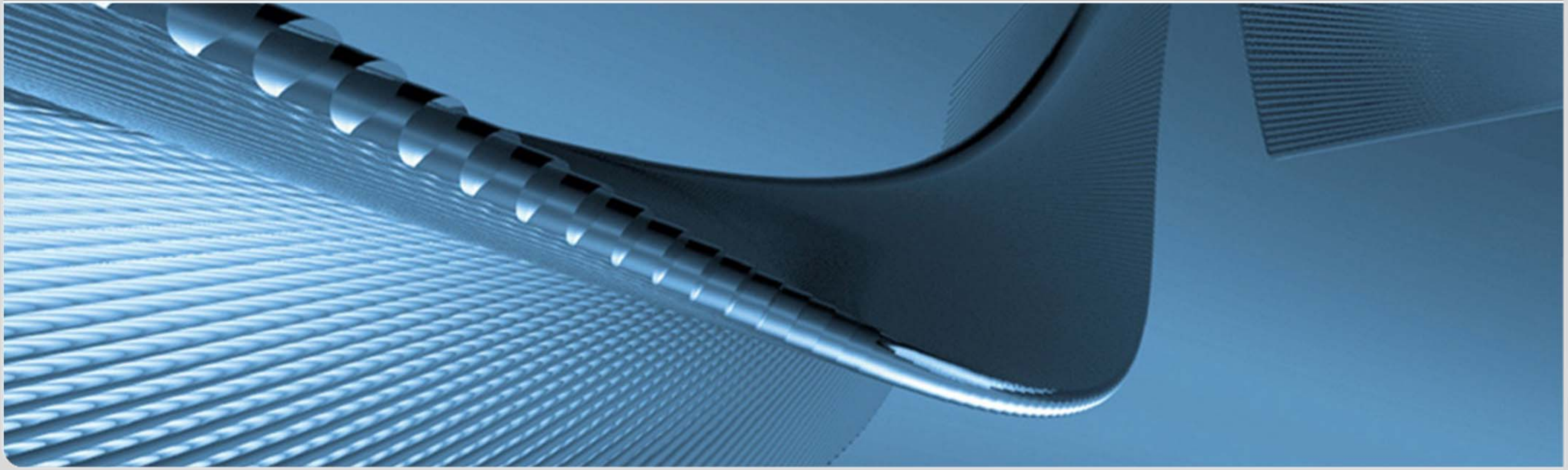
Karlsruher Institut für Technologie

KIT-INR Contribution to CESAM WP40: Status of ASTEC Simulation of a PWR Konvoi Plant

I. Gómez García-Toraño, V. Sánchez
(ignacio.torano@kit.edu)

Institute for Neutron Physics and Reactor Technology (INR)
Reactor Physics and Dynamic Group (RPD)



Content

1. **Motivation**
2. Approach
3. ASTECV2.0 modelling of a German Konvoi PWR
4. Analysis of reference severe accident sequence
5. Summary and outlook

1. Motivation

- The Fukushima accidents have shown that further improvement of SAM measures is necessary
- Within CESAM, KIT-INR is focused on the evaluation of SAM measures (e.g. reflooding of overheated cores) for a German Konvoi PWR plant
  - Injection of water in the reactor pressure vessel may stop the accident progression, but it may also derive in enhanced hydrogen generation and fission product release
- For this purpose, ASTECV2.1 must be validated against the QUENCH facility and an integral model of the PWR Konvoi plant must be developed in ASTECV2.1
  - Use Konvoi plant model to evaluate the impact of SAM measures (core reflooding) for selected scenarios

Content

1. Motivation
2. **Approach**
3. ASTECV2.0 modelling of a German Konvoi PWR
4. Analysis of reference severe accident sequence
5. Summary and outlook

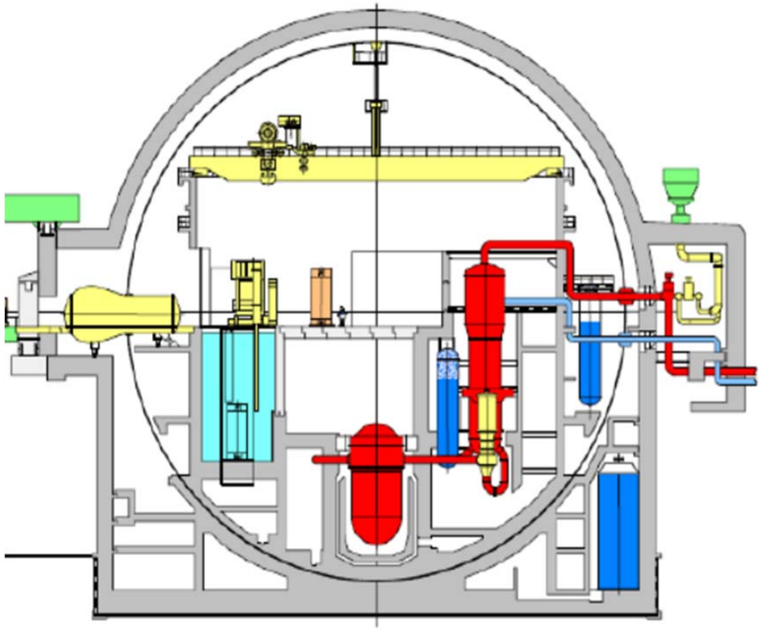
2. Approach

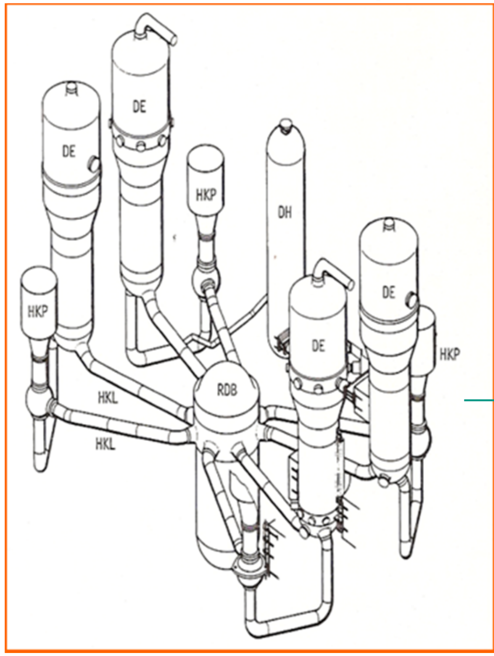
- Starting point: ASTECV2.0 PWR Konvoi model provided by GRS Köln
- Documentation of the Konvoi PWR input deck (ASTECV2.0)
  - In progress (coordination RUB-USTUTT-KIT) → open for discussion
  - Feedback given to GRS
- Selection of severe accident sequences based on PSA-level 1
  - LBLOCA with passive system intervention in cold legs
- Conversion of the input deck from ASTECV2.0 to ASTECV2.1
  - In progress in cooperation with IRSN Cadarache → primary, secondary, vessel
- Study of performance of SAM measures based on the selected base scenarios, involving reflooding of overheated cores

