# Analyses of the Plant Behaviour of a PWR During Severe Accidents with Multiple Failures of Safety Systems

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- Structure and capabilities of used analysis codes
- Analysis of a station blackout (SBO) in a PWR
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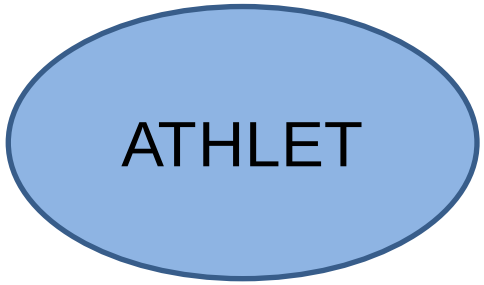
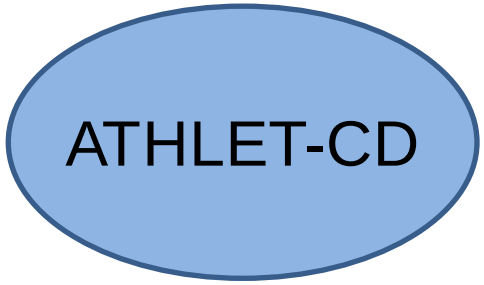
# Introduction

- GRS is contracted by the German federal authority BMUB to analyse in detail the plant behaviour of a Konvoi-PWR during severe accidents
- Simulation of these accidents with an integral code from initiating event until failure of RPV, utilising
  - GRS simulation software ATLAS (with possibility of online interaction)
  - Coupled version of ATHLET-CD/COCOSYS
- Analysing
  - Core melting in detail (when, where and how)
  - Relocation to lower plenum and behaviour of molten pool
  - Zircaloy steam oxidation, release of hydrogen, fission products and aerosols out of the core
  - Transport and deposition of fission products and aerosols in primary circuit and distribution in containment

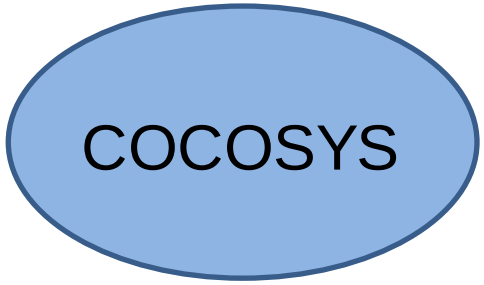
# GRS Codes Utilised




Design basis accidents
Basis for thermofluid dynamics




Severe accidents
- Oxidation, quenching and melting processes
- Debris bed and formation of melting pool and crust
- Release and transport of $H_2$, fission products and aerosols in primary circuit
- Relocation of mass and energy
- Phenomena in lower plenum

