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Application of TRACE code for DBA safety analyses for NPP Gösgen

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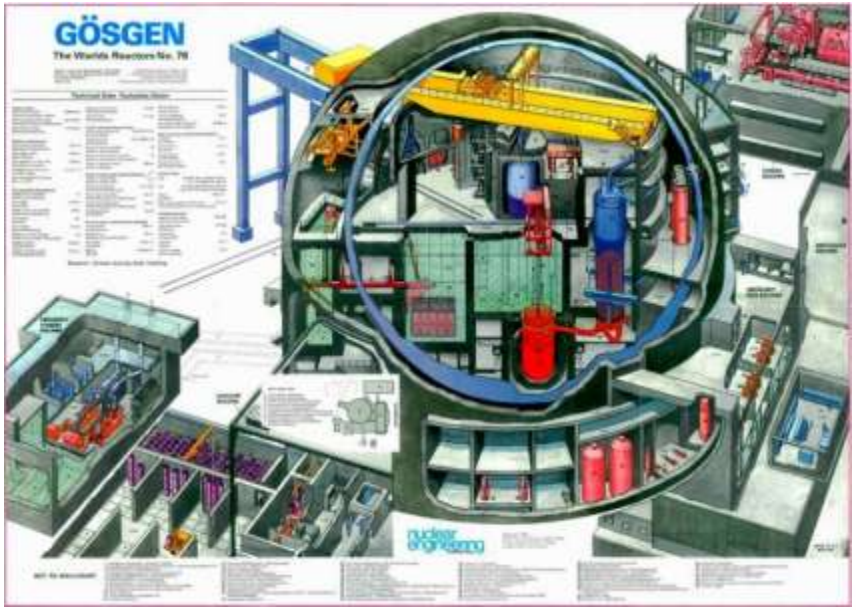
Introduction

- Currently, NPP Gösgen is using S-RELAP5 (AREVA version) code for safety analyses (SAR and PSA) for design basis accidents and MELSIM for beyond design basis accidents

- KKG decided to move on to TRACE for the future safety analyses

- Scope of modelling
  - Transfer S-RELAP5 model for LOCA events into TRACE model
  - Transfer S-RELAP5 model for Transients events into TRACE model
  - Develop integrated TRACE model based fully 1D model
  - GUI development
- Scope of validation against
  - S-RELAP5
  - PKL III H4.1 experimental facility
  - KKG full scope simulator
- Application
  - LOCA scenarios (DN25 mm – DN100 mm)