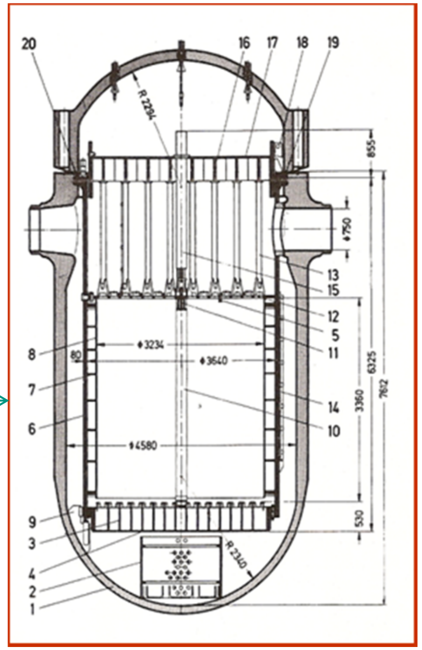
Content

3. PWR Konvoi Plant

- Thermal power: 3760 MW
- Number of FA : 193
- T-inlet: 284.7 °C
- Primary pressure: 157.8 bar
- Secondary pressure: 67.8 bar
- Design pressure of the containment: 4.8 bar
- Number of Loops: 4
- Konvoi plants: Neckarwestheim-2, Emsland and Isar-2



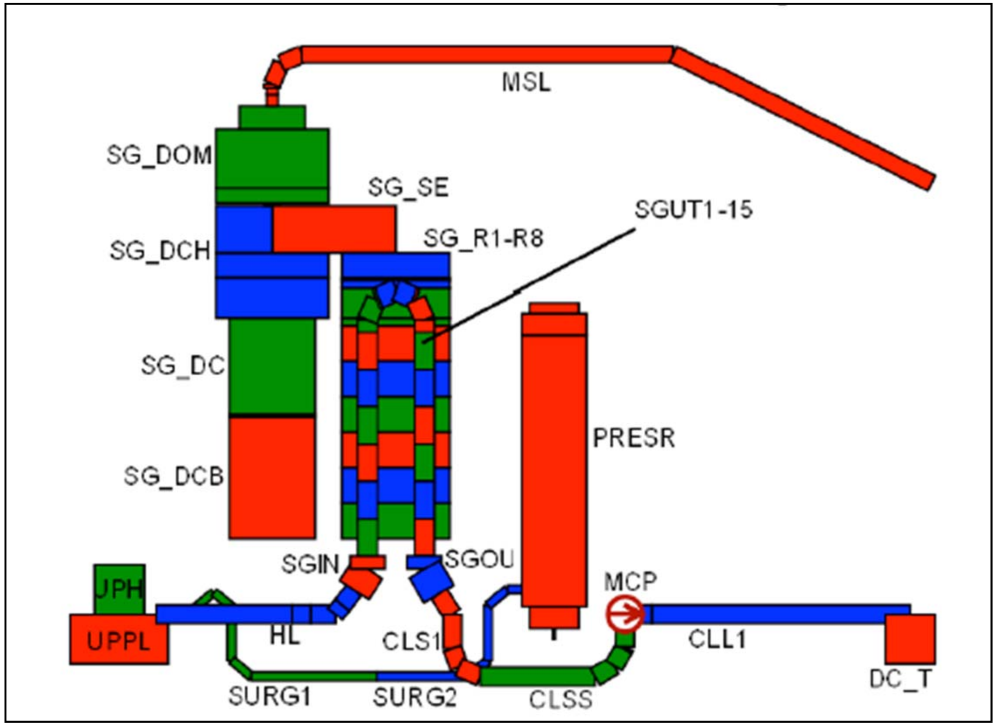




3. ASTEC Modelling of a German Konvoi PWR: Primary and Secondary System

Karlsruher Institut für Technologie

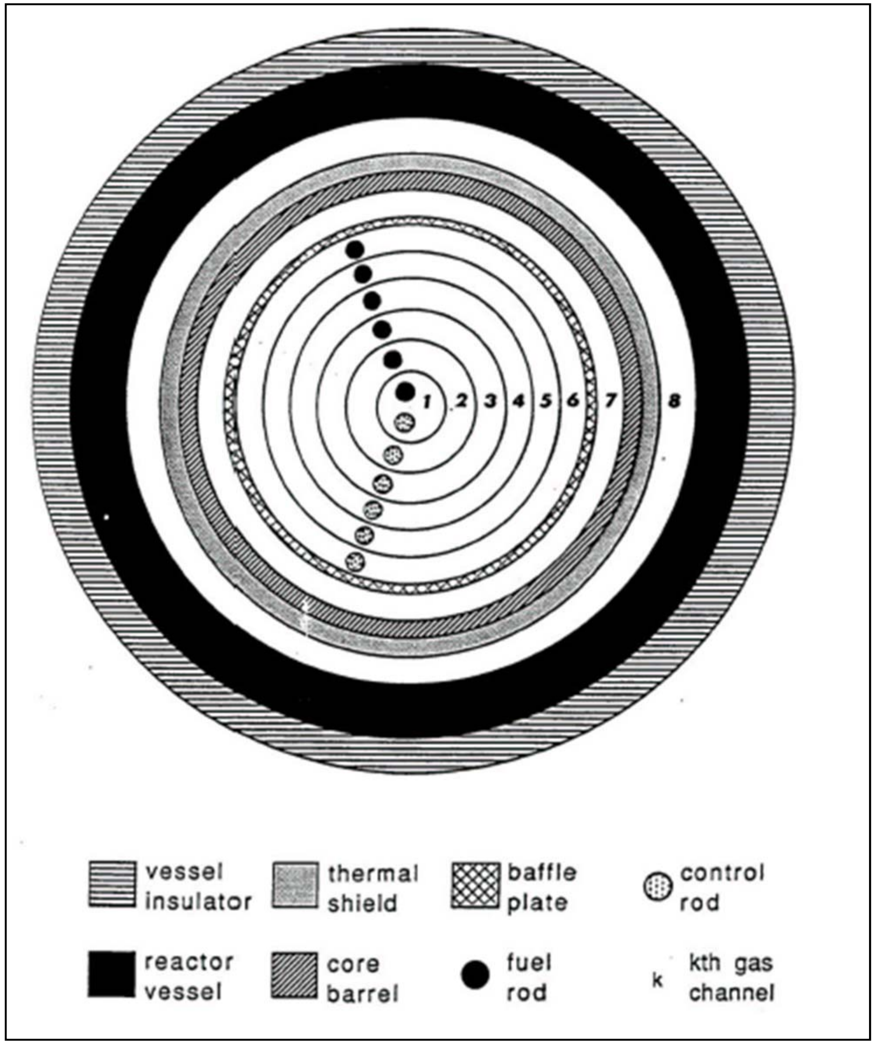
- Two loops have been modelled: single loop B (Loop with pressurizer) and triple loop A
- Primary circuit: upper plenum, hot legs, pressurizer, pressurizer safety valves, primary side of steam generators (inlet and outlet, U-tubes), cold legs, main coolant pumps
- Secondary circuit:
  - SG: downcomer, riser region, separators, dome
  - Main steam lines and sammler and safety valves
  - Feedwater system (as B.C.)
- Safety systems:
  - HPIS: hot leg
  - ACC: cold and hot legs
  - LPIS: cold and hot legs



H. Nowack, W. Erdmann, N. Reinke . Application of ASTEC V2.0 to Severe Accident Analyses for German Konvoi Type Reactors. NURETH 2011, Toronto

INR

3. ASTEC Modelling of a German Konvoi PWR: Reactor core



Patrick Chatelard et al. “ASTEC V2 code ICARE physical modelling”. Report IRSN 2011.