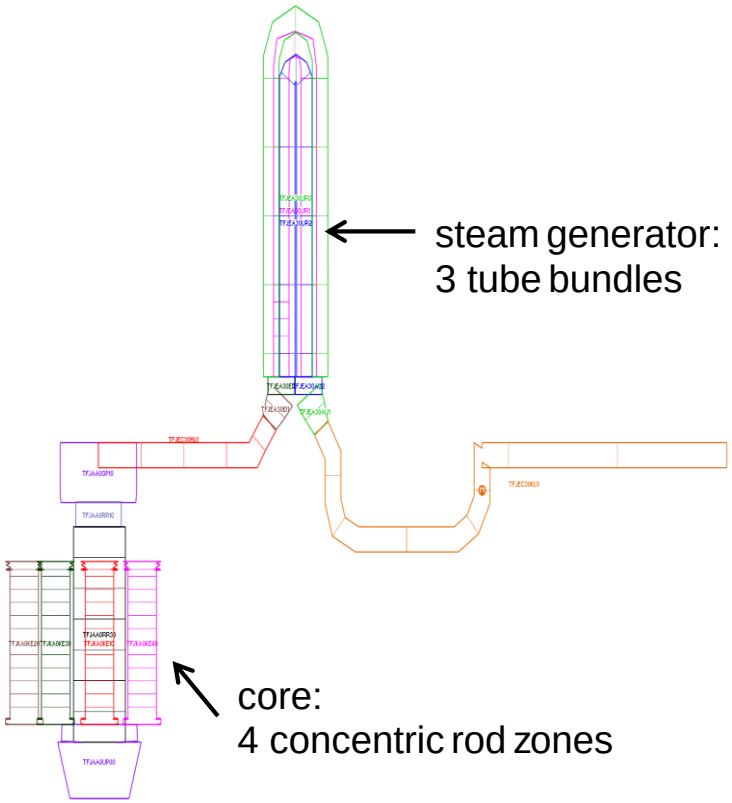


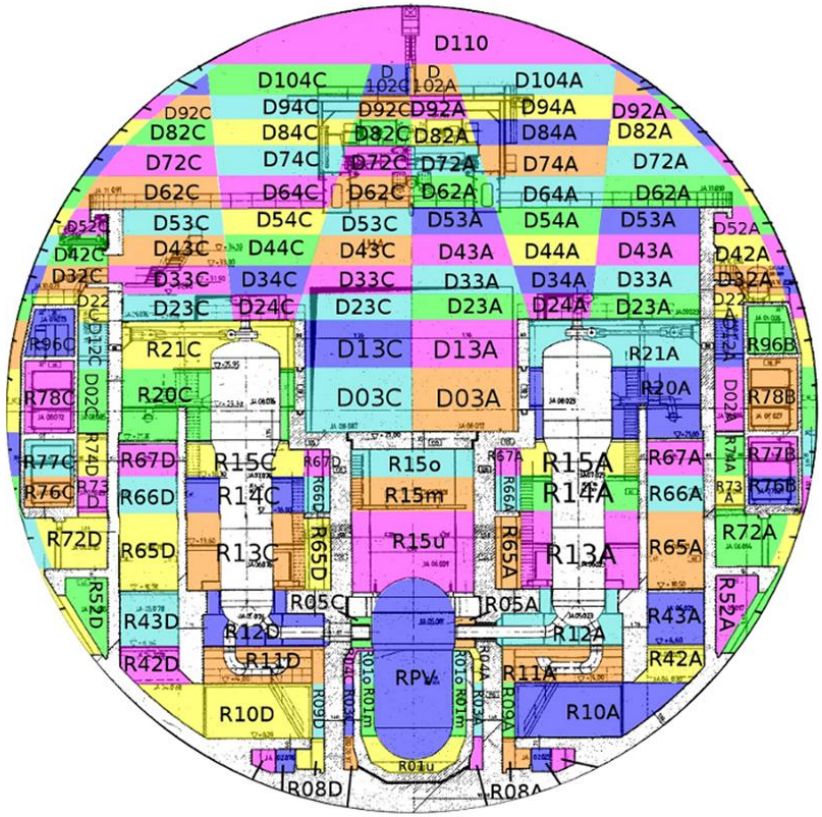

Containment behaviour during
- Design basis accidents
- Severe accidents

more information on GRS-Codes: www.grs.de

# Simulation of Station Blackout (SBO)

Nodalization scheme of the PWR primary circuit and of containment

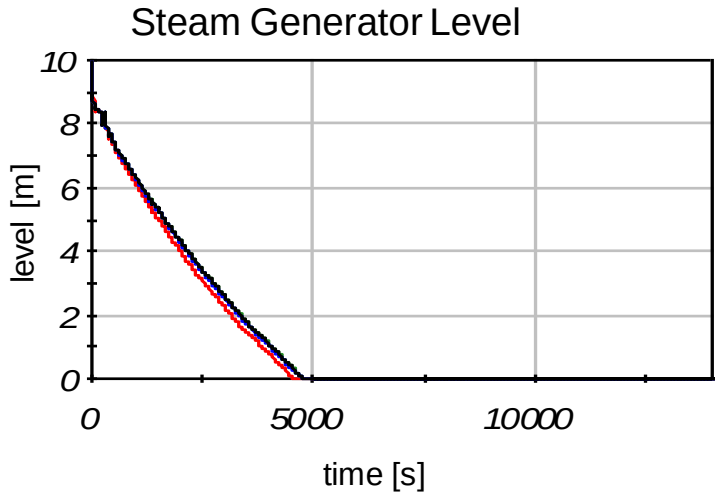


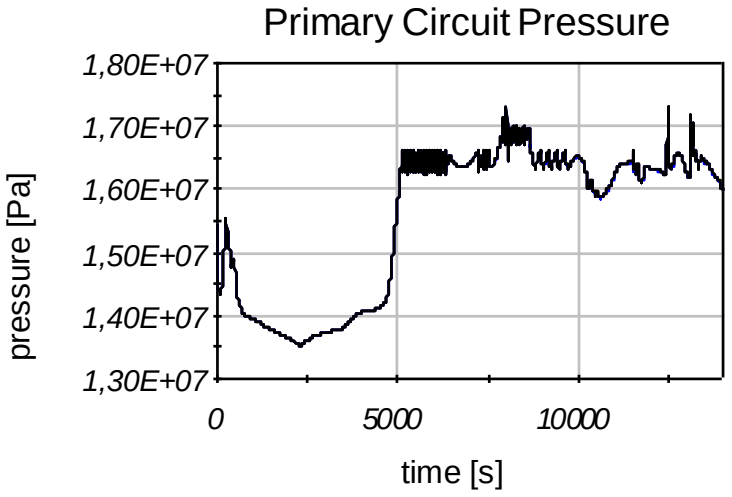




COCOSYS containment model
(226 zones)

# Plant Behaviour before Core Melting (1)

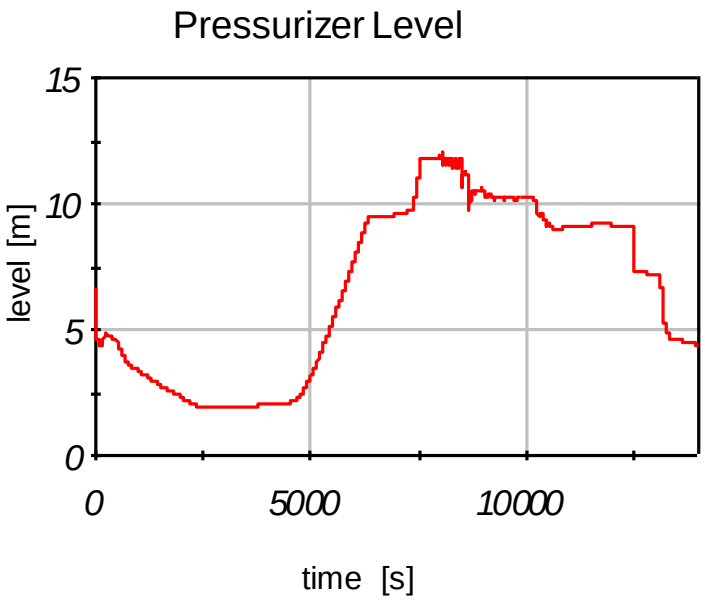
- SBO was initiated by setting grid, generator and all emergency diesels unavailable
- For 5000 s after SCRAM: Heat removal via natural circulation and secondary side steam release
- After 5000 s: Due to emptying of steam generator heat removal via opening of pressurizer valves

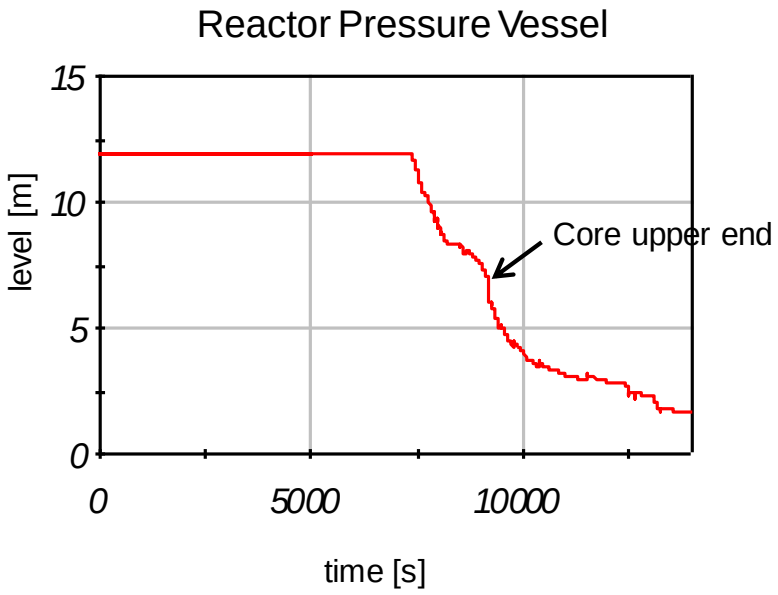


# Plant Behaviour before Core Melting (2)

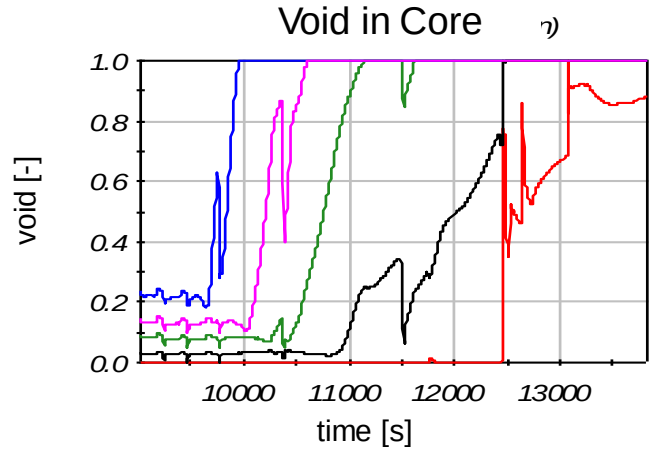
- After ca. 7500 s: After fill up of pressurizer due to volume expansion pressurizer safety valves open
  → Two phase flow into containment
- Reactor Pressure Vessel (RPV) level begins to drop