NPP Gösgen



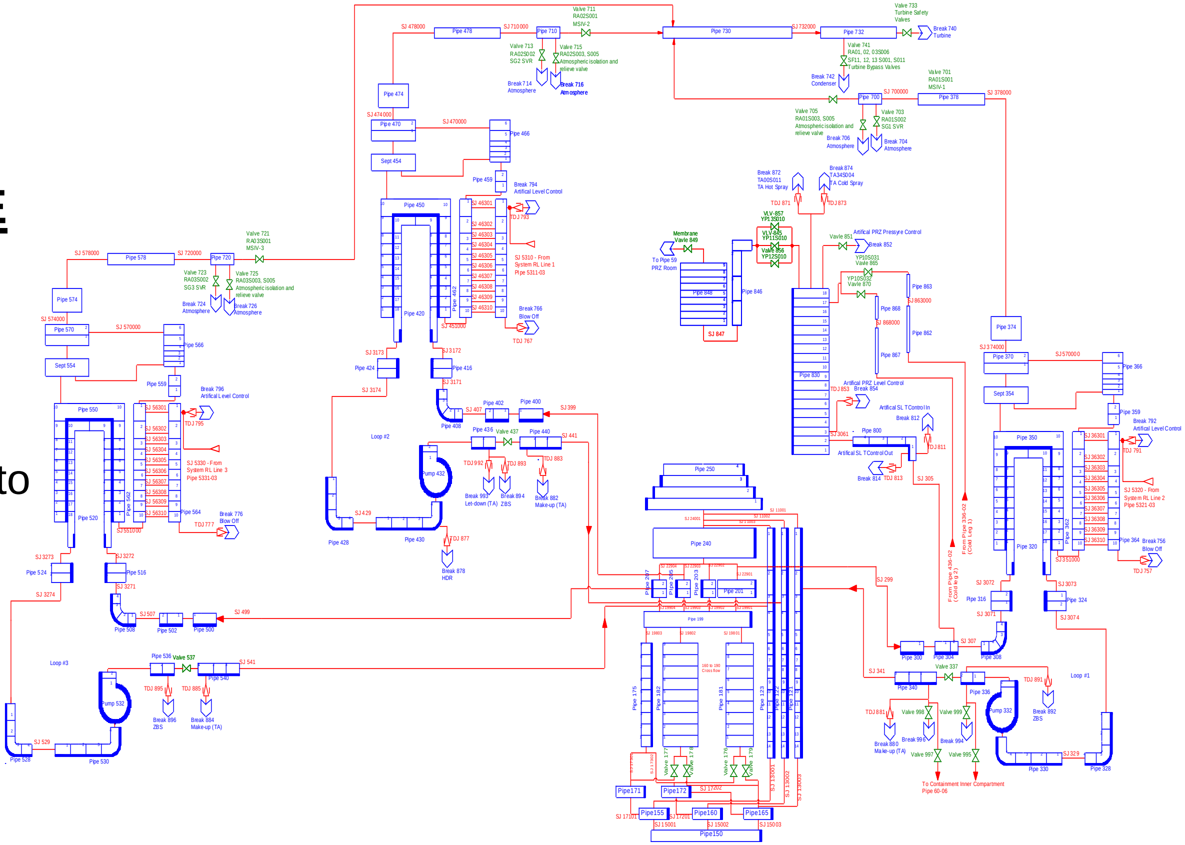
- Pressurised water reactor
  - Start of commercial operation: 1979
  - Nominal thermal output of reactor: 3002 MW
  - Gross electrical output: 1060 MWe
  - Net electrical output: 1010 MWe
  - 3 loops
  - Vertical SG
  - 6 hydro-accumulators
  - 4 trains of ECCS
  - 2 trains of SECCS
  - Stainless steel primary containment

TRACE – KKG project

- Engineering Services and Support of QA:

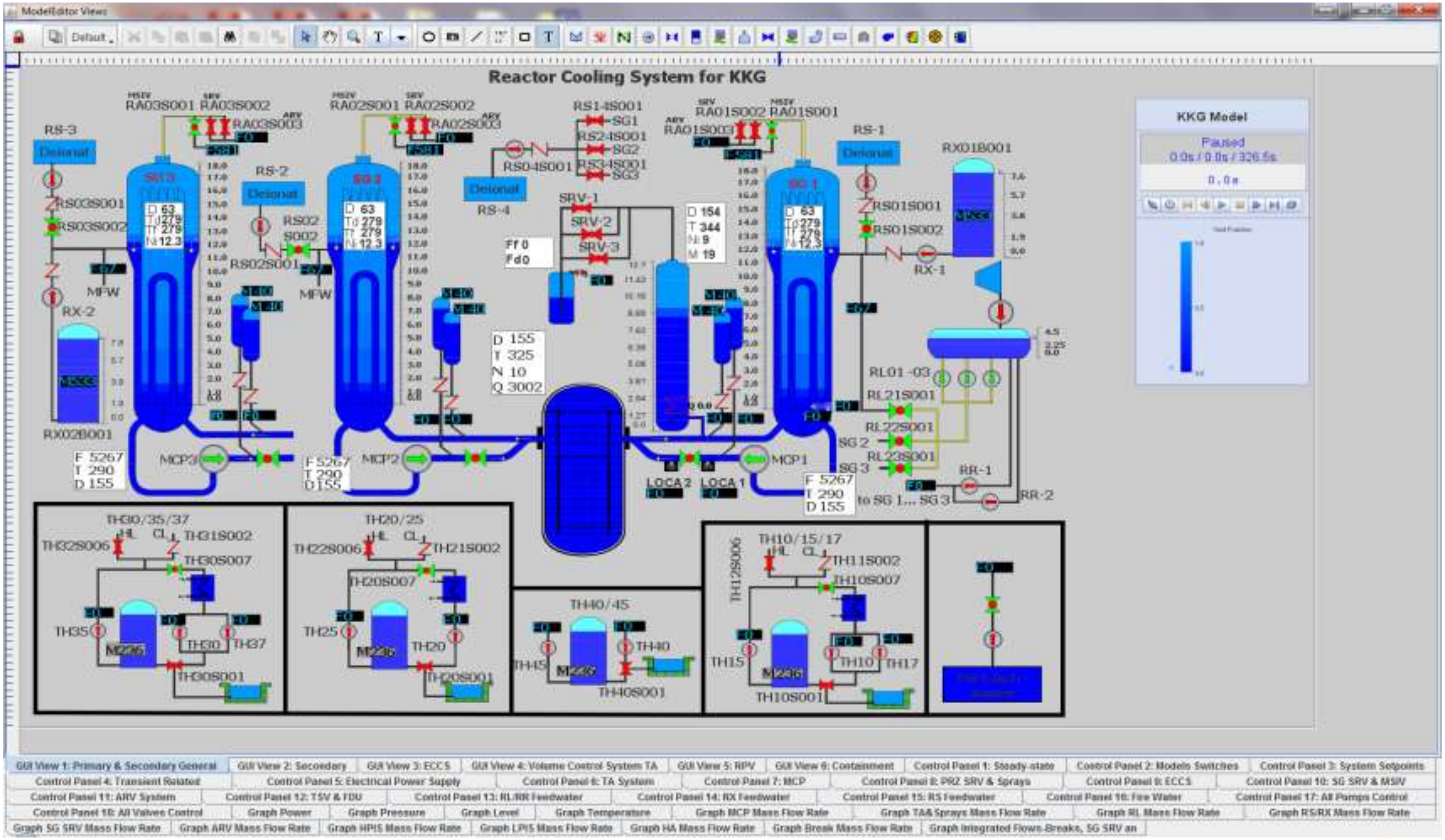
  Development of a TRACE Model for NPP Gösgen