- Channels:
  - Core channels (6)
  - Bypass channel (1)
  - Downcomer
- For each core channel:
  - Fuel rod (fuel stab + cladding)
  - Control rod (AgInCd + steel cladding + guide tube)
  - Grid spacers for each fuel rod
  - Plate
- Solid structures:
  - Baffle (6th channel - bypass)
  - Barrel (bypass - downcomer)
  - Vessel wall
  - Insulation

3. ASTECV2.0 Modelling
Physical phenomena considered for core degradation

Karlsruher Institut für Technologie

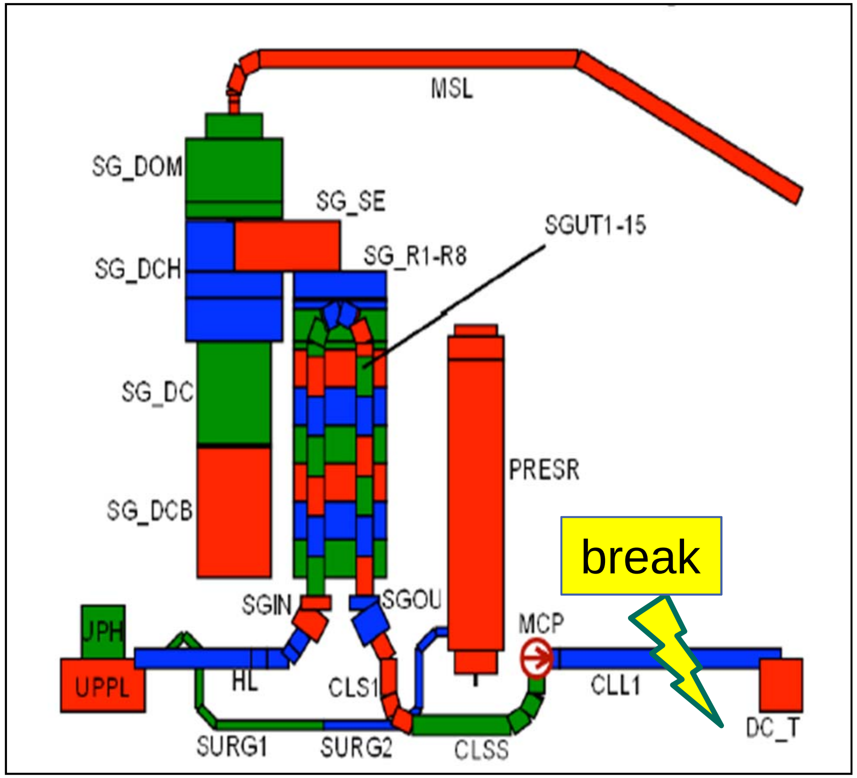
- **Radiation** → bundle in intact state (RADR) and in degraded state (RADCAV)
- **Mechanical failure** of Zry-4 cladding: ballooning and burst (CREE)
- **Oxidation** of solid Zircaloy-4 (claddings, grids, guide tubes) by **steam** (ZROX) → Urbanic
- **Chemical failure** of Zry-4 cladding: dissolution by molten Zircaloy (INTE)
  - First criteria: T > 2600 K and thickness of ZrO_2 < 250 microns
  - Second criteria: T > 2700 K
- **Decanting** of core structures to feed magma components (DECA)
- **Relocation** of molten material → 2D relocation model (MAGMA)
- **Oxidation of molten material** (UZOXMAG)
- **Slumping** of corium into the lower plenum (SLUMP)

Content

4. Definition of the PWR Konvoi Accident Scenario

- Initiating event: LB LOCA (440 cm²) in the cold leg of the pressurizer loop, between the Main Coolant Pump and the cold leg collector

- Assumptions :
  - Reactor is shutdown by SCRAM:
    - Pressure RCS < 132 bar
    - Pressure containment > 1.030 bar
  - Passive systems: 3/8 accumulators injecting in cold leg (hot leg excluded due to <u>counter current flow uncertainties</u>):
    - Pressure cold leg < 26 bar
  - Unavailability of active systems: LPIS (3 trains), HPIS (3 trains) and Residual Heat Removal system.
  - No SAM considered

