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GRS

Influence of ZnB on the core cooling in the event of loss of coolant accidents

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- Influence of chemical process in German PWR: the problem of zinc-borate
- Results from experimental investigations
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State of knowledge about Clogging

- Operational experience has pointed clogging phenomenon as significant problem for the cooling of reactor core
  - International incident: Barsebäck (Sweden – 1992), Perry Unit 1 (USA – 1993), Limerick Unit 1 (USA – 1995)

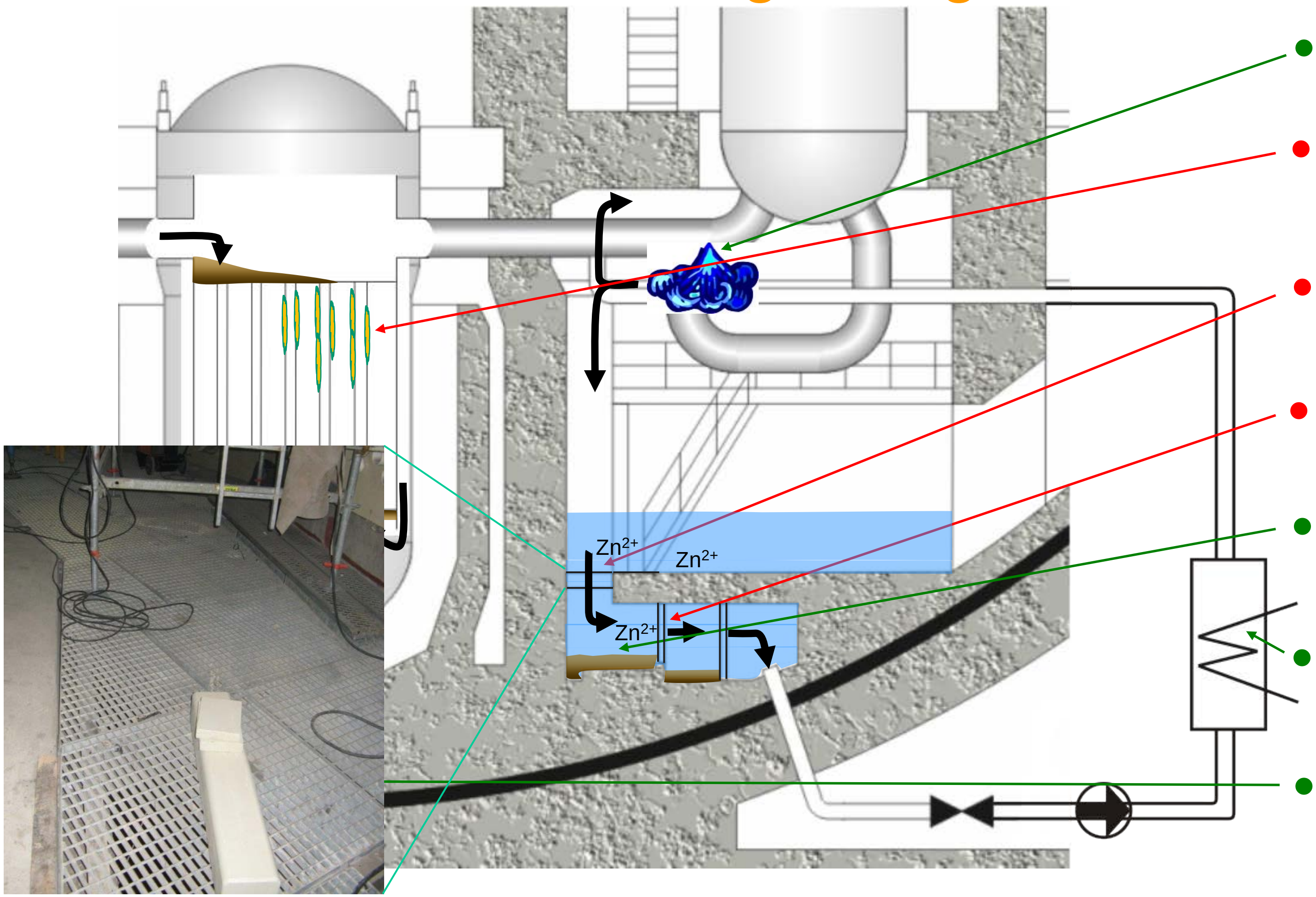
After LOCA event, a release of fibrous insulation material into containment sump was observed