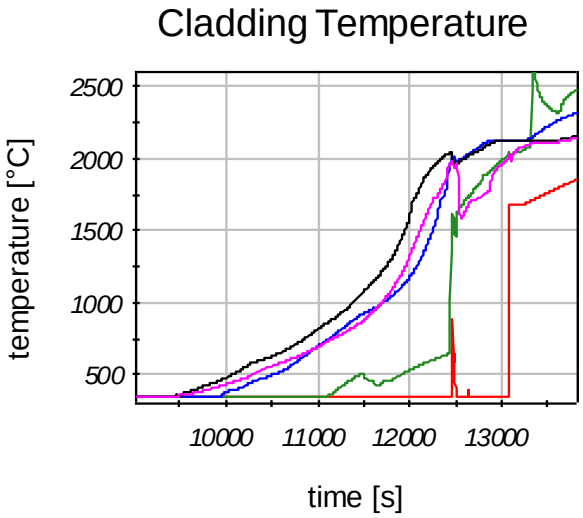


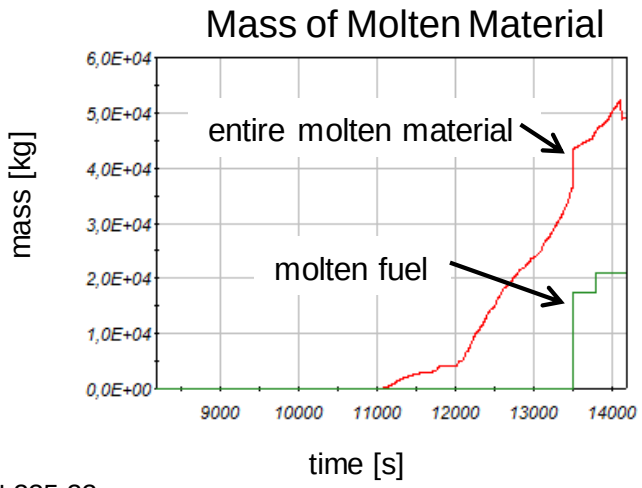



# Start of Core Melting

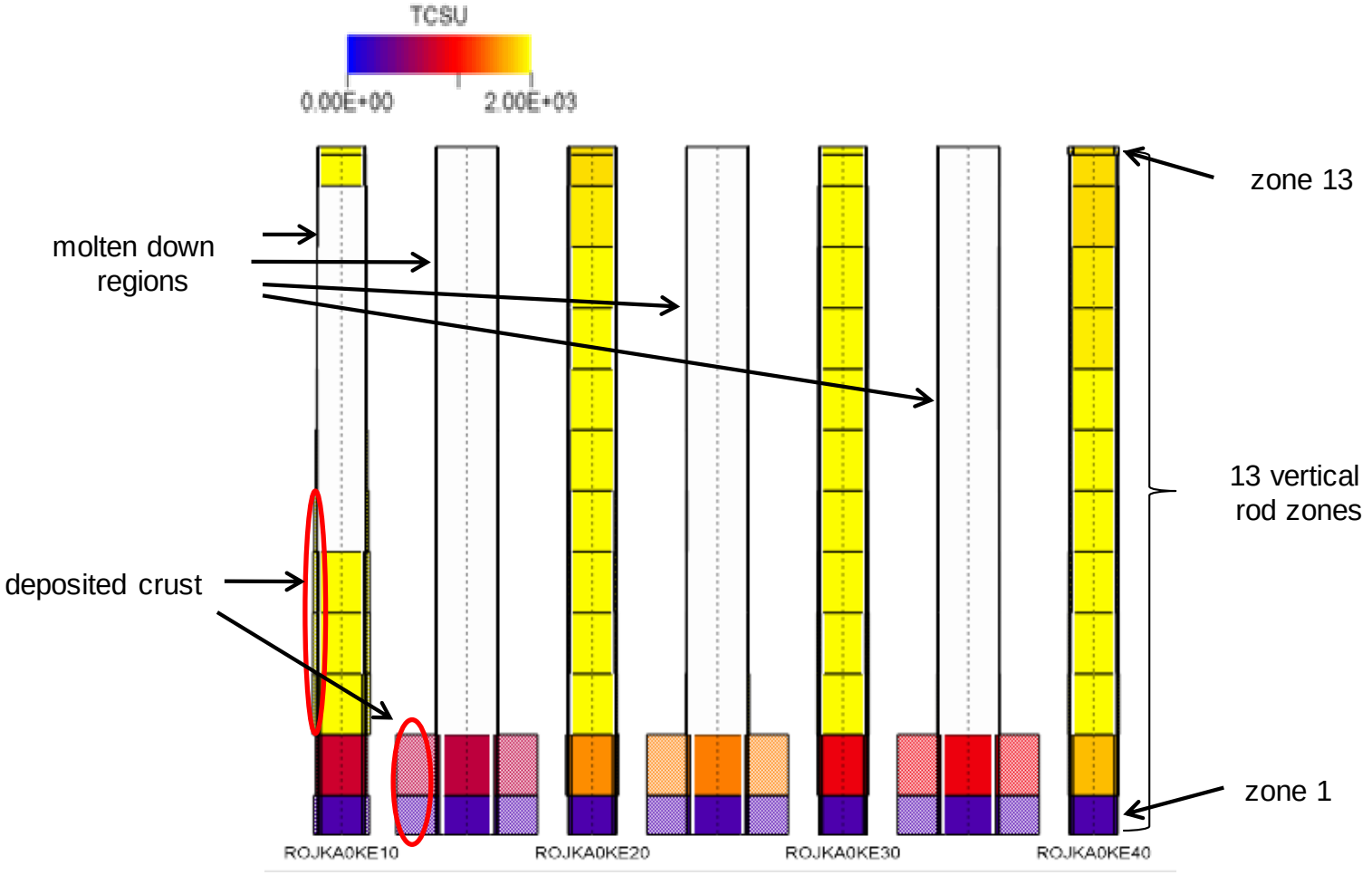
- After ca. 10000 s: rise of void fraction and of core temperature
  → Begin of core melting: Control rod material (at 800 °C), cladding (at 1200 °C), fuel (at 2300 °C)