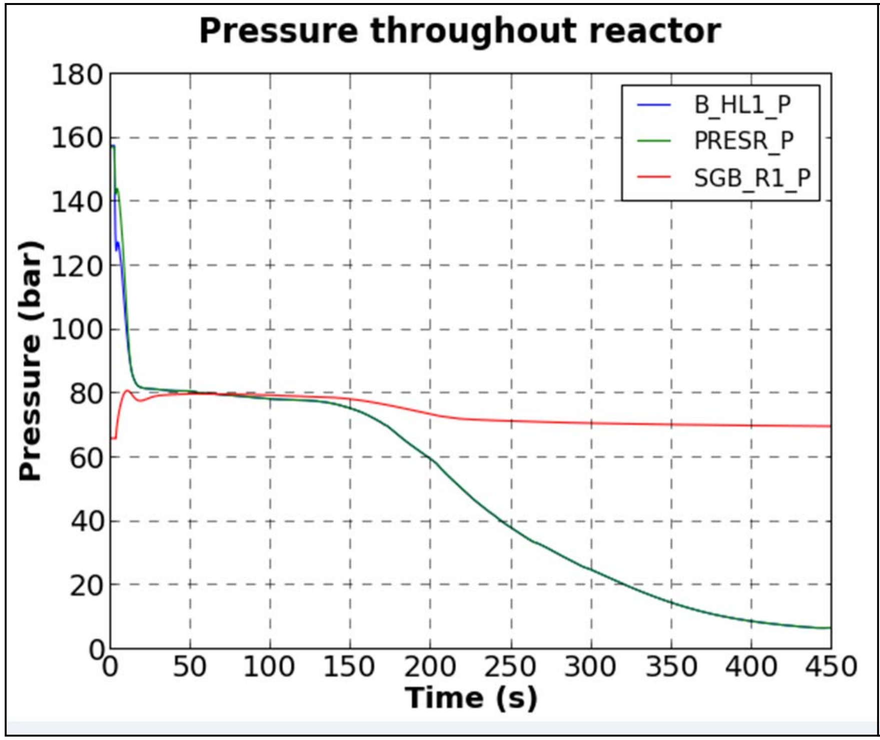


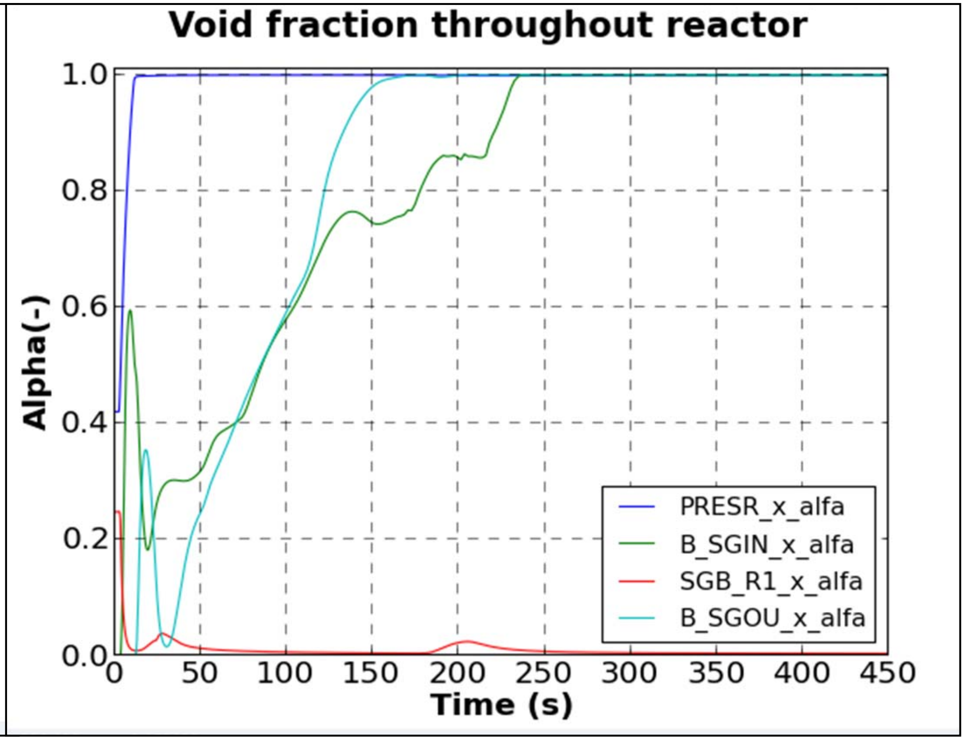
4. ASTEC: Predicted Sequence of Events (Part I)

Main events leading to core degradation	Relative time
Break opening from cold leg of pressurizer to containment	0 s
Containment overpressure of 30 mbar	0.100 s
SCRAM	0.100 s
Coast-down of Main Coolant Pumps	0.629 s
Admission to turbines are closed	0.740 s
Accumulators discharge	290.35 s
Accumulators are empty	446.76 s
Start of ICARE	451.19 s

Entrance in core degradation in almost 7 min

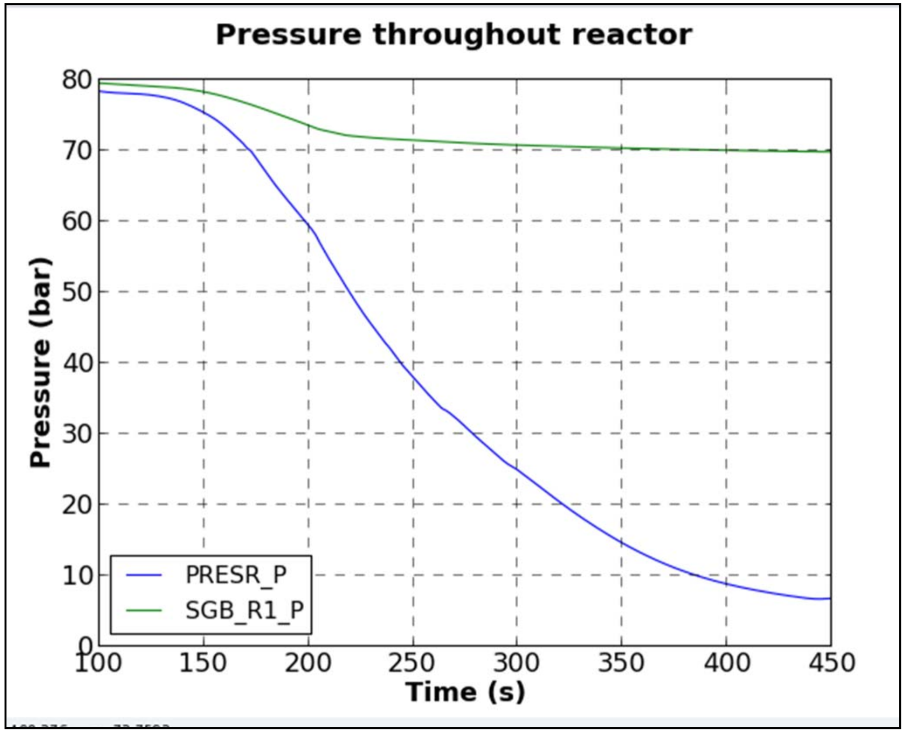
4. ASTEC: Predicted Trends of Selected Parameters (1/3)

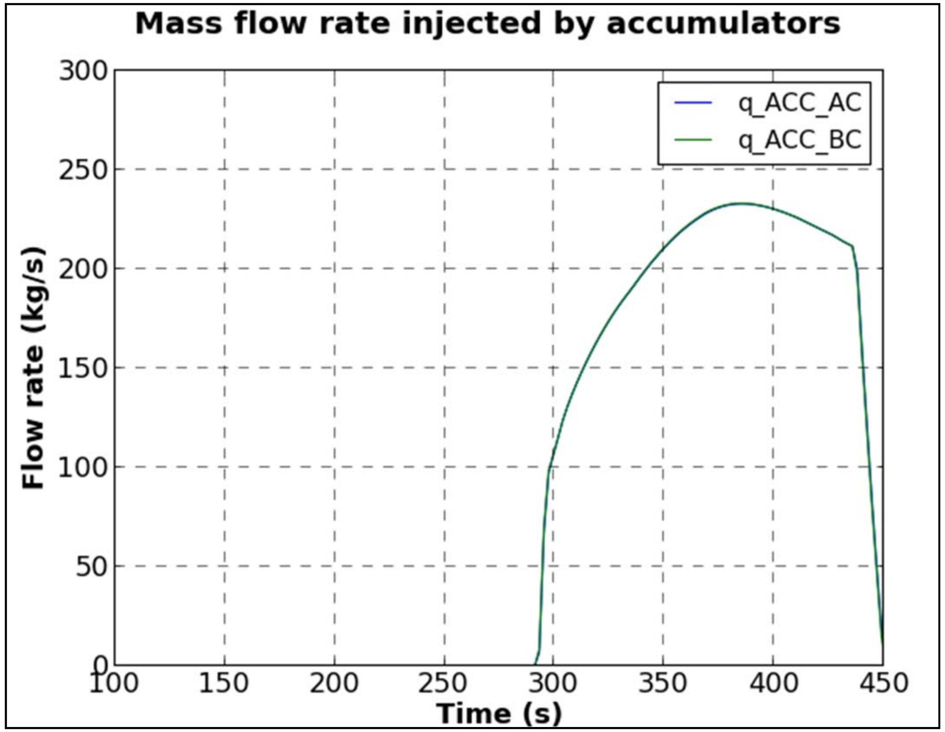




1. Rapid loss of mass and energy from RCS to containment, leading to fast decrease of RCS pressure (PRESR, B_HL1).
2. Thermo-dynamical coupling between the primary and the secondary side from 25 to 125 s (as long as there is water flowing through the primary side of the steam generator).