Safety-relevant character regarding the residual heat removal in NPP

Worldwide attention and intensive investigation of clogging phenomenon

- In the last years the attention has been focused on the effects of chemical processes
  → Formation and deposition of ZnB particles in reactor core

Influence of physical and chemical effects on the core cooling during LOCA

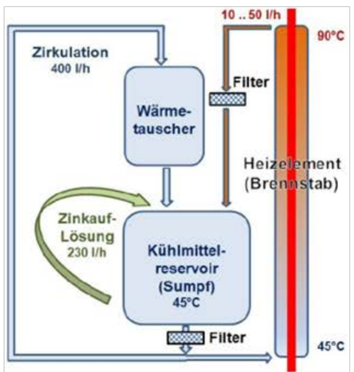


- Release
- Zinc-borate deposition in core
- Zn^{2+} from dipped gratings in sump
- Zn^{2+} dilution from sump strainers
- Deposition of debris on sump strainers
- Transport of particles through ECCS
- Deposition of debris particles in core

Analogy to Clogging → Deposition of corrosion products in reactor core

Experiments for estimating the impact of chemical processes

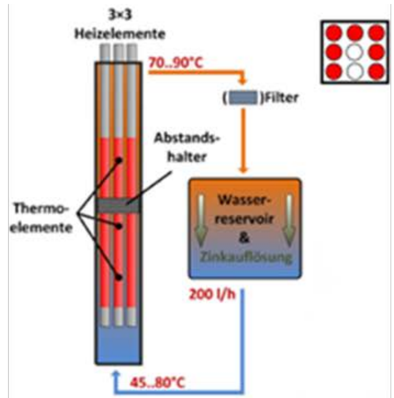
- Chemical effects have been investigated in the framework of the BMWi-funded projects from Helmholtz-Centre Dresden-Rossendorf and University of applied science Zittau/Görlitz.



BMWi-founded project Nr.1501430

KorrVA

1 heating rod
0.06 m³ coolant inventory



Ring Line II

3 x 3 rod bundle
0.3 m³ coolant inventory

BMWi-founded project Nr.1501431

Zittauer Flow Tray (ZSW)

16 x 16 rod bundle with 56 heating rods
15 m³ coolant inventory

- Three test facilities have been built with different scaling factors and used for:
  - Investigation about zinc-ions dilution and solubility in coolant
  - Research about composition, formation and deposition of ZnB

Influence of chemical process in German PWR: the problem of zinc-borate

- In test facilities deposition layers of zinc-borate have been observed on heating rods and fuel assembly spacers

  → Clogging of channels and heat-up of heating rods

⇨ Question: reasonable effects for a sufficient core cooling during LOCA scenario for German PWR?

- Direct transfer of results from lab-scale tests is not possible

Model for the transfer of results on real plant is required

The input variables for the empirical model in ATHLET are derived from experimental results

Results from experimental investigations (1/2)

- Two relevant aspects for the ZnB formation process can be pointed out: chemical and physical
- Containment internals of PWR are particularly affected by corrosion process, since the coolant after LOCA contains up to 2200 ppm boric acid.
- Zinc-ions dilution and ZnB formation depends on: →
  - Water chemistry
  - pH-value of the coolant
  - Coolant temperature
  - Impact of leak jet
  - Turbulence in sump
  - Turbulence close to strainers
- Important aspects concerning zinc-ions release and solubility:
  - Zinc solubility depends strongly on temperature gradient of the coolant
  - Different ZnB compounds for different coolant temperature

Property of ZnB particles → *f*(T)

