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ASTEC Code Validation and Application to Safety of NPPs with VVER

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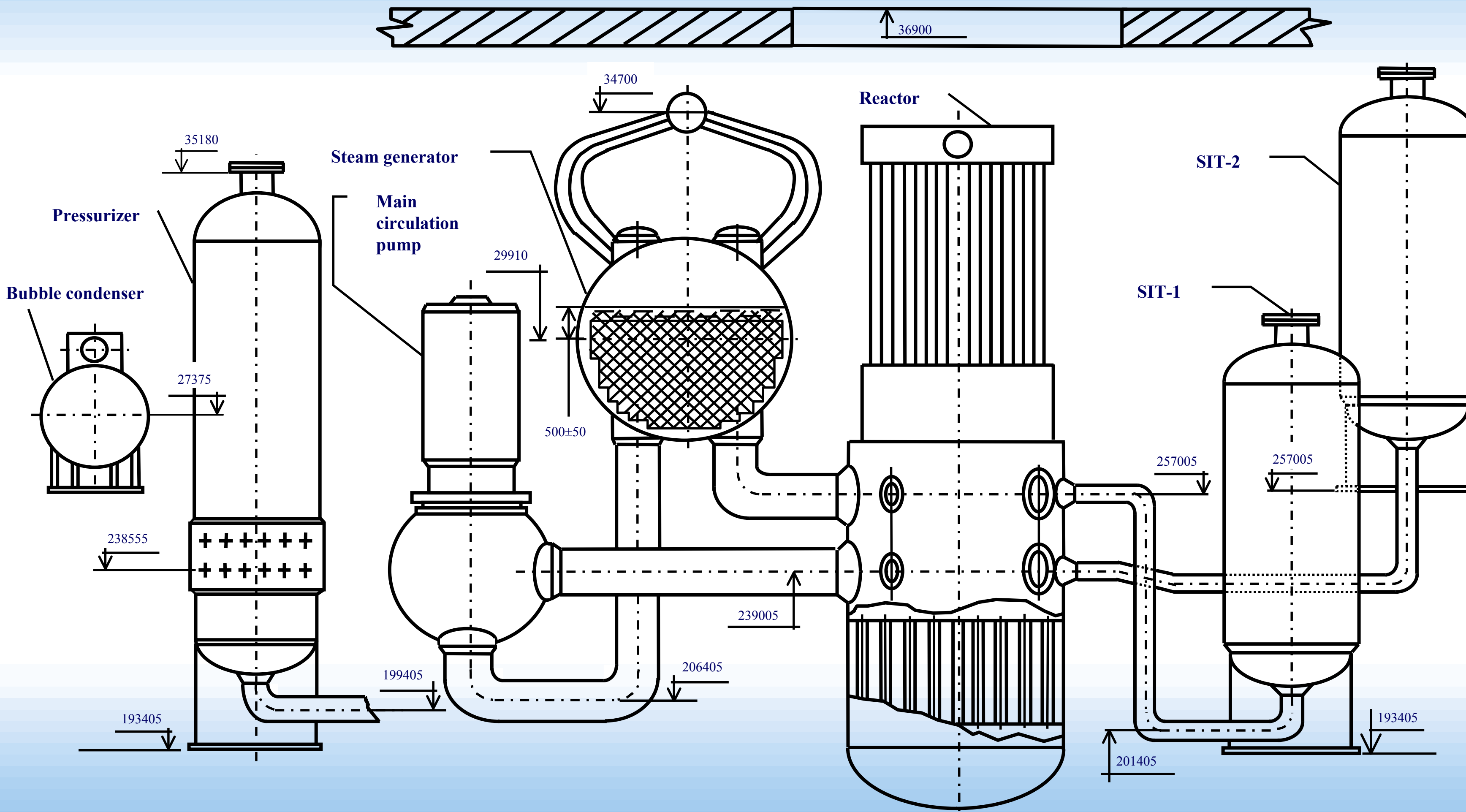
Main provisions of ASTEC code adaptation

- Modification of the code to meet requirements to VVER features, including:
  - development of the VVER input decks,
  - nodalization schemes,
  - replacement of the material properties,
  - development of the algorithms for safety systems work simulation,
  - development or modification of the modules specific for VVER equipments etc.
- Verification of the code models on the base of the experimental data specific to VVER conditions.
- Approbation of the code on some hypothetical scenarios of severe accident on NPPs with VVER.
- Benchmarking between ASTEC and ICARE/CATHARE and other well-known codes used for analysis of severe accidents.
- Simulation of the real incidents on the NPPs with VVER.