- Phases
  - RELAP models transfer to TRACE model (1D)
  - V&V against RELAP
  - V&V against PKL facility
  - V&V against KKG full scope simulator



Primary side nodalization

TRACE - KKG GUI model



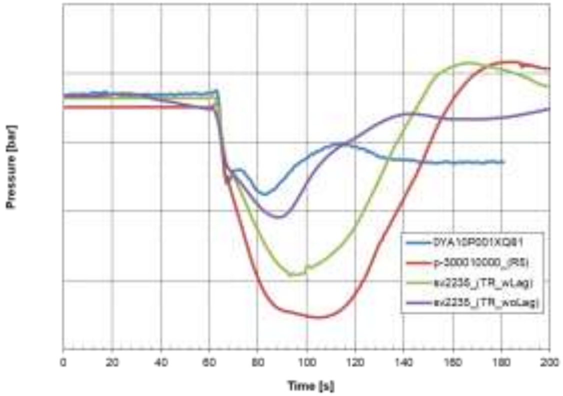
Validation process

- Steps:
  - RELAP models transfer to TRACE model (1D)
  - V&V against RELAP
    - S-RELAP for LOCA model
    - S-RELAP for Transient model (including SGTR)
  - V&V against PKL facility
  - PKL H III.4 – partial validation
  - V&V against KKG full scope simulator