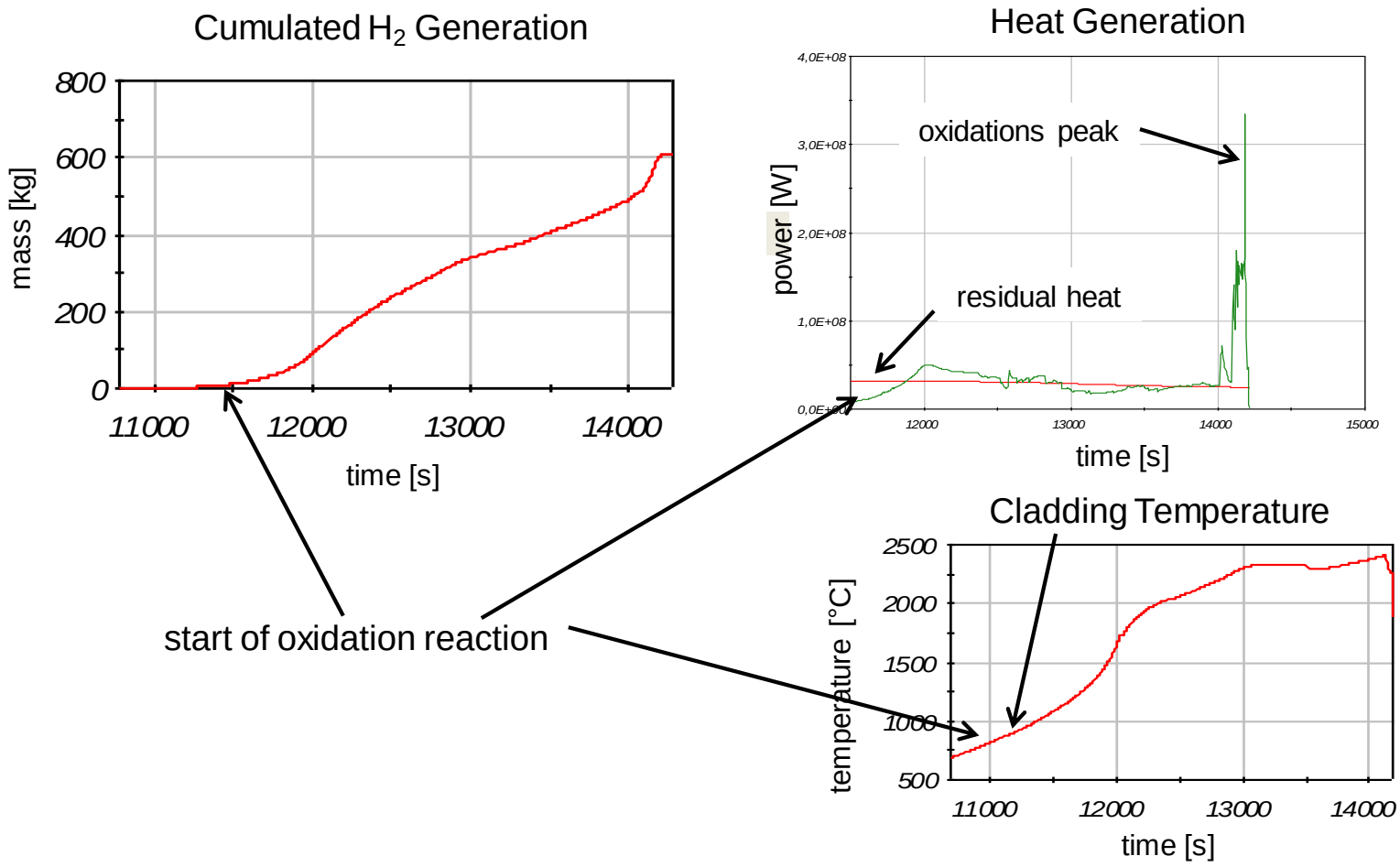



# Core Status at 14000 s



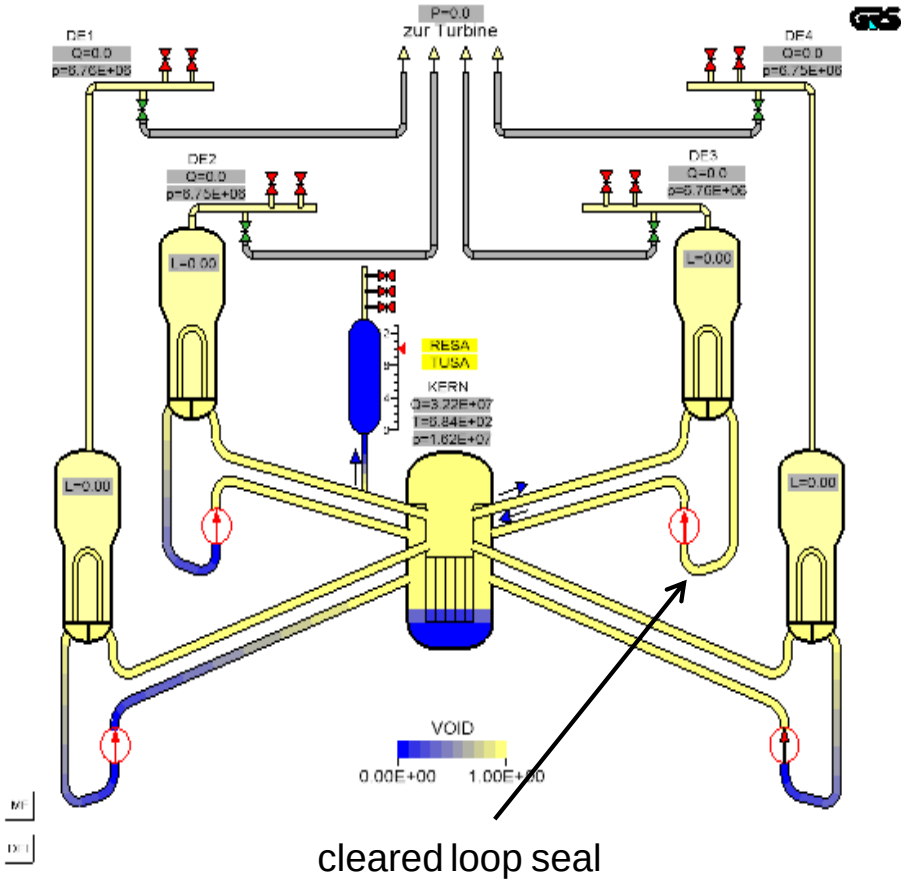
# Oxidation and $H_2$ Generation

- At 800 °C cladding temperature → additional heat and $H_2$ generation due to zirconium-water-reaction