Up to 70°C:
Easily to mobilize, partially dissolvable

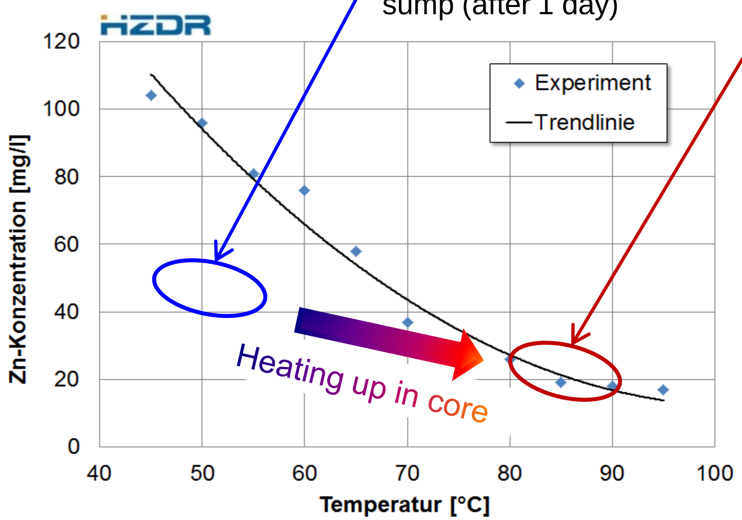
At 90°C:
Not dissolvable particles, **incrusted porous layers**

Results from experimental investigations (2/2)

- Difference between the coolant temperature in the core and coolant temperature in sump is an important driving force for the ZnB deposition

Temperature in containment sump (after 1 day)

Deposition on hot surfaces and grid spacers
Zn-concentration > Zn-solubility limit concentration



Source: Report HZDR\FWD\2014\01

Source: Report HZG-IPM-1501431
Deposition at bundle spacer
(Test RLII-HZ9-V13)

- Increase of pressure loss through the spacers because of ZnB deposition → strong reduction of axial flow path

→ Negative impact on core cooling caused by ZnB particles deposition

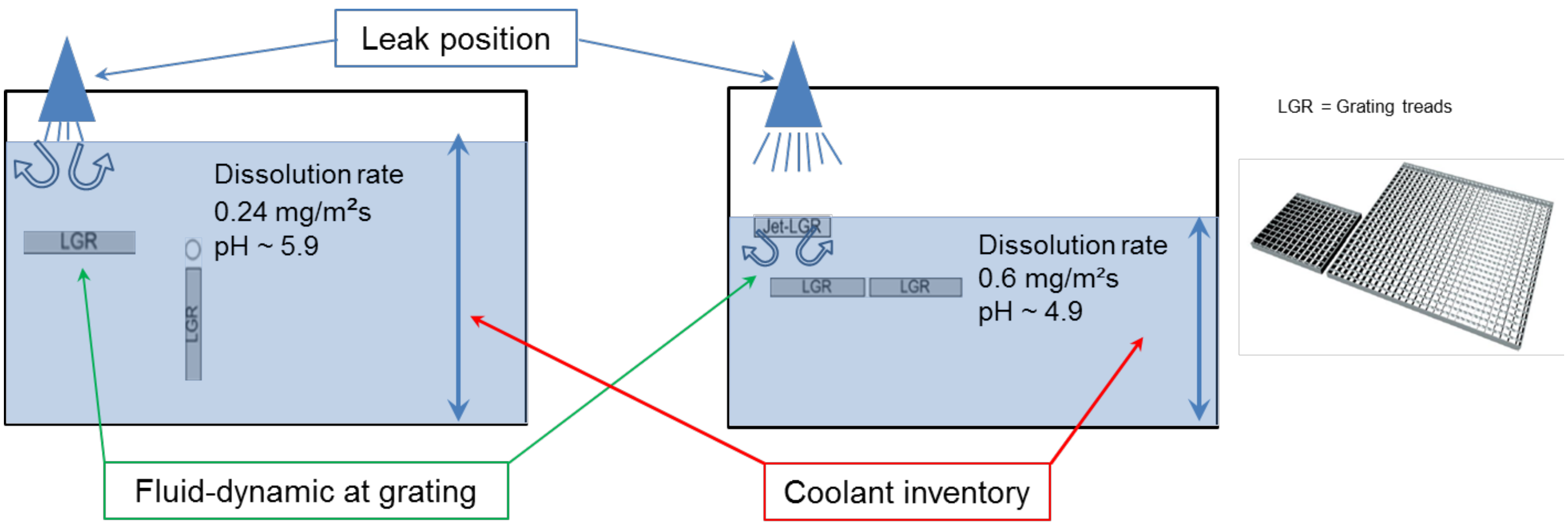
Overview of GRS work about ZnB topic

- Main tasks:
  1. **Verification** of the transferability of experimental results to real PWR
  2. **Investigation** about a **worst case scenario** concerning Zn^{2+} dilution in sump and formation and deposition of ZnB particles
  3. **Development of an empirical model** for the analysis of zinc dilution and zinc-borate deposition in ATHLET code
- The new ATHLET model takes into account:
  - Transport and deposition of ZnB in reactor core
  - Dissolution rate of zinc from galvanized surfaces
  - Form loss coefficient as a function of ZnB deposited mass