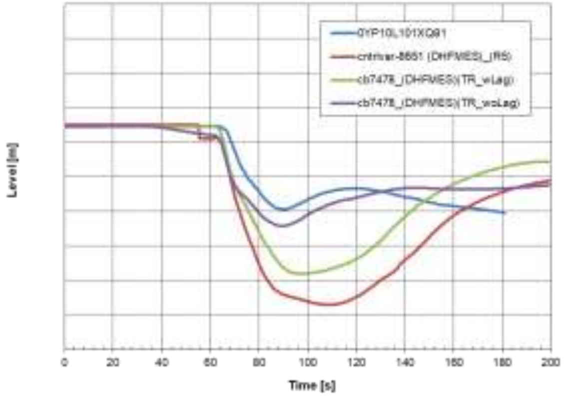
Validation matrix

N	TRACE_KKG model version	Event type	IC type / Cycle	System validated	Validated against
1	initial	SB LOCA (DN 50 mm)	Conservative / BOC	All	S-RELAP5
2	initial	SGTR	Conservative / BOC	All	S-RELAP5
3	7_0_07	LOOP	Realistic / BOC	All	S-RELAP5
4	7_0_06	LOOP	Conservative / BOC	All	S-RELAP5
5	7_0_06	LOOP	Realistic / EOC	All	S-RELAP5
6	7_0_06	SBO	Realistic / EOC	Containment*	MELSIM_KKG*
7	7_0_06	SB LOCA (DN 50 mm)	Conservative / BOC	Containment*	MELSIM_KKG*
8	7_0_06 6_0_46	MCP 2 trip	Realistic / BOC	All + reactor power control + turbine control	KKG operational transient (S-RELAP5)
9	7_0_06	Natural circulation tests	Realistic / -	Primary side	PKL experimental facility
10	8_0_0_Beta26	LOOP	Realistic / BOC	All + TA + RR + ARV+TB	KKG simulator
11	8_0_0_Beta26	LOOP	Realistic / BOC	All + RR + RS + ARV + ECCS	KKG simulator
12	8_0_0_Beta26	LOOP	Realistic / BOC	All + TA + RR + RS+TB	KKG simulator
13	8_0_0_Beta26	LOOP	Realistic / BOC	All + TA + RR + ARV+TB	KKG simulator
14	8_0_0_Beta26	MCP 2 trip	Realistic / BOC	All + reactor power control + turbine control +TB	KKG simulator
15	8_0_0_Beta26	SGTR	Realistic / BOC	All + TA + RL/RR +TB	KKG simulator
16	8_0_0_Beta26	SGTR	Realistic / BOC	All + TA + RL/RR +TB	KKG simulator