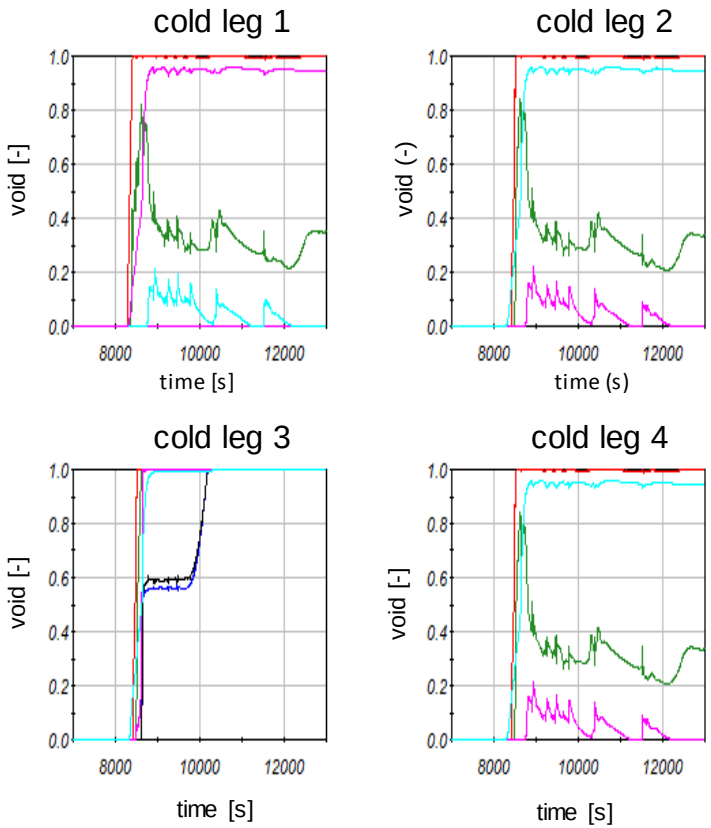


# Clearing of Loop Seal

- Clearing of loop seal in loop 3 after 10000 s

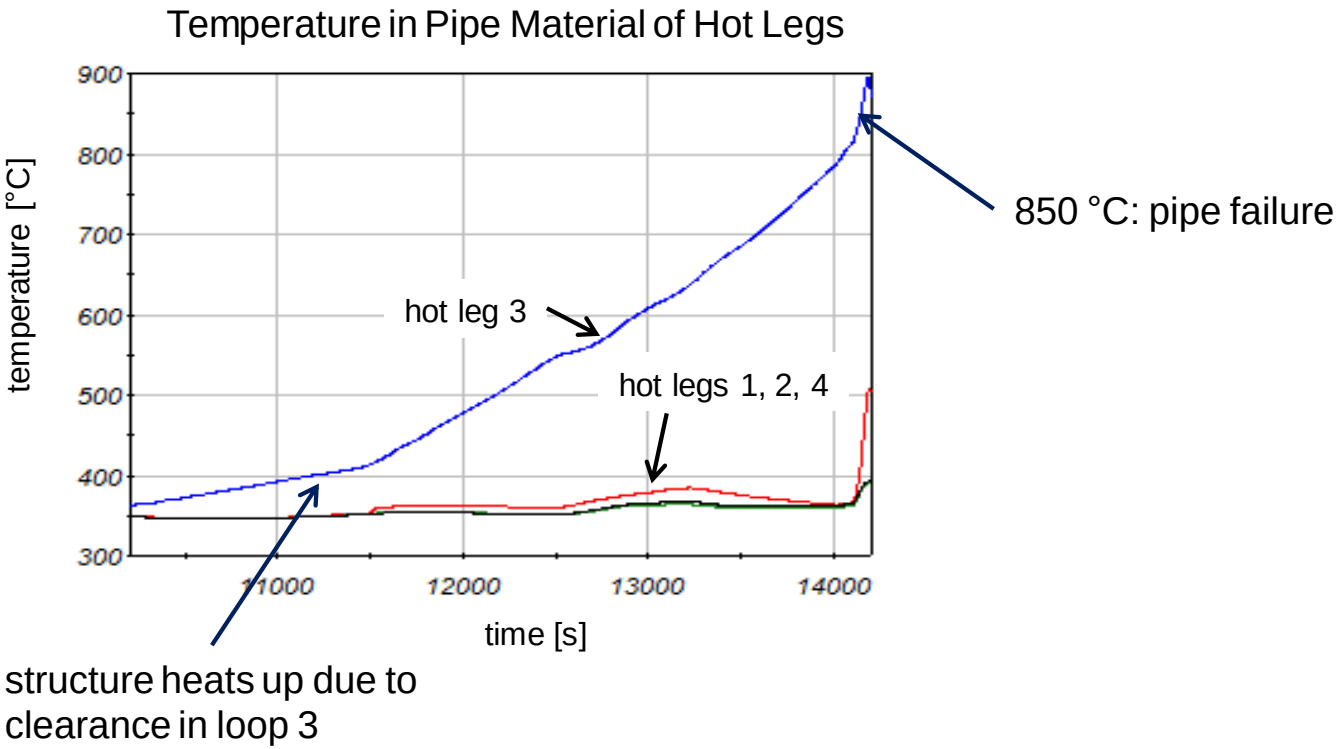



Void in Loop Seals
(different nodes)

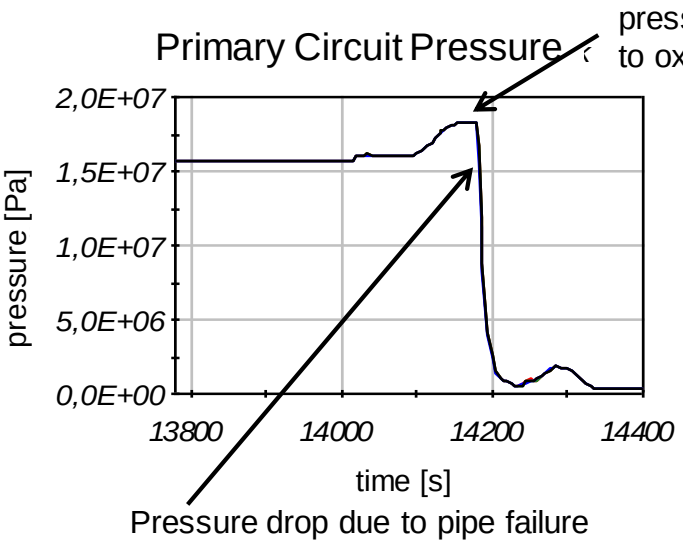


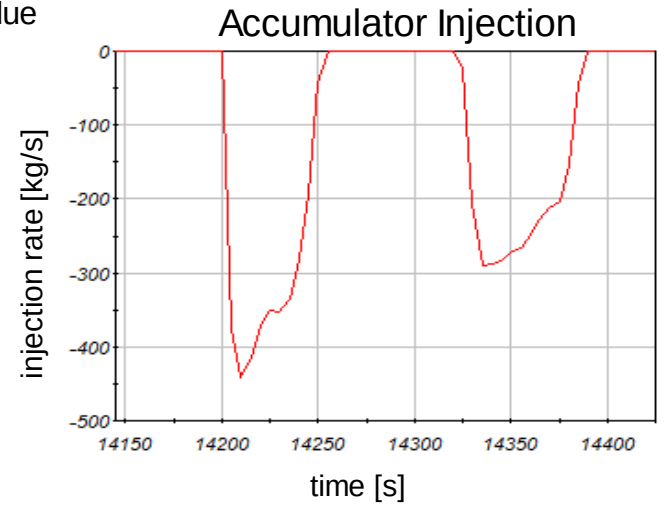
# Thermal Load on Primary Circuit Pipes

- Thermal load in loop 3 rises after clearance of loop
  - Prior structure analysis:
    pipe failure at ca. 850 °C under high pressure
  - Assumption: Large LOCA (0,44 m²) in hot leg 3 at 14200 s (850 °C)