→ Main objective: Safety relevance of the ZnB topic

Transfer of test results to German PWR

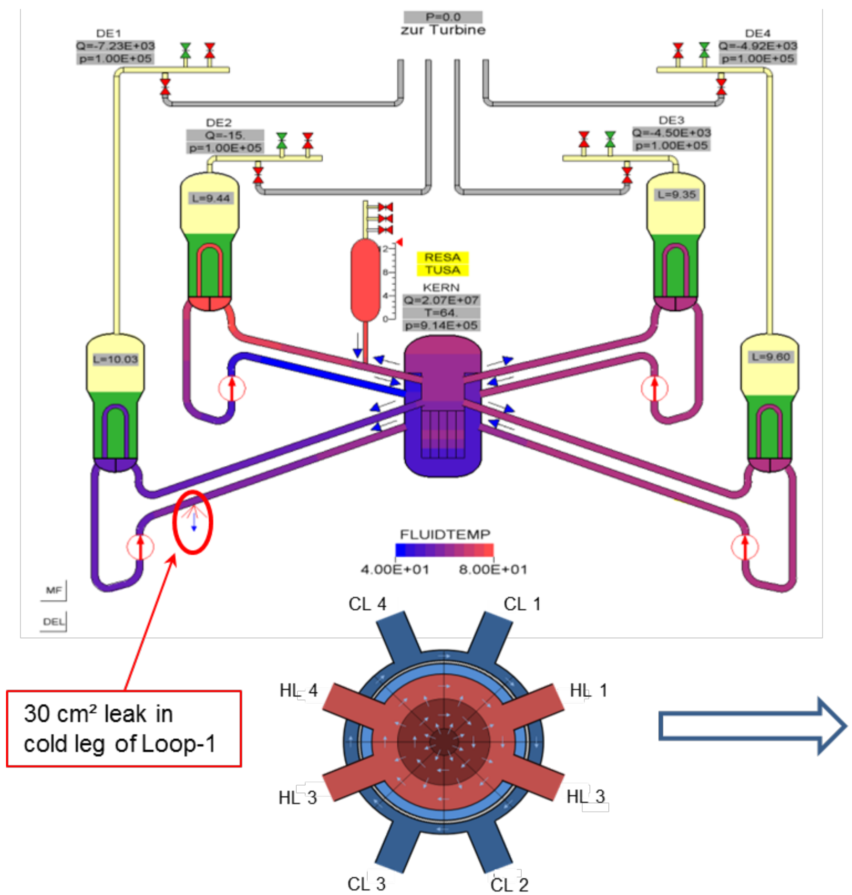
- Zinc-ion dilution in the empirical ATHLET model (boundary condition derived from experiments in ZSW facility):
  - Zinc dissolution rate increases proportionally to the effective dipped zinc-coated surface
  - pH range between 4.5 and 6.2
  - For galvanized surfaces under the leak jet → Zinc dissolution rate about 7 times greater



Leak position and turbulence at gratings has been considered in empirical model

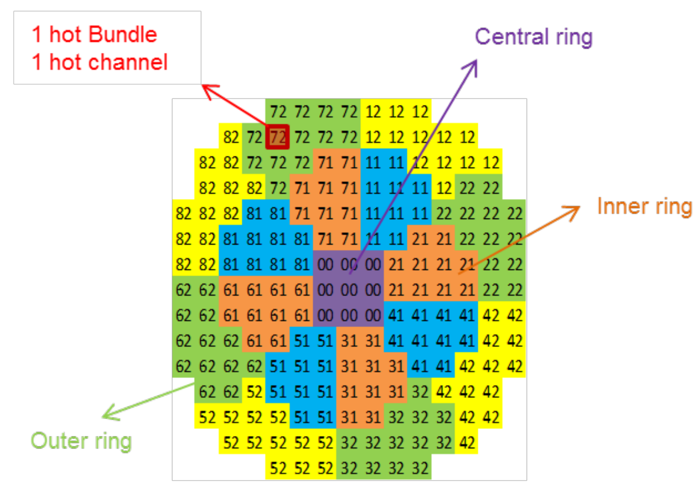
Results of GRS analysis (1/5)