4. ASTEC: Predicted Trends of Selected Parameters (2/3)

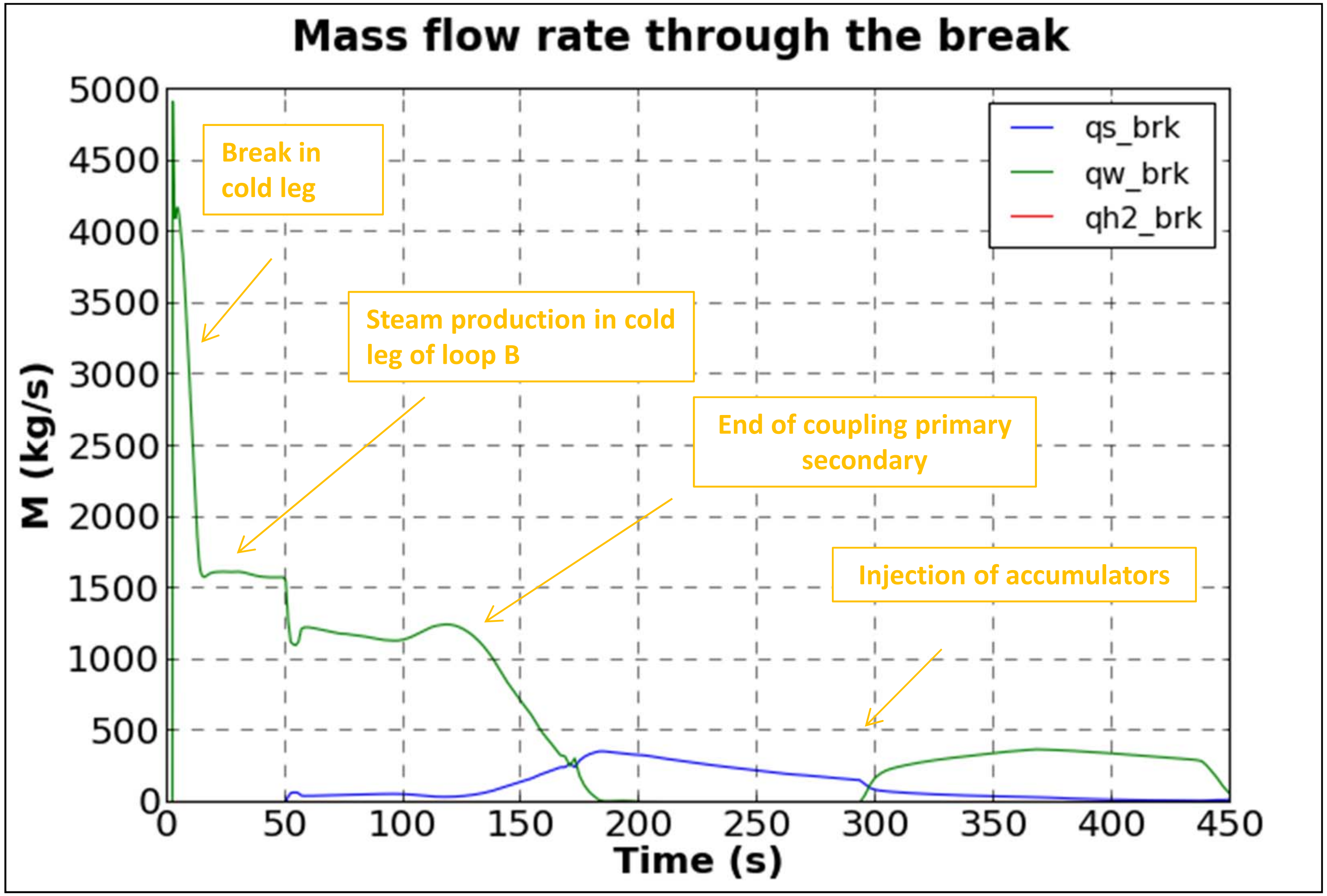




The injection of accumulators by the accumulators decrease the velocity of depressurization, but they cannot avoid the entrance in core degradation at 450 s