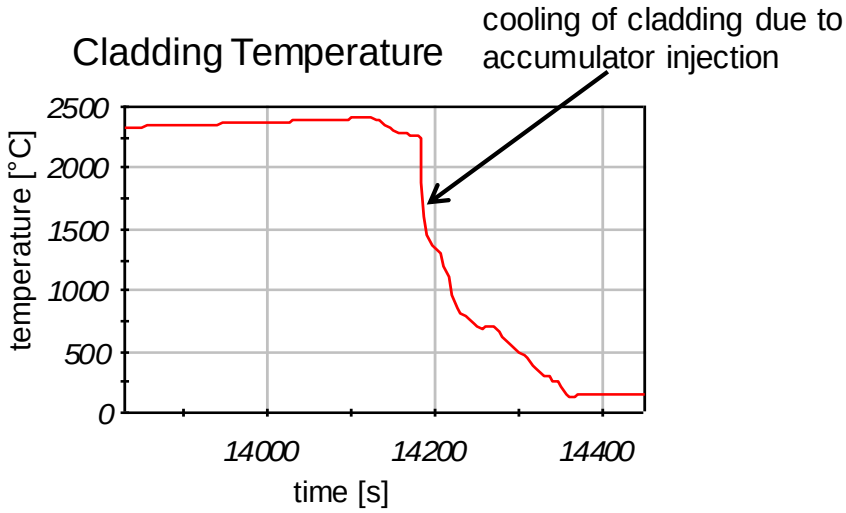


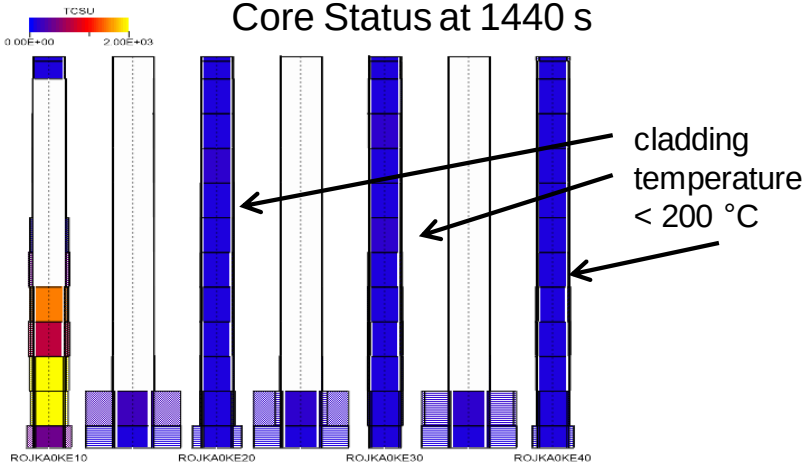
# Situation after Hot Leg Pipe Failure




Accumulator injection after primary side pressure falls below 25 bar

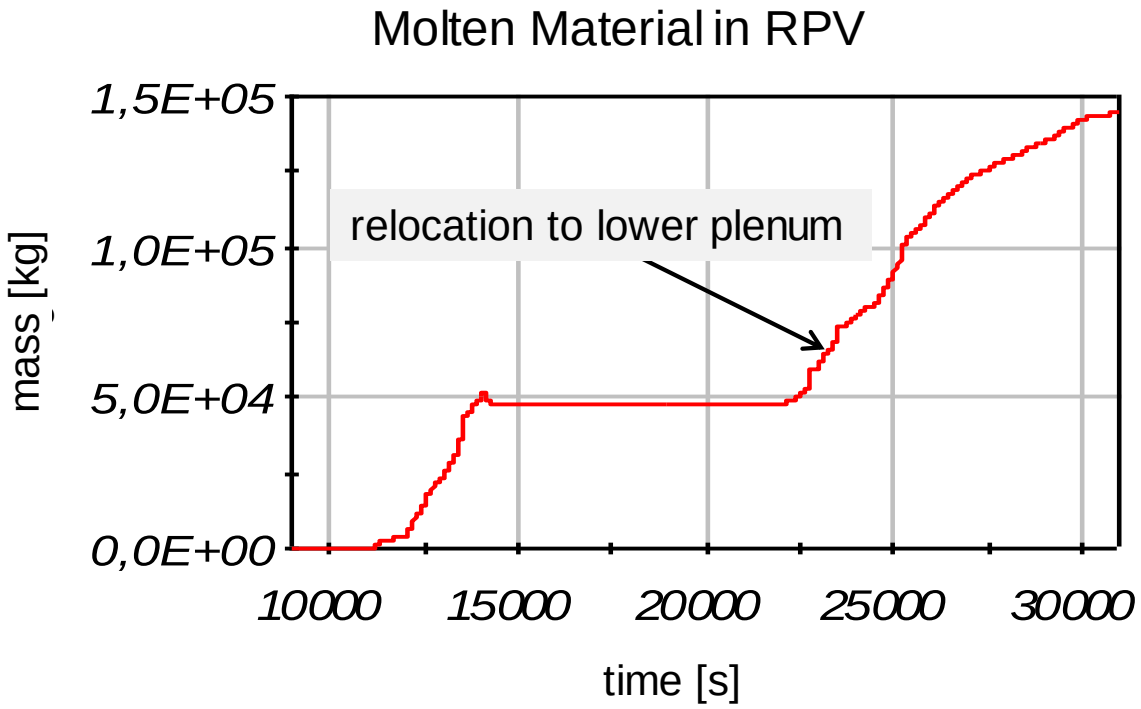


# Relocation of Core Melt

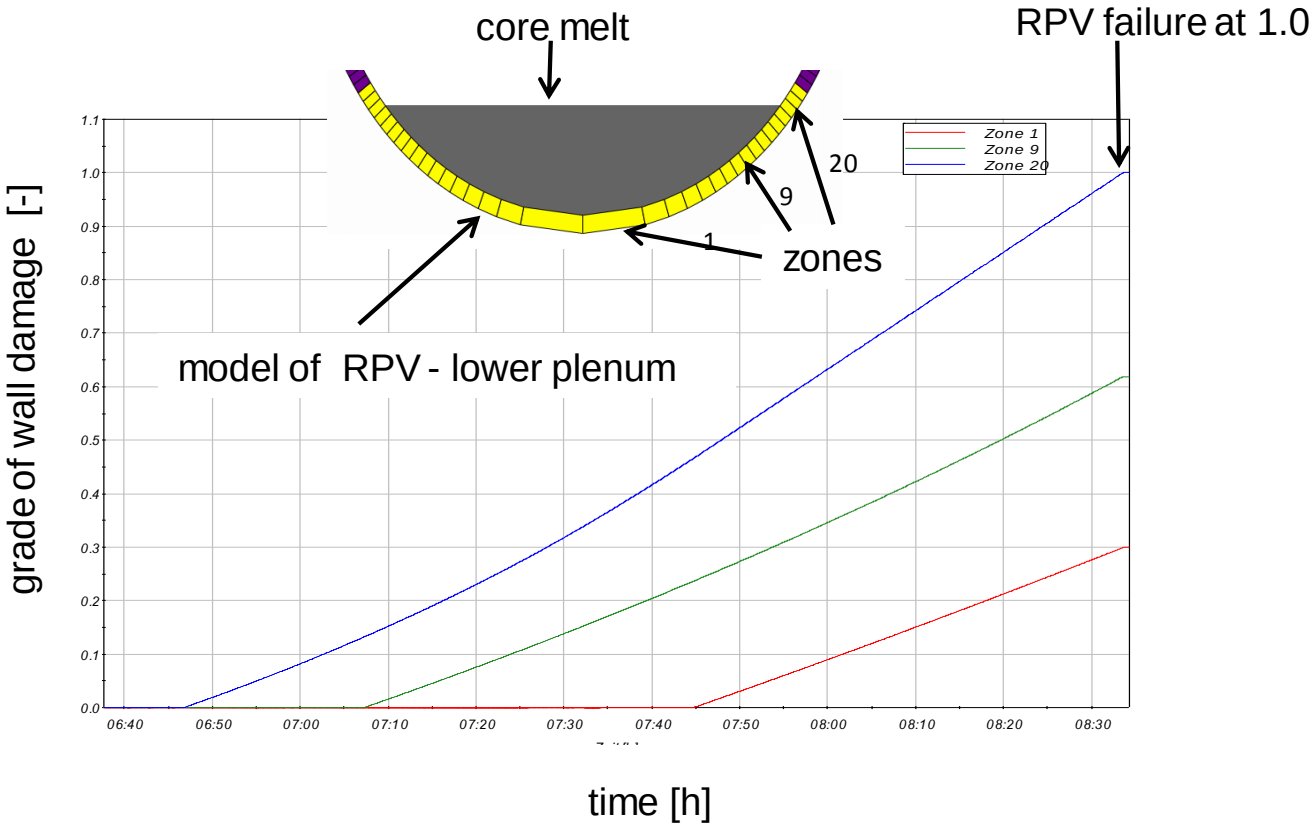
Assumption:
failure of lower core grid plate caused by load of 65 t molten core material