Validation against RELAP and real plant data

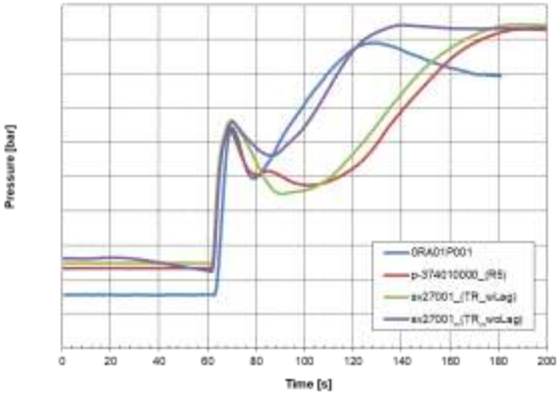


Primary pressure

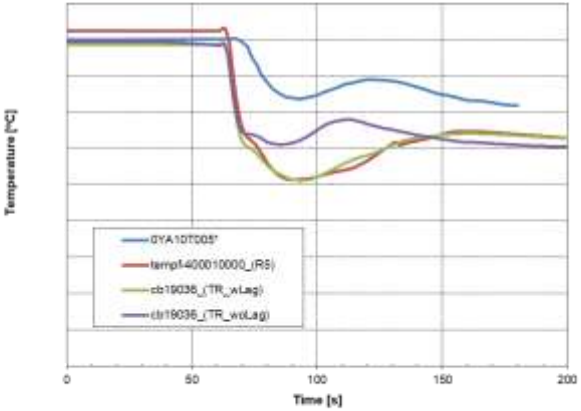


MCP trip

Pressurizer measured level



Secondary pressure for SG1

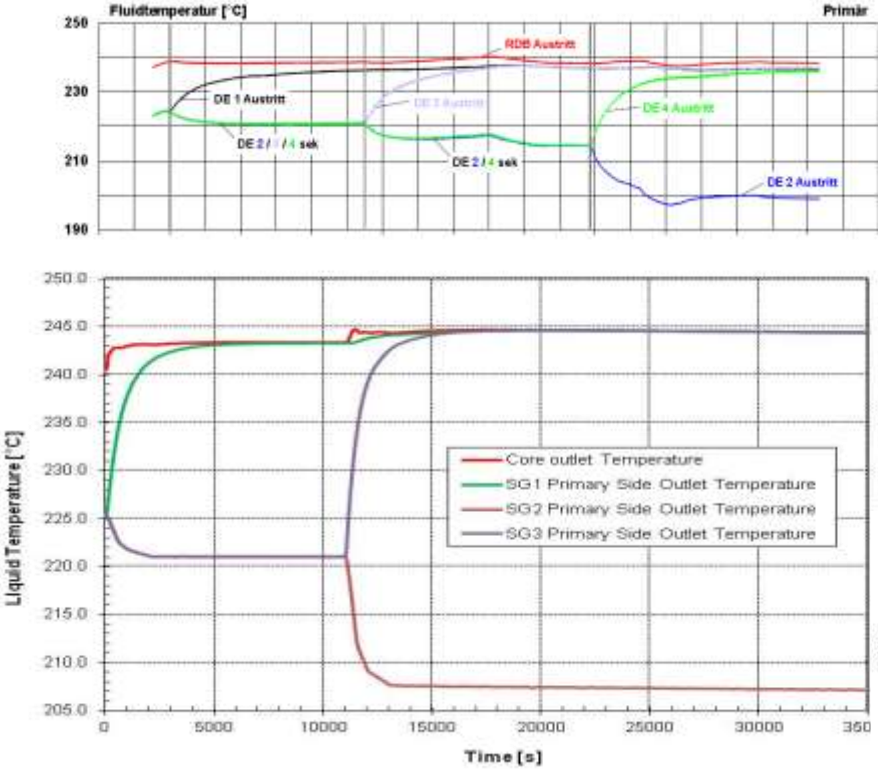


Loop 1 outlet temperature

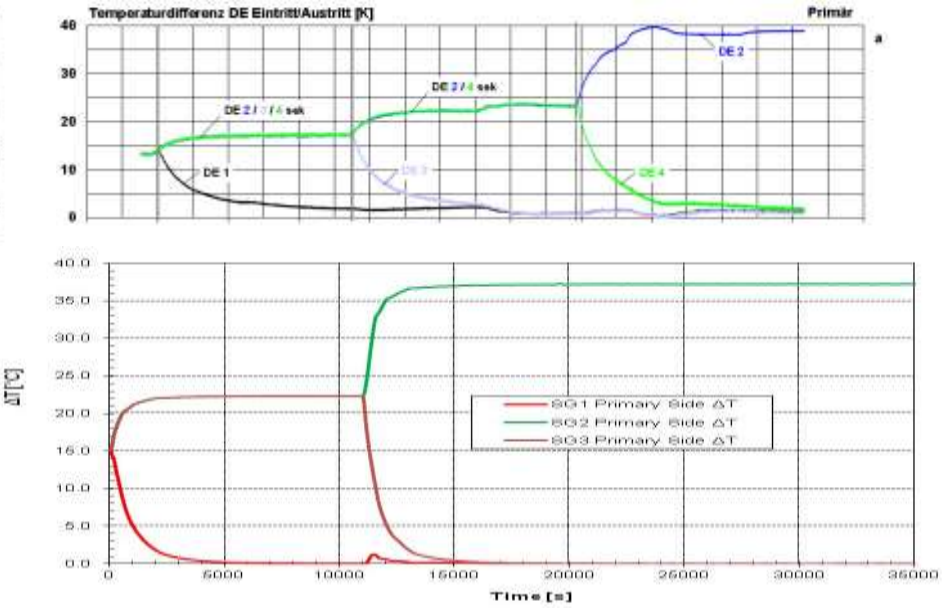
Validation against experimental facility PKL

Phase 1

In Phase 1 of the experimental program steady state conditions were established with one, two and three isolated SG. The core power and the primary pressure (40 bar) were kept constant and the subcooling at the core outlet was approximately 10 K. For Gösgen model, only two out of three SG are isolated for the Phase 1