ASTEC code modification to meet requirements to VVER features



Main circulation circuit. Location of the main equipment

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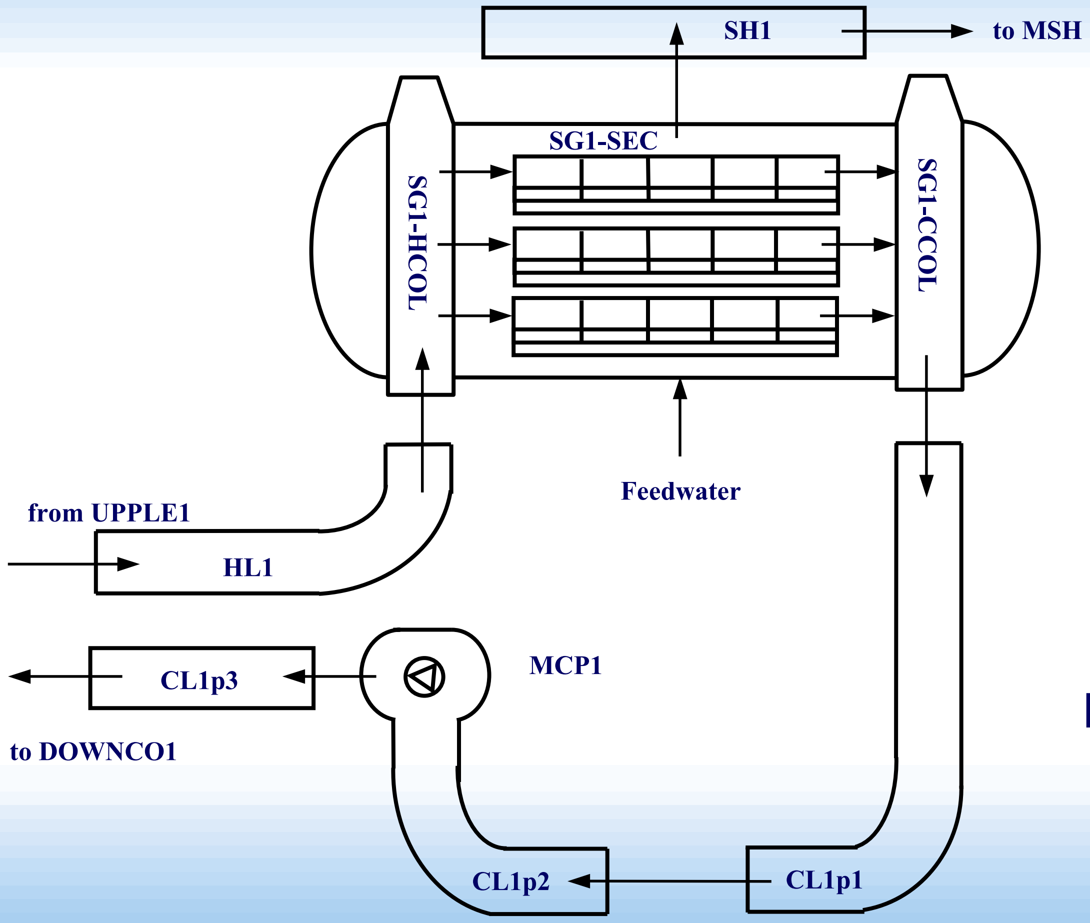
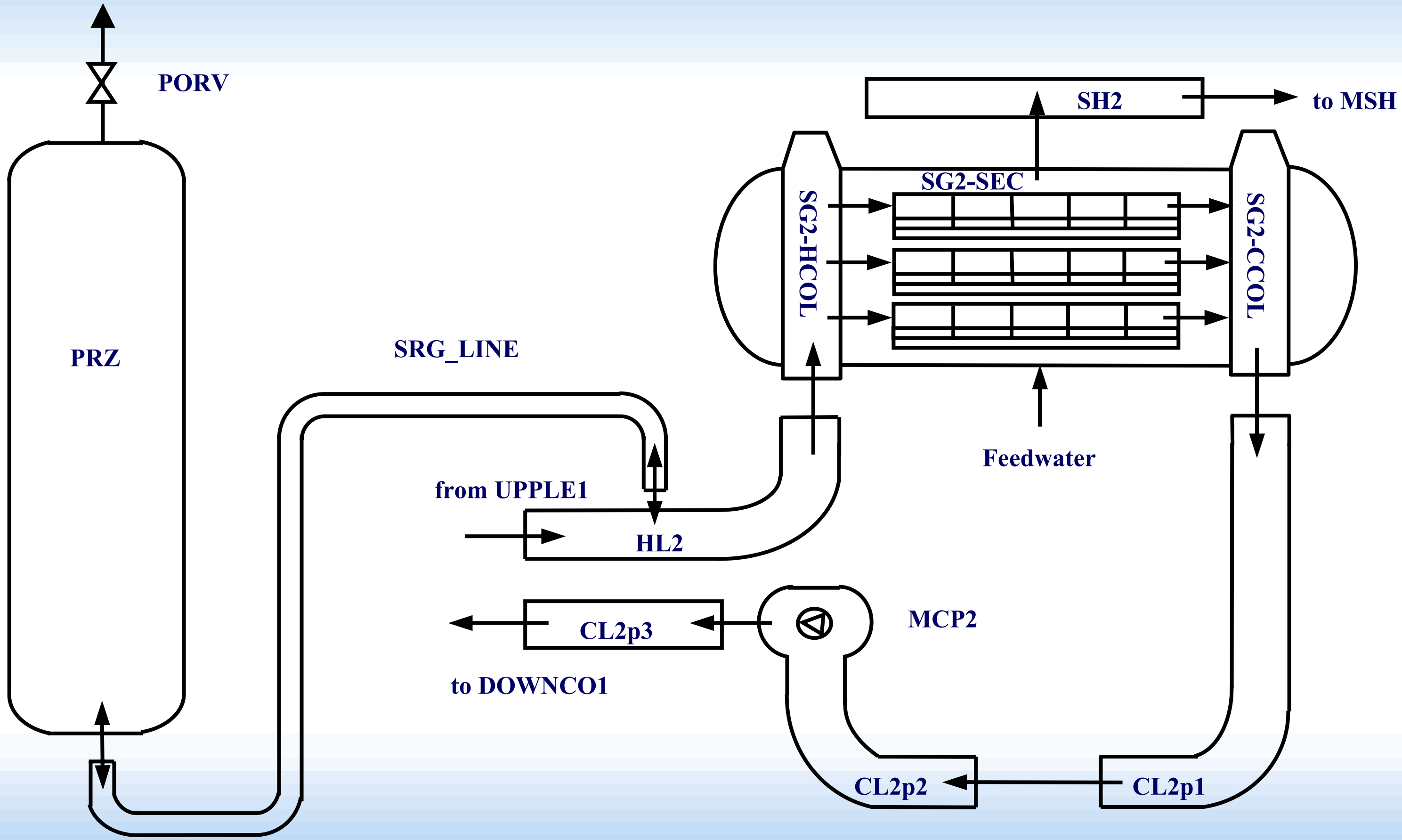
ASTEC code modification to meet requirements to VVER features