- Core melt relocation to lower plenum at ca. 23000 s



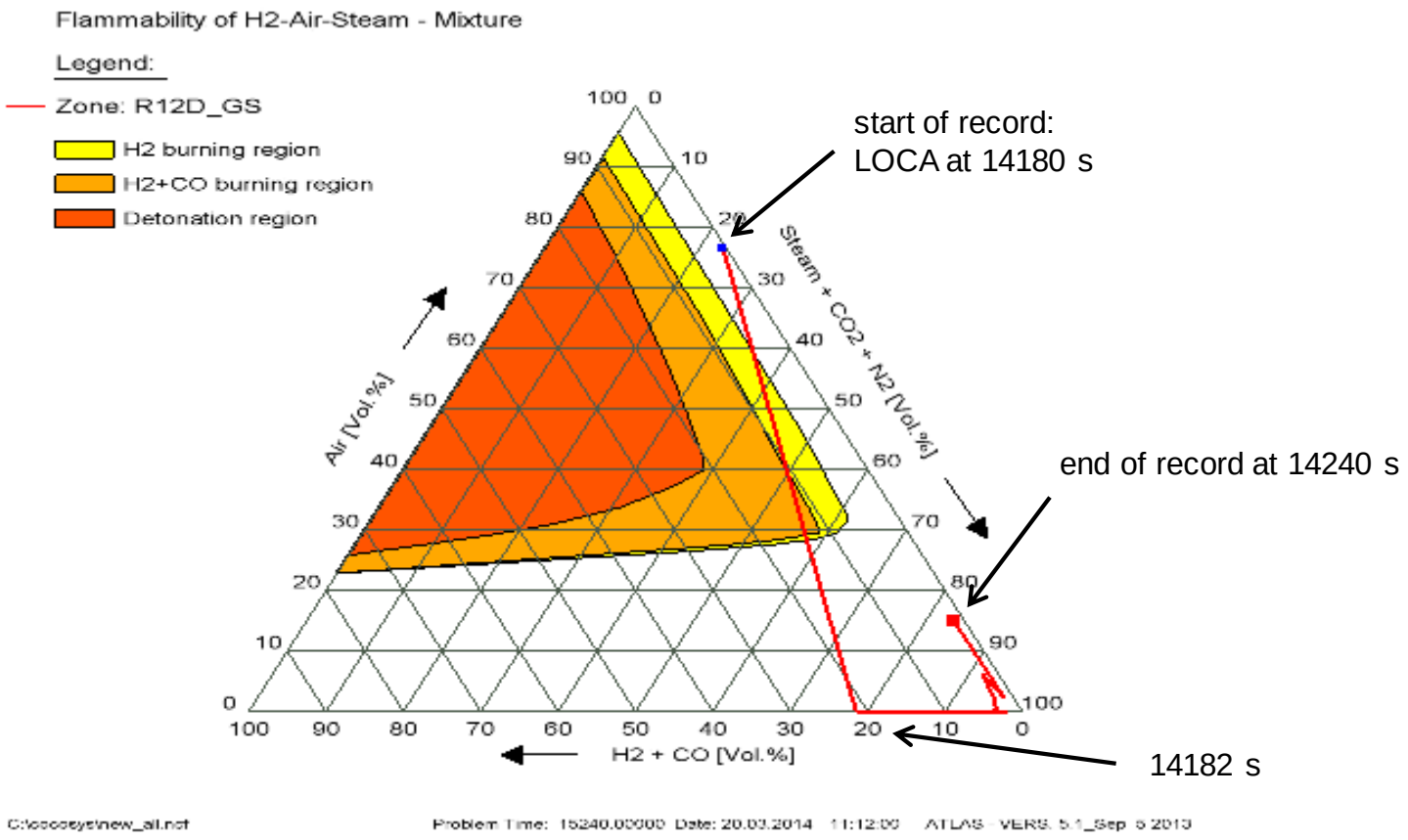
# Lower Plenum Behaviour and RPV Failure

- Interaction of core melt with RPV-wall
  - RPV failure at ca. 30800 s ≈ 8,5 h



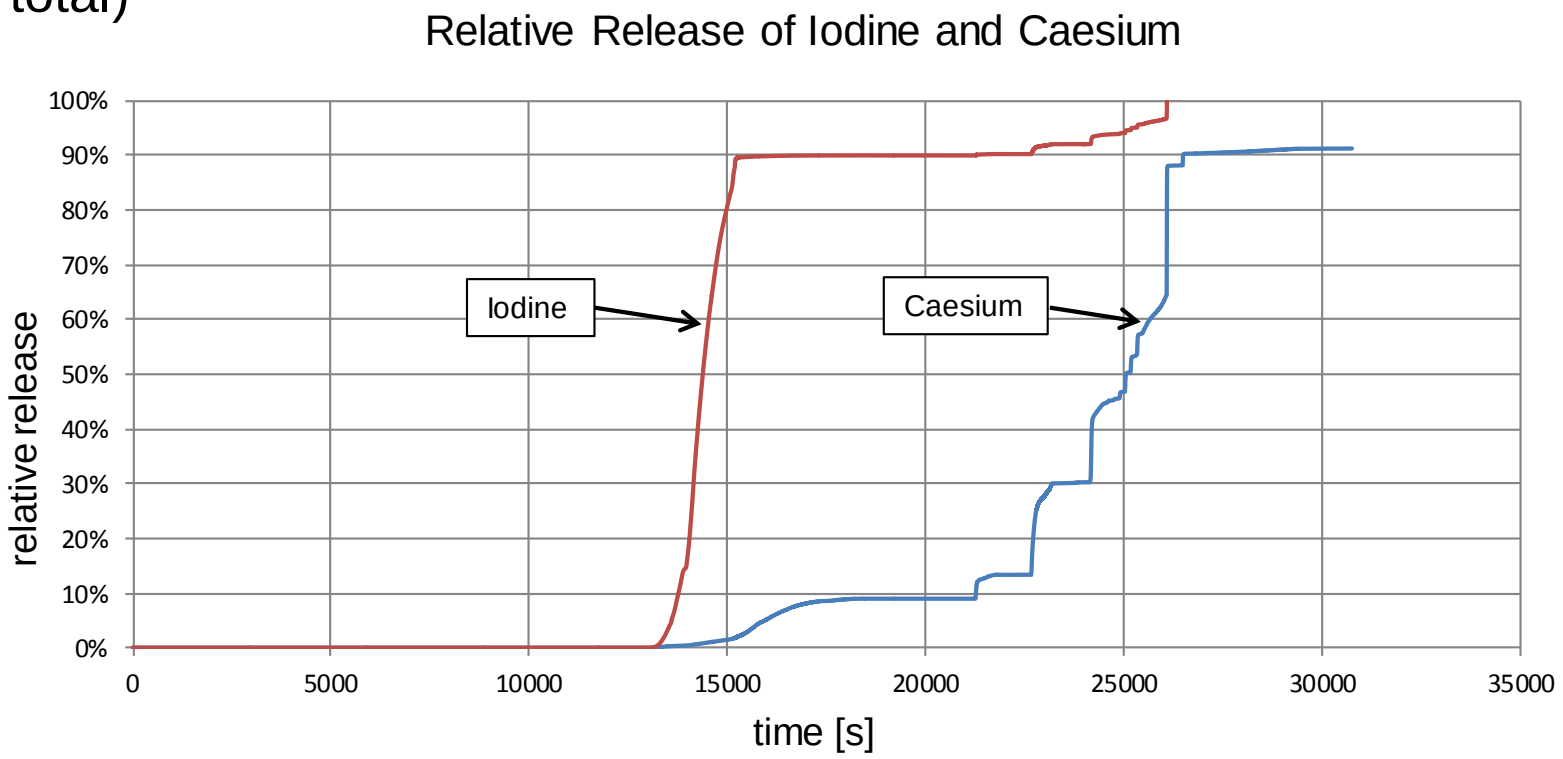
# Hydrogen Release in Containment

Burning region at LOCA location is passed within 2 seconds



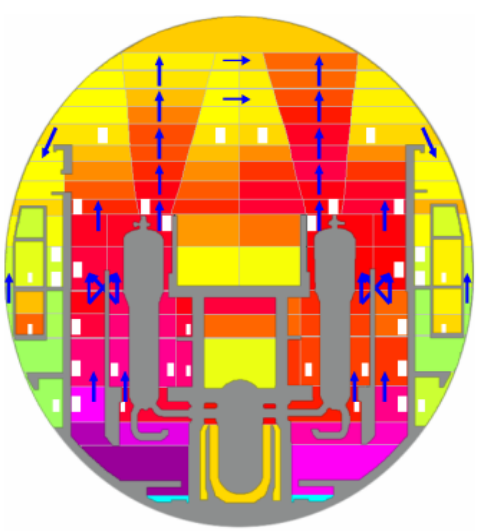
# Release of Fission Products into Containment