4. ASTEC: Predicted Trends of Selected Parameters (3/3)

Karlsruher Institut für Technologie



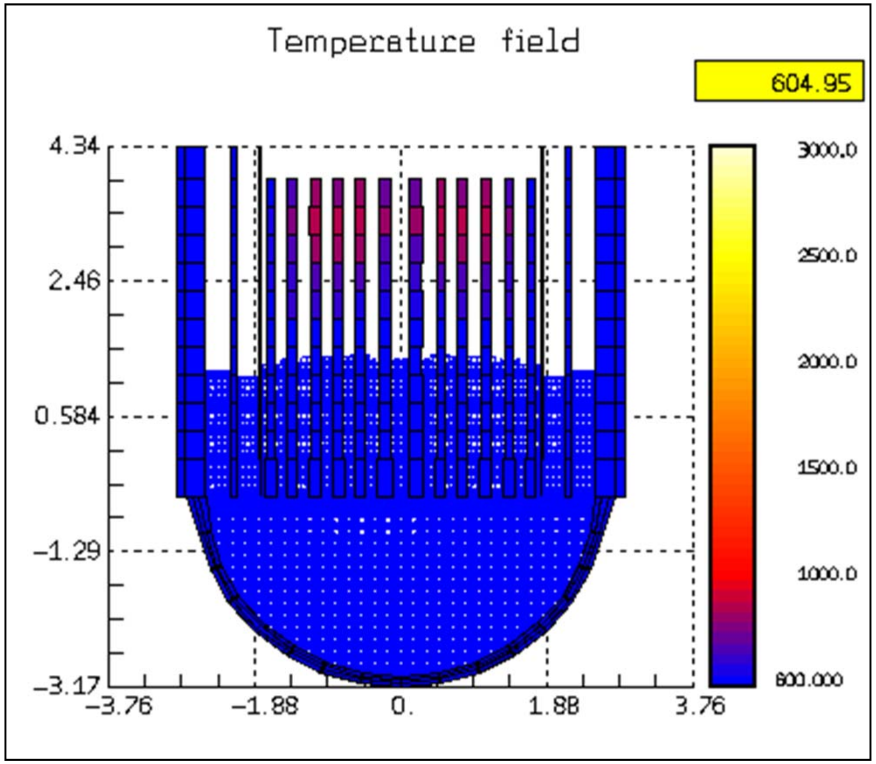
INR

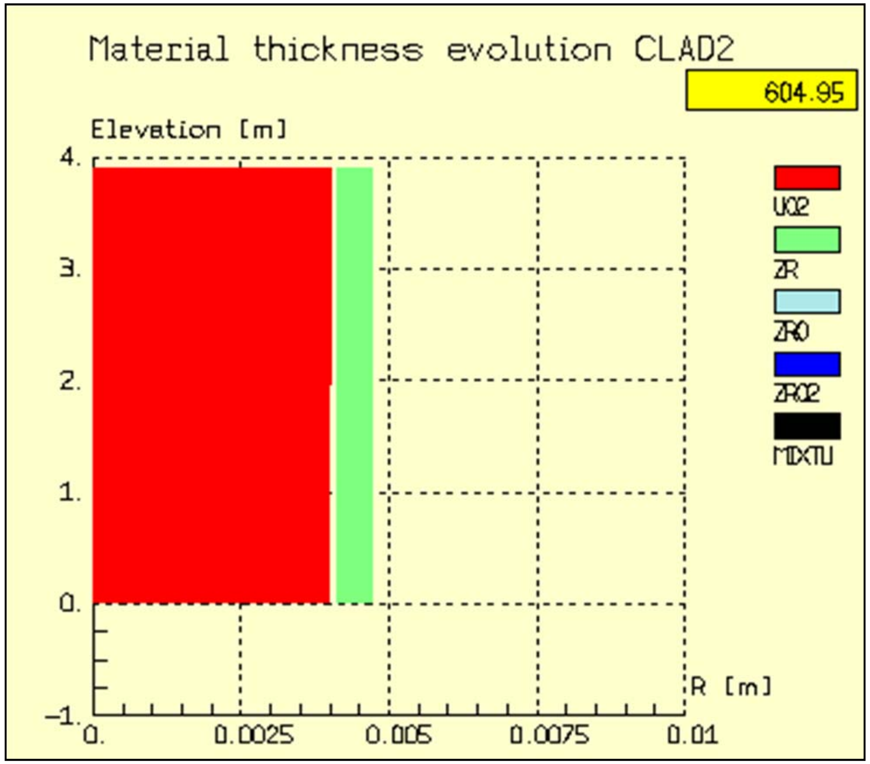
4. ASTEC: Predicted Sequence of Events (Part II)

Main events during core degradation	Time
Start of ICARE: onset of core degradation	451.19 s
Beginning of oxidation	451.29 s
First cladding creep rupture	767.23 s
Start of fission product release from fuel pellets	769.64 s
First material slump into the lower plenum	1767.50 s
Lower head failure	4722.01 s

Reactor Pressure Vessel Rupture 1 h 20 min after break opening

4. ASTEC Predictions: Oxidation of core materials (1/4)

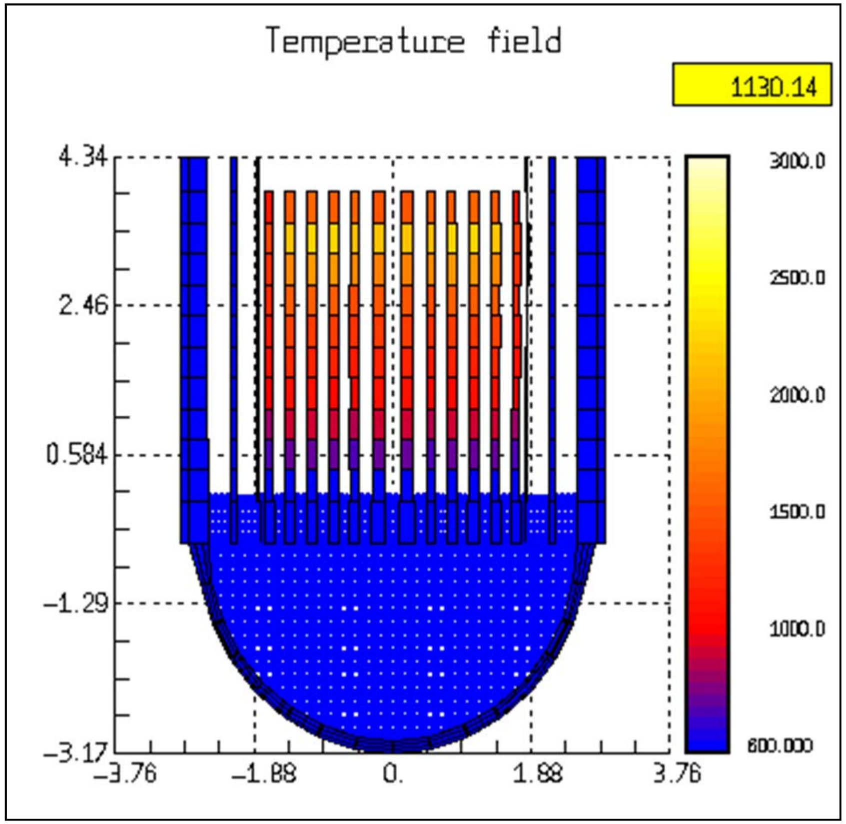


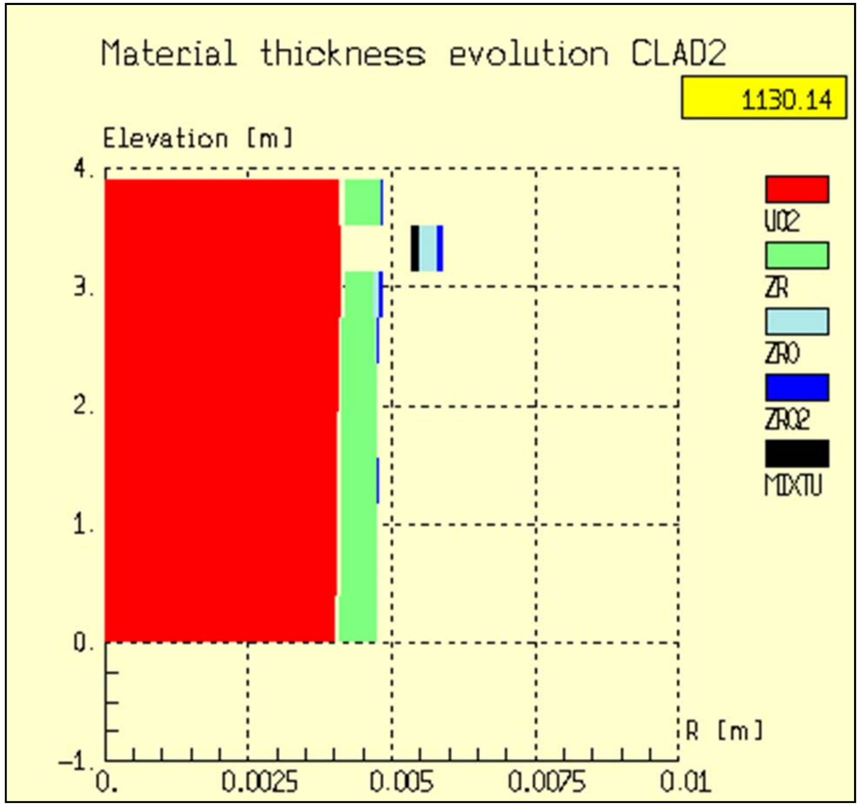


The claddings are initially heated up due to the decay heat, rather than by oxidation

(maximum temperatures are approximately 900 K)