Nodalization of the loop without pressurizer

ASTEC code modification to meet requirements to VVER features



Nodalization of the loop with pressurizer

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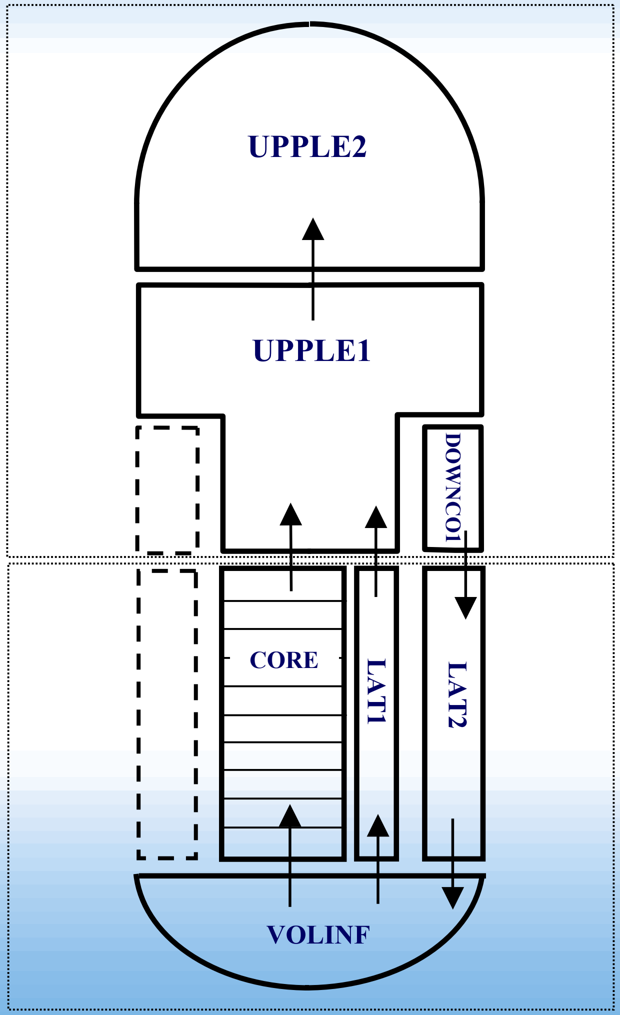
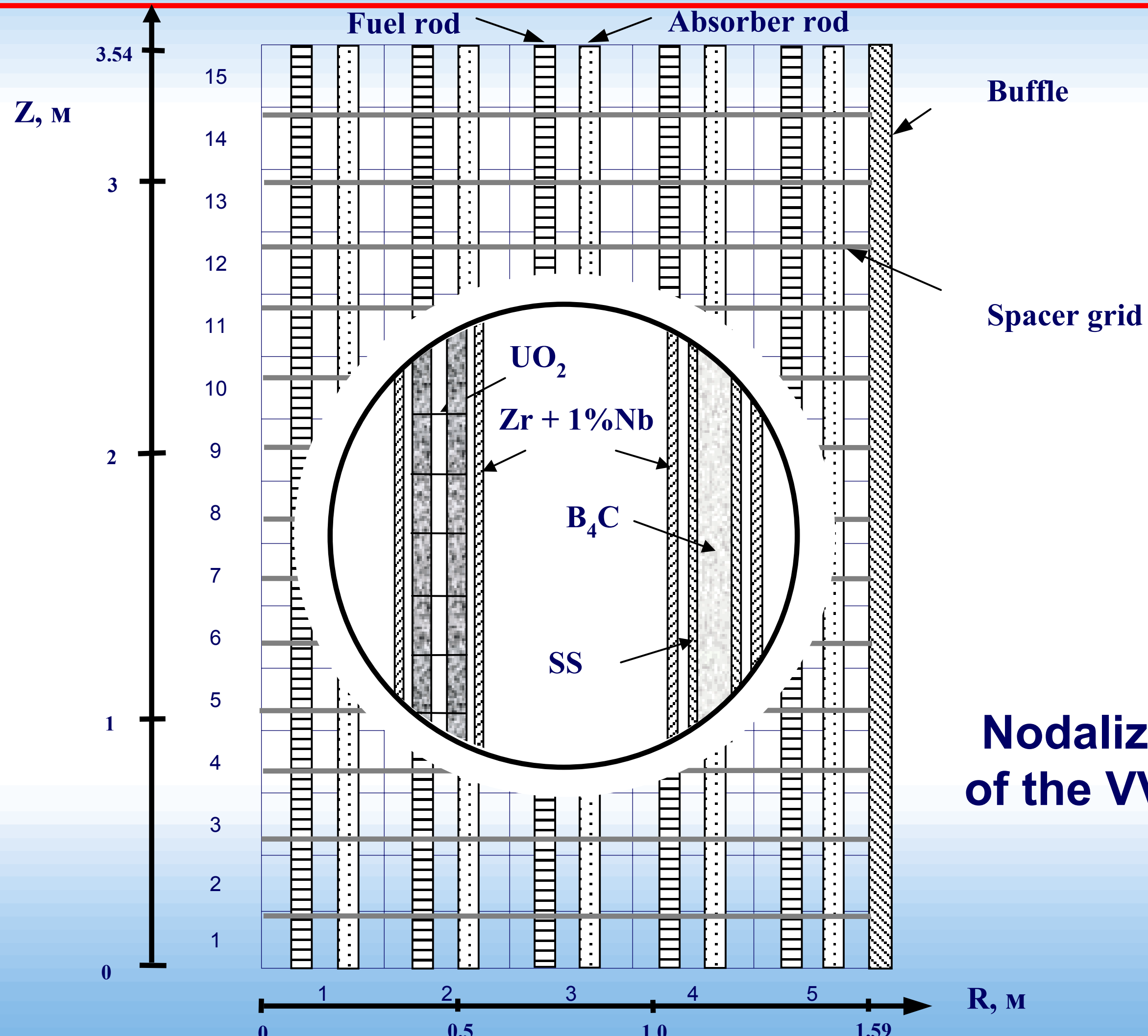