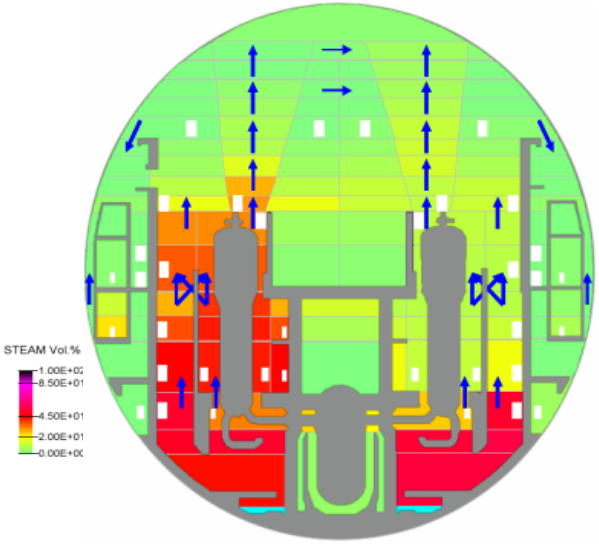
- After LOCA ≈ 90 % of Iodine rapidly released (gaseous)
- ≈ 10% of Iodine released later as chemical combination with heavier elements
- Most part of Caesium released after core melt relocation (≈ 90 % in total)



# Distribution of Containment Parameters: Steam, $H_2$ and Temperature

At 14200 s (after large break LOCA in hot leg)





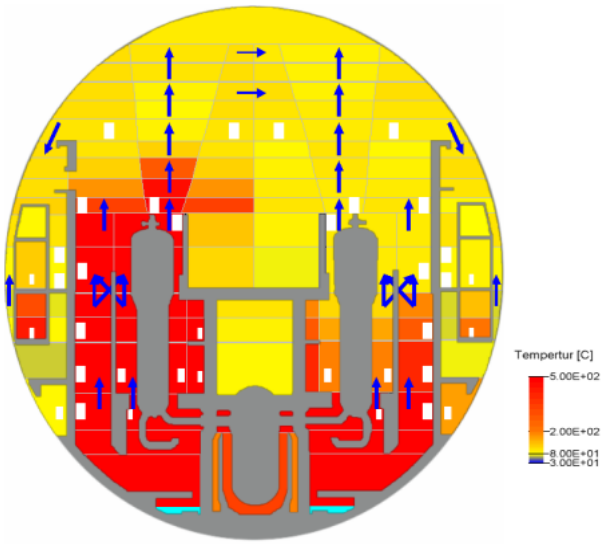

Steam fraction up to 85 %

Scale: 0 % - 100 %




$H_2$ fraction up to 15 %

Scale: 0 % - 20 %

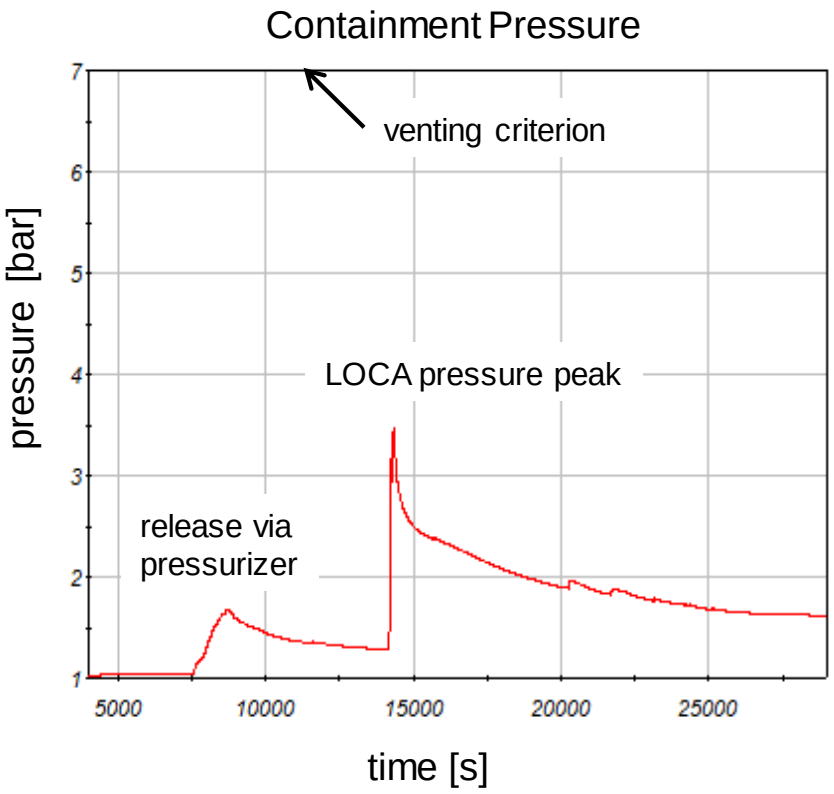


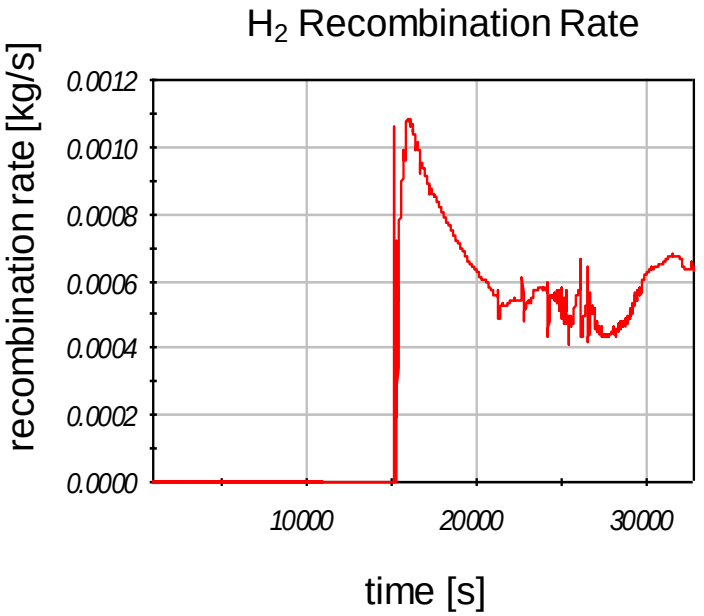

Temperature up to 230 °C

Scale: 30 °C – 500 °C

# Pressure in Containment

- Pressure remains below venting criterion (7 $bar_{abs}$)
- Pressure reduction due to recombiners ($H_2$), condensation at containment structures (steam) and heat losses to environment



# Summary and Conclusions (1)

- SBO was analysed for a Konvoi type PWR
  - Grid, generator and all emergency diesels are set unavailable
- Results:
  - 10200 s: clearance of loop seal in loop 3 with consequent circulation of hot gases
  - 11500 s: start of core melting
  - 14200 s: failure of hot leg pipe (loop 3) after exceeding 850 °C with transition to low pressure conditions (→ accumulator injection)
  - 23000 s: relocation of molten core to lower plenum
  - 30800 s: RPV failure

# Summary and Conclusions (2)

- Results (cont.):
  - Steam and $H_2$ released to containment:
    - Steam condensation at structures
    - $H_2$ recombination by autocatalytic recombiners
  - More than 90 % of Iodine is released in an early stage of core melting and cumulates mainly in the containment dome
  - Ca. 90 % of Caesium is released but main part after core melt relocation
  - Containment remains within design limits until RPV failure
- ATHLET-CD/COCOSYS analyses of containment behaviour after RPV failure with consideration of e.g. “Direct Containment Heating” (DCH) and “Molten Core Concrete Interaction” (MCCI) are subject of ongoing research at GRS

# Thank you for your attention!

For questions please contact:

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