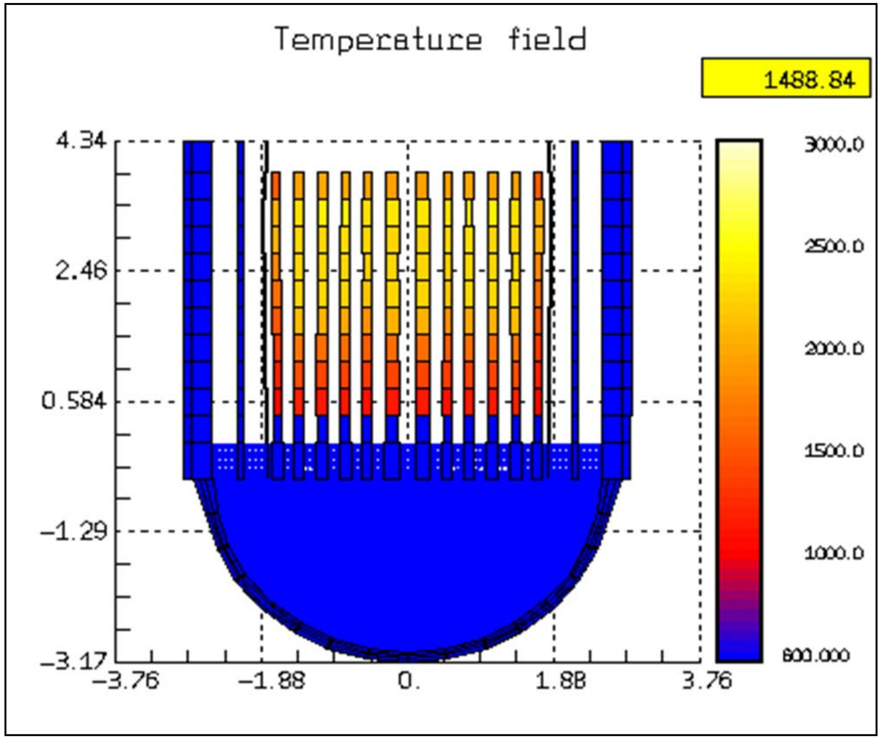
4. ASTEC Predictions: Oxidation of core materials (2/4)

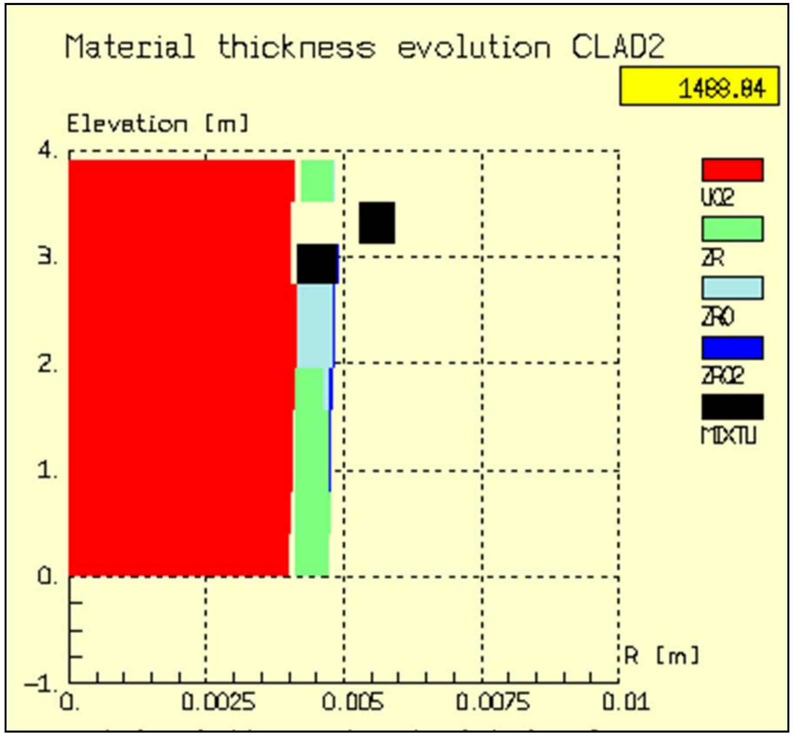




The oxidation of Zircaloy-4 starts to accelerate once the cladding temperature outweigh 1800 K, due to the entrance in high temperature oxidation

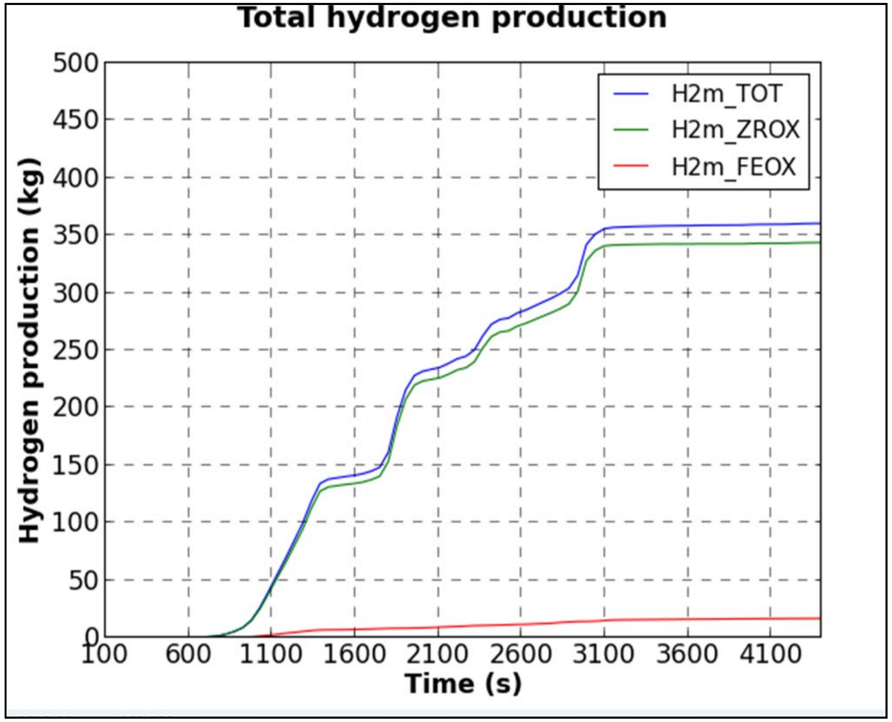
4. ASTEC Predictions:
Oxidation of core materials (3/4)