CESAR

DIVA

Reactor nodalization

ASTEC code modification to meet requirements to VVER features



Nodalization scheme of the VVER-1000 core

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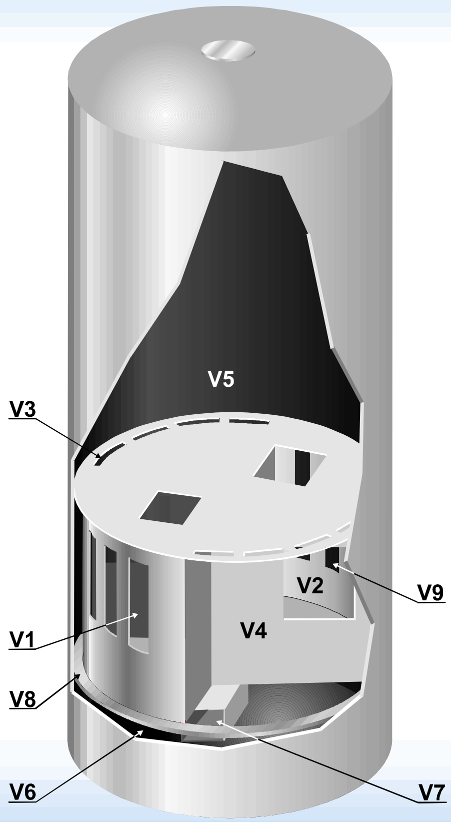
Preliminary validation matrix specific to VVER

Test	Main features of the experiment
CORA-W1, CORA-W2	VVER-type reactor fuel element bundle degradation and impact of B_4C control rod on the fuel bundle degradation
CODEX-2, CODEX-B4C	VVER-type reactor fuel element bundle high temperature behaviour, control rod degradation and B_4C oxidation
RASPLAV AW-200-4	Molten corium interaction with reactor lower head
BETA V7.1	Molten corium interaction with serpentine concrete, which used for fabrication of upper layer of the VVER-1000 reactor cavity
ACE L4	Molten corium interaction with two-layered serpentine/lime concrete basement
HD-3, HD-6, HD-8, HD-9	Hydrogen distribution in the compartments of the VVER-1000 containment mock-up
RUT Sth-6, Sth-9	Combustion of hydrogen-air-steam mixtures with different composition of components

General view of the hydrogen distribution test facility



The facility cells V1-V9 correspond to the following VVER-1000 containment compartments:

Cells V1 and V2 – the steam generator compartments;

Cells V3 and V4 – the compartments with ECCS basic equipment;