- Analysis simulator of a generic German PWR
  - 4-Loop model, 8 downcomer channels, 17 core channels (+ 1 hot channel and 1 hot bundle)



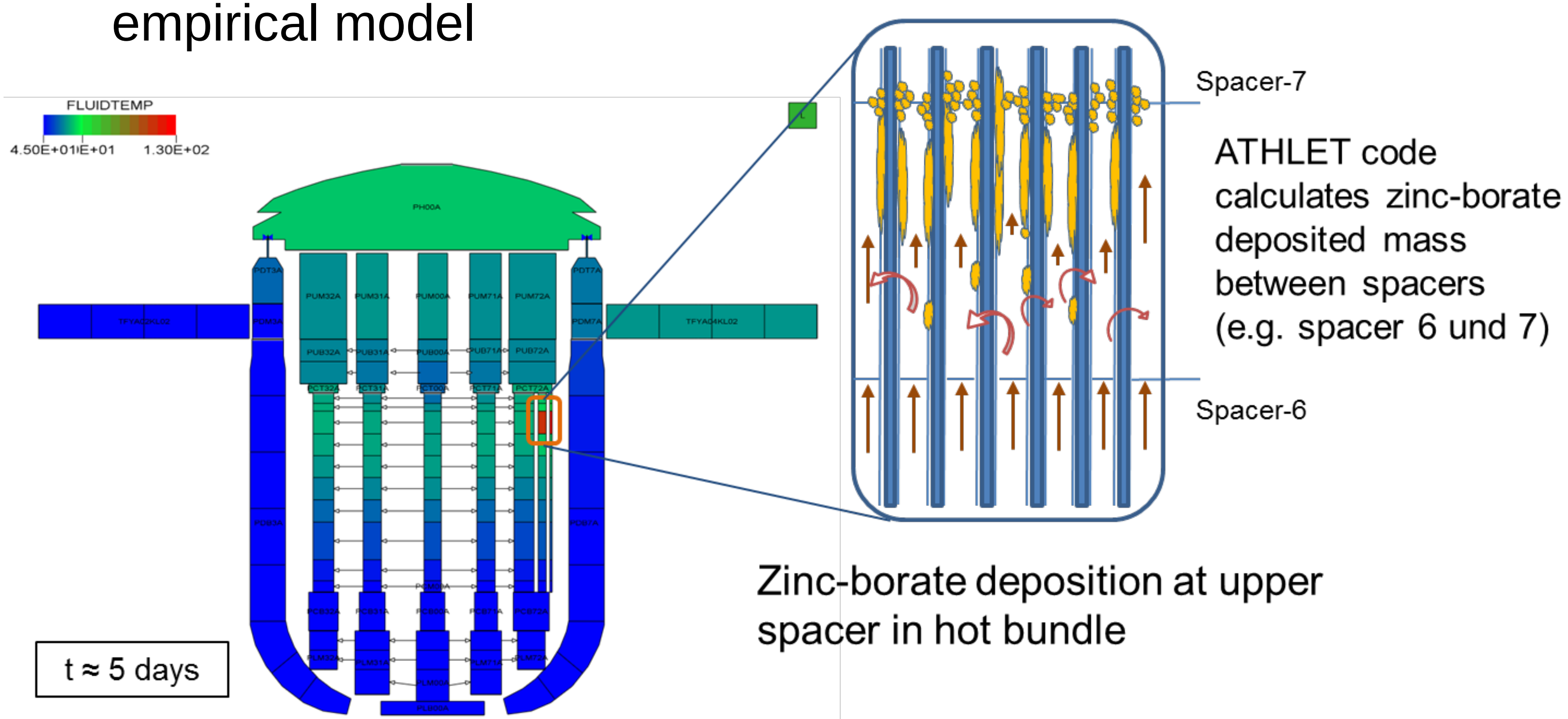
Boundary conditions:

- 2 of 4 ECCS chains available (coolant replacement in loop-1 and residual heat removal in loop-2)
- 560 m² hot-dipped surface submerged
- 40 m² hot-dipped surface under leak jet
- Maximal Zn-dissolution rate: 0.6 mg/m²s



Results of GRS analysis (2/5)