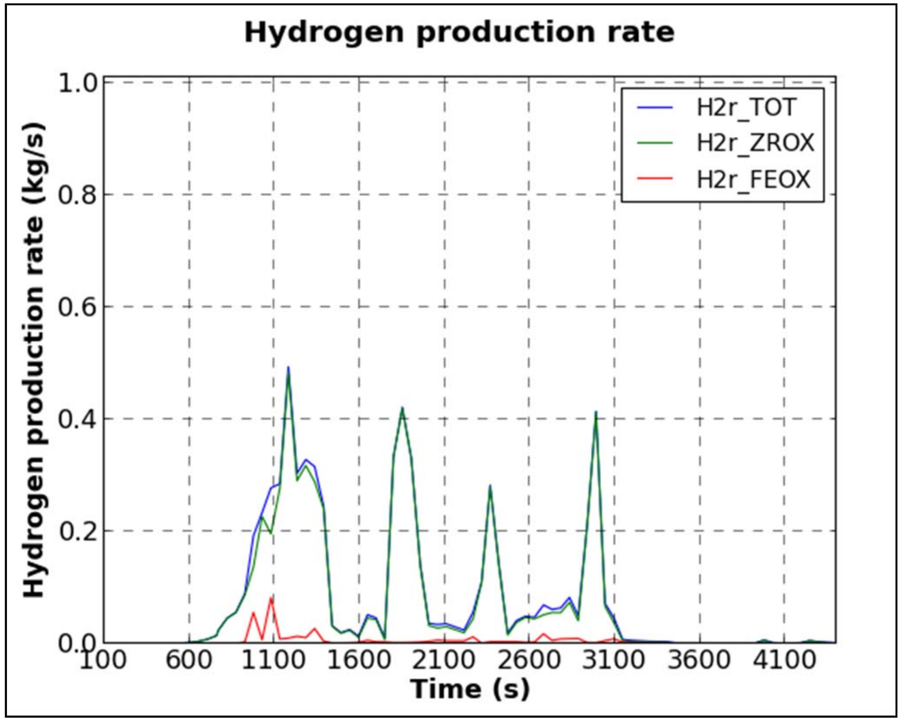




The Zr and the Zr-O become molten within the cladding and start to decant to the magma once the integrity criteria is reached (T> 2600 K and oxide < 250 microns)

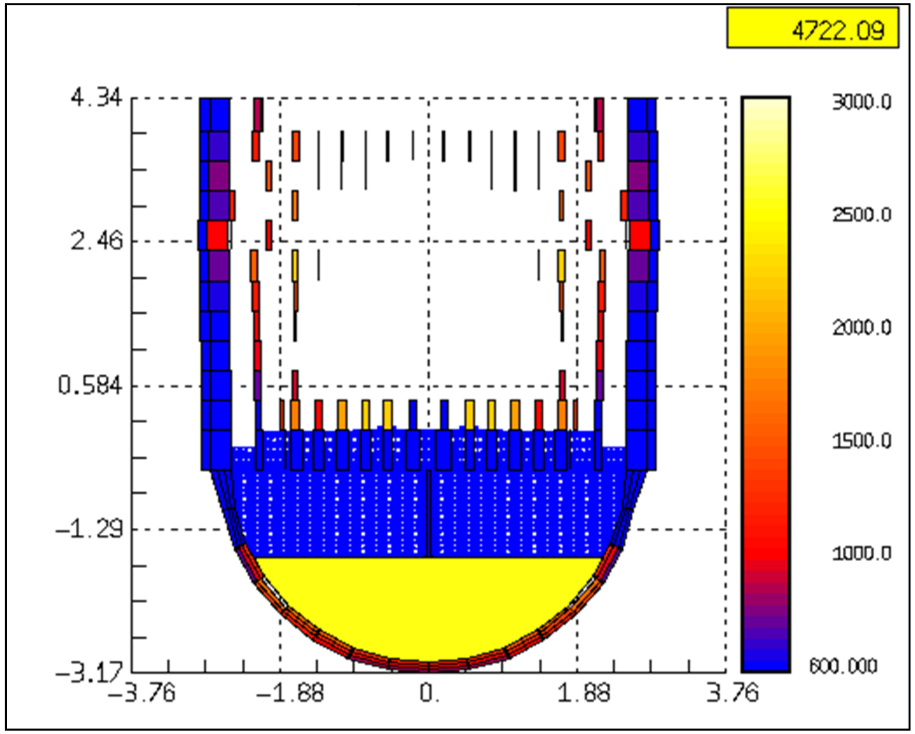
4. ASTEC Predictions: Oxidation of core materials (4/4)

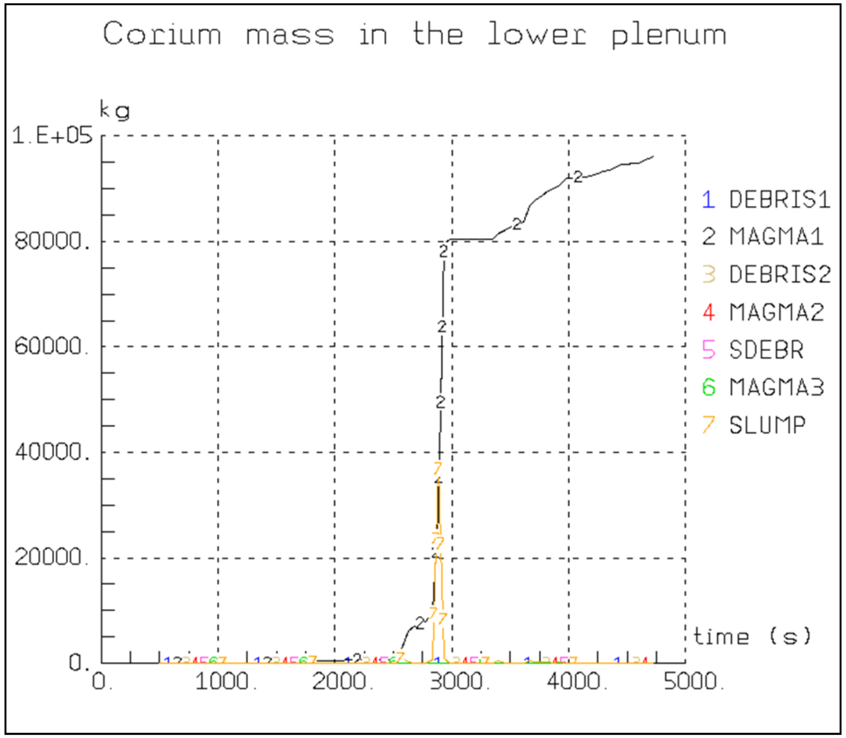




1. Claddings enter the high temperature oxidation regime, and undergo a first temperature peak → strong hydrogen generation
2. Later on, dissolution of cladding and slumping of molten material to the lower plenum, producing steam and the following three spikes in the hydrogen generation

4. ASTEC Predictions: Reactor Pressure Vessel Failure





1. Almost 100 tons of molten material relocate to the lower plenum in the form of magma (MAGMA1)
2. Collapse of Reactor Pressure Vessel occurs due to plastic failure at 4722 s (1h and 20 min after the break opening)

Content

5. Summary and outlook

- Considerable progress done regarding documentation of the ASTECV2.0rev3 plant model: primary, secondary circuit, connections, regulations and systems of the German Konvoi input deck

- Input deck is being converted from ASTECV2.0 to ASTECV2.1 since January 2015: primary, secondary and vessel

- Reference severe accident sequence without SAM has been successfully modelled and simulated
  - Extensive melt formation and relocation predicted

- The aim for the third year is to perform SAM (core reflooding) to stop the progression of the reference severe accident during the early-in vessel phase → mass flow rate and time of injection

Thank you for your attention