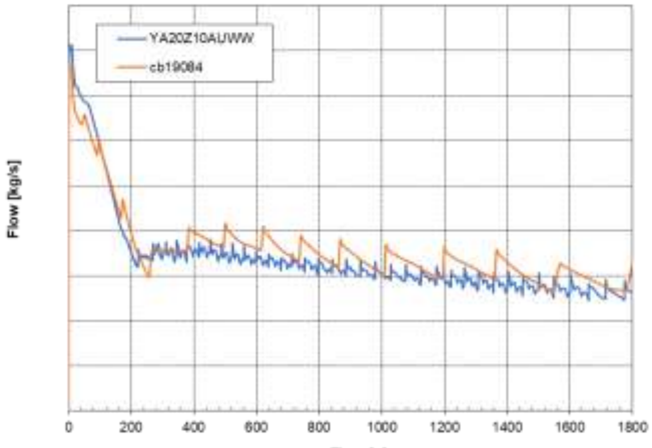
Temperatures and Mass flows in Primary



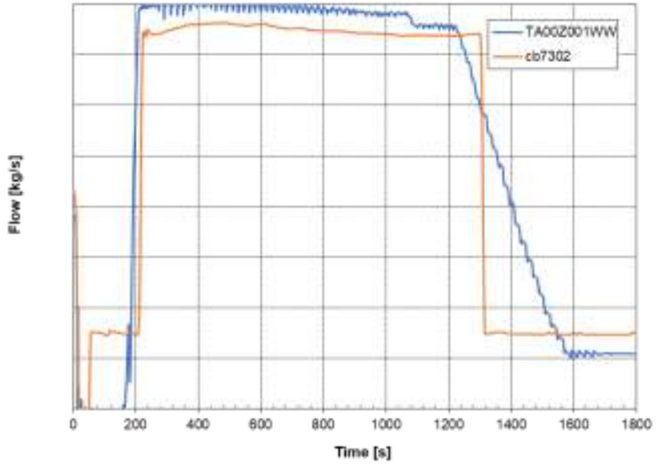
SG’s temperature differences

Validation against Full-Scope Simulator

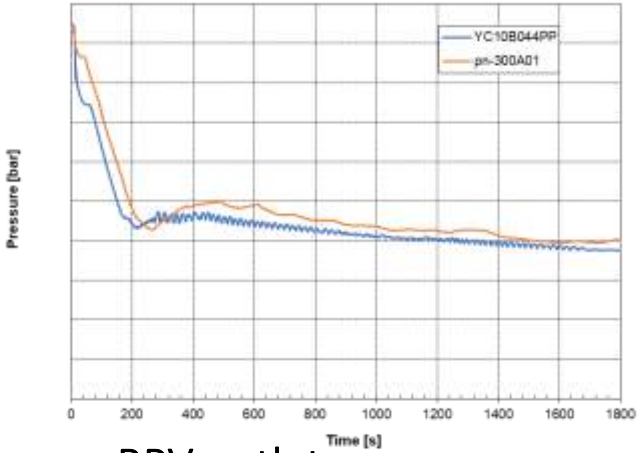
SGTR from the hot part of the tube bundle with Notstromfall (LOOP)