- Simulation of zinc-borate deposition in core with new empirical model

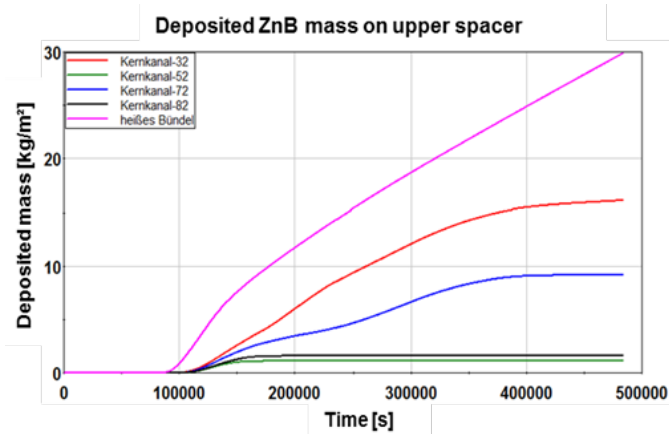


Zinc-borate deposition at upper spacer in hot bundle

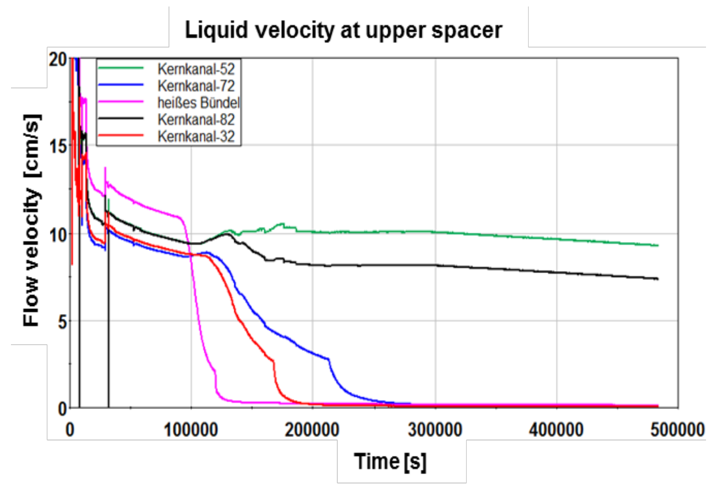
- Deposition on spacers leads to **restriction of axial flow path** and **occlusion** of the affected core channels

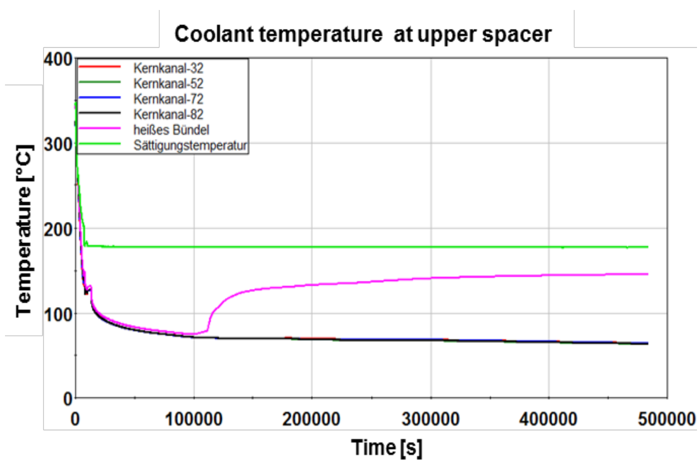
Results of GRS analysis (3/5)

- Deposition of ZnB in core channels causes decrease in core flow in the axial flow path



Coolant fluid velocity is strongly reduced in those core channels where deposited ZnB mass becomes ≥ 10 kg/m²