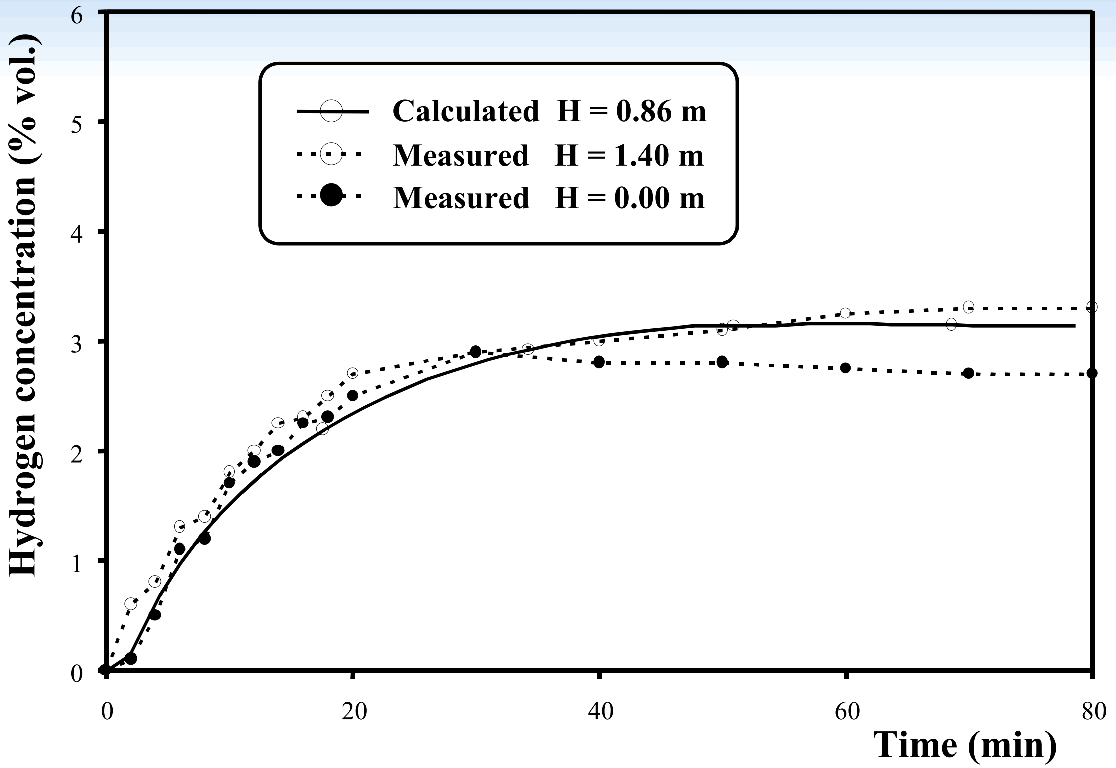
Cell V5 – dome part of the containment;

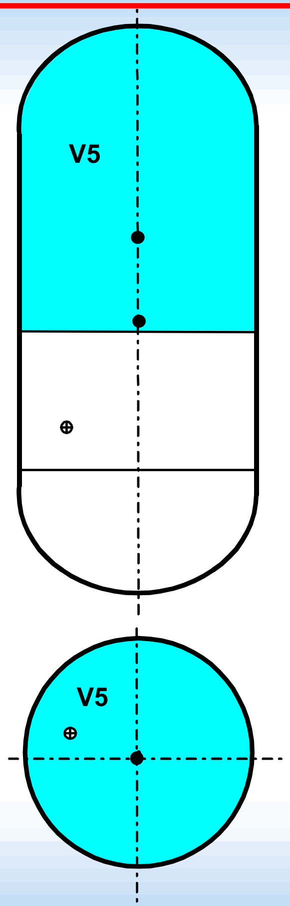
Cell V6 – the compartments for the maintenance of the auxiliary equipment in the containment lower part;

Cell V7 – the rectangular tank with one of the side walls lacking, corresponds to the terminal compartments in the lower part of the containment;

Cell V8 and V9 – the compartments with fans and to corridors.

ASTEC validation against HD-3 test





● Hydrogen Concentration Sensor
⊕ Place of Hydrogen Feeding

Hydrogen concentration versus time in the cell V5

Simulation of hypothetical severe accidents on a VVER-1000

Severe accident scenario simulated with help of the ASTEC code

1. **Large Break LOCA**
   Double-ended rupture of the RCS (D = 850 mm) and failure of all active parts of ECCS
2. **Middle Break LOCA**
   Hydro-accumulator pipe rupture (D = 279 mm) and failure of all active parts of ECCS
3. **Small Break LOCA**
   Break in the cold leg of the RCS (D = 70 mm) and failure of all active parts of ECCS

Benchmark between ASTEC and ICARE/CATHARE codes for LB and SB LOCA scenarios on a VVER-1000

Approach to benchmark calculation performance