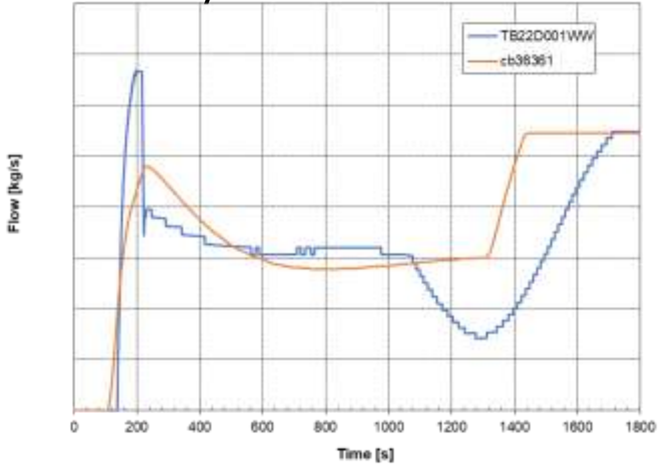
SG1 leakage rate from both sides



TA system letdown flow



RPV outlet pressure



TB22D001 flow

Main conclusions

- Validation against RELAP
  - For all the analysed groups of scenarios is achieved acceptable level of qualitative agreement with the referent data and/or referent calculations;
  - For the cases which are not entirely compared against referent data or calculations the assessment is based upon theoretical and analytical knowledge for the respective accident progression sequences and physical phenomena occurrence;
  - The plant systems response is in compliance with their intended function and the main physical parameters behaviour follows the expected tendency for specific initiating event, systems malfunctions or operator actions;
  - Some of the differences are significant for specific time frames, but these differences do not change the entire accident progression and all the events which occur have logical and physical explanation
- Validation against PKL III H4.1
  - Most of the parameter behaviour is similar to the ones obtained in the test facility (excluding reverse flow)
  - TRACE can predict the reactor installation steady state parameters under a natural circulation conditions
  - Current 1D TRACE model cannot predict precisely cooldown of the reactor installation under natural circulation conditions. Nevertheless, dynamics of the process during cooling down mode in the three runs is quite similar to the test results;
  - Phenomena related to cold water backward flows cannot be simulated with the current 1D TRACE nodalization, which can explain lack of reverse flow in case 1.2 and in case 2. The impact of the 1D nodalization should be further investigated.

Main conclusions contd.

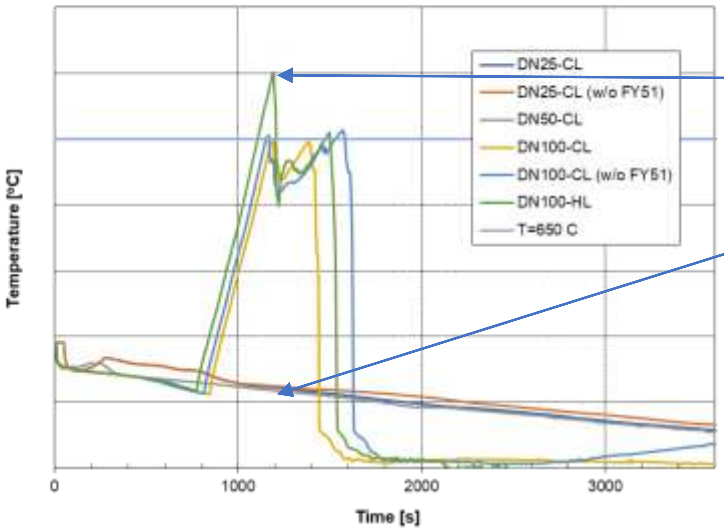
- Validation against Simulator
  - TA system response including letdown, makeup, cold and hot sprays, TB21, 22, 30D001 pumps and VAB tank for all the scenarios (except for Scenario 2 where the system is not available) is predicted accurately, and the observed differences are not significant in terms of setpoint actuation and system function in the simulated accident scenarios
  - The newly developed ARV model reflects correctly, for all the scenarios, the cooldown mode with rates of 45 K/h and 100 K/h. This model includes all the options for simulation of the necessary operator actions, including stepwise cooling of the secondary side according to the plant procedures
  - RR and RS systems response is predicted accurately for all the scenarios in which these systems are automatically started, and the observed differences are not significant in terms of setpoint actuation and system function in the simulated accident scenarios. An important part of the RR system response is the possibility to work in parallel with RS system in case of YZ51 signal actuation
  - RL system response for Scenario 5 and 6 is predicted correctly and SG levels are maintained accurately by the respective feedwater controller. Condenser pumps mass flow rate is predicted also accurately which means that the assumed simplifications in the feedwater system model for the TRACE_KKG is adequate for modelling accident sequences with partial decrease of the reactor power
  - Even though the FDU and Turbine controllers are not specifically and extensively checked against the KKG plant documentation their operation for Scenario 5 and 6 are deemed reasonable and accurate enough in the course of the respective transient

TRACE Application

- Current project
  - 6 Scenarios with LOCA from DN 25 mm÷ DN100 mm
- ERNOS program:
  - Automatic cooldown via Secondary Side (100 K/h)
  - Manual start-up of Special ECCS (TH17/TH37)
  - Automatic start-up of Special EFW pumps (RX01,02)
  - Automatic start-up of Special Boron injection system (TA81,82)