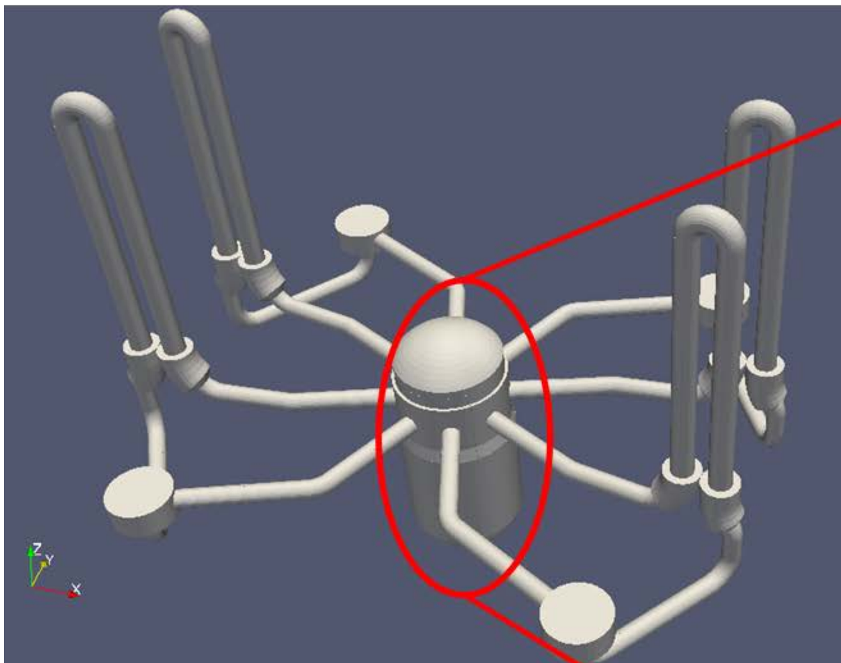




→ Local temperature increase

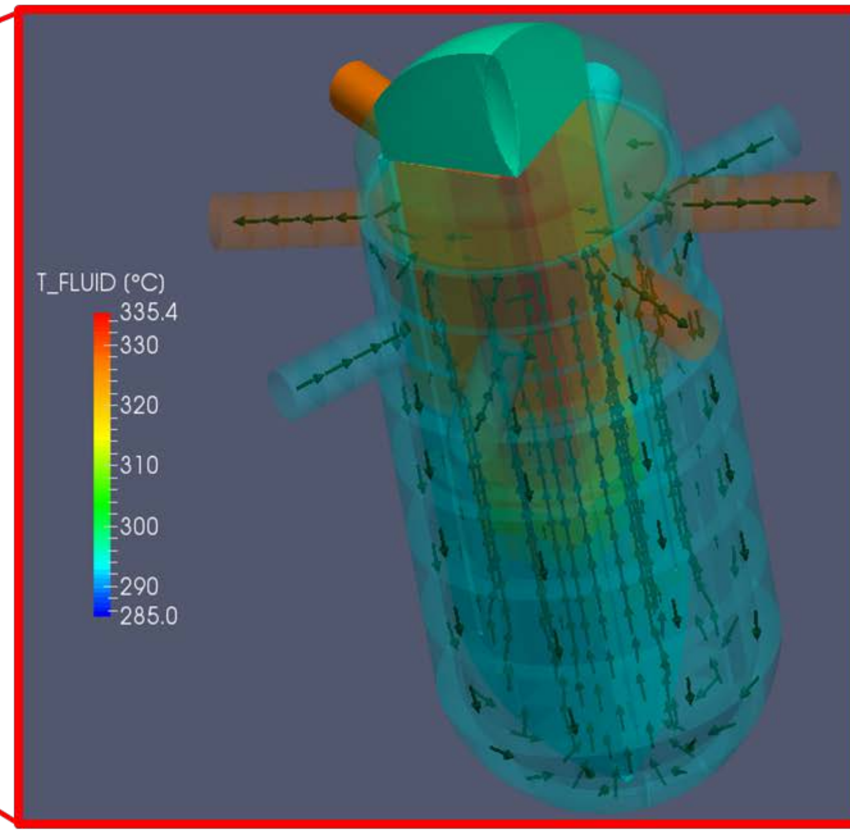
Results of GRS analysis (4/5)