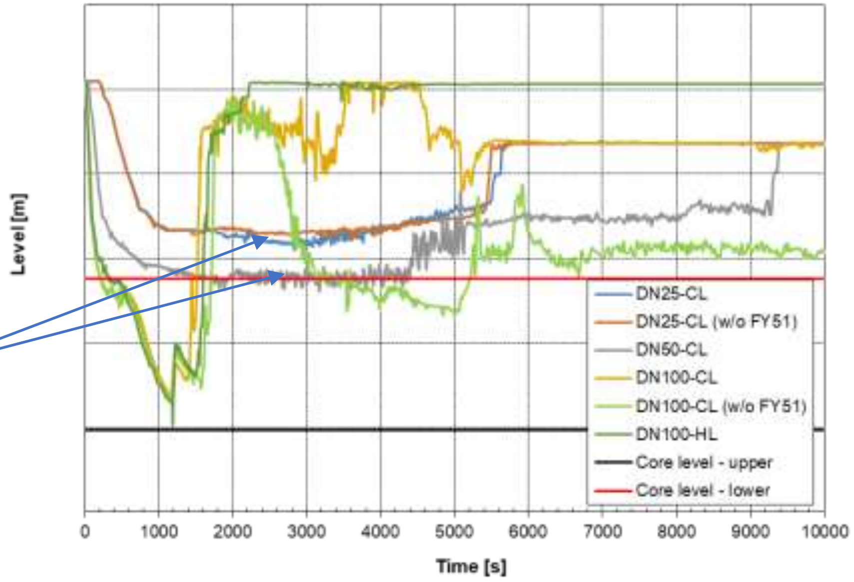
SC	Location of LOCA	LOCA size	Cooling rate via ARV	Failed hydro-accumulator	Failed FY	Failed TA/TH pump	Failed RX pump	Failed ARV
1	Cold leg 1 – after MCP	25 mm (4.9 cm^2)	100 K/h	TH16B001	None	None	None	None
2	Cold leg 1 – after MCP	25 mm (4.9 cm^2)	100 K/h	TH16B001	FY51	TA81/TH17	RX01	RA01S005
3	Cold leg 1 – after MCP	50 mm (19.6 cm^2)	100 K/h	TH16B001	None	None	None	None
4	Cold leg 1 – after MCP	100 mm (78.5 cm^2)	100 K/h	TH16B001	None	None	None	None
5	Cold leg 1 – after MCP	100 mm (78.5 cm^2)	100 K/h	TH16B001	FY51	TA81/TH17	RX01	RA01S005
6	Hot leg 1 – close to RPV	100 mm (78.5 cm^2)	100 K/h	TH18B001	None	None	None	None

TRACE Application - results



Temperature is significantly below 800 degC, which guarantee cladding tightness

For LOCA < DN50 mm no temperature rise is predicted



Level in RPV does not drop below top of the core for LOCA < DN 50 mm

Main conclusions

- For the first three scenarios there is no core heat up, i.e. there is no core uncovery till the moment of SECC pumps injection. This means that in case of LOCA up to 50 mm the coolant loss rate is lower than the core cooldown via secondary side
- For accidents with LOCA DN 100 mm, the coolant loss rate is higher than the core cooldown via secondary side, which leads to core uncovery and consequent cladding heat up
- The maximal cladding temperature does not exceed 800 C for all of the scenarios
- A stable injection of TH pumps is established
  - For DN100 mm scenario with 1 available pump and for DN<50 mm scenarios is after the secondary side pressure decrease
  - For DN100 mm scenarios with 2 available pumps is after the hydro-accumulators ejection

KKG future services under discussion

- Design basis thermal hydraulic analyses
  - Upgrade of the KKG_TRACE model
    - 3D model
    - Open reactor model
    - SFP model and etc.
  - Model application
    - TH analysis update (SAR purposes) and for PSA purposes
    - Strength analyses and fatigue analyses

Acknowledgement

- I would like to express our deepest appreciation to KKG who provided us the possibility to complete all these tasks. Our fruitful collaboration with KKG started in 2015.
- We also need to express our appreciation to Risk Engineering Ltd., since the models was developed in the times when our team was part of the company. We completed all the mentioned tasks with the help of our colleagues in REL company

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