- New tool for dynamic 3D-representation of the simulation results

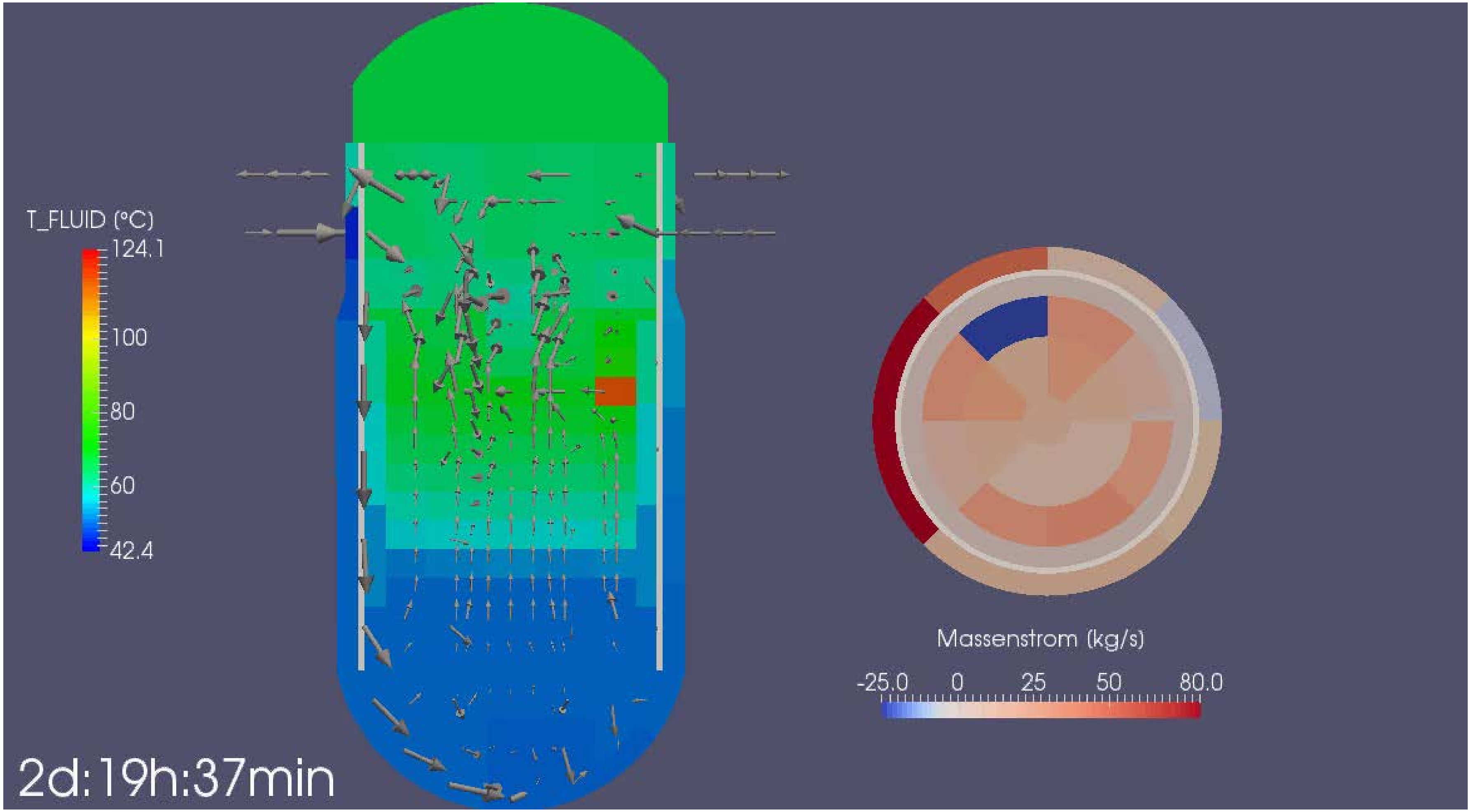


3D-model of PWR

Reactor Pressure Vessel



Results of GRS analysis (5/5)



→ Tool for dynamic quasi-3D presentation of the influence of ZnB deposition on physical parameters

Conclusions and open issues

- The **formation** and **deposition** of zinc-borate are **complex processes** based on interaction between chemical and physical effects
- **GRS experience** about clogging phenomenon helps with the analysis of zinc-borate deposition process
- **Transferability** of the investigated zinc-borate phenomenon in German PWRs **is possible with GRS-developed model** in ATHLET code
- **Important parameters** considered in the analysis of zinc dilution and ZnB formation and deposition in core:
  - Zinc content in sump depending on location of hot-dipped gratings
  - Coolant inventory in sump
  - pH value and chemistry of the coolant

Conclusions and open issues

- **Further experiments and analyses** are required in order to:
  - Improve the zinc-borate deposition model in ATHLET
  - Determine conservative boundary conditions in terms of zinc-ions release and zinc-borate formation

- **Open issues:**
  - Different pH values in experiment → influence on Zn^{2+} dilution
  - Zinc-ion dilution as function of local turbulence in sump as well as under leak jet flow
  - Influence of ZnB mass deposition on flow loss coefficients for cross-flow in parallel core channels
  - Dependency of the pressure loss from coolant flow velocity

Thanks for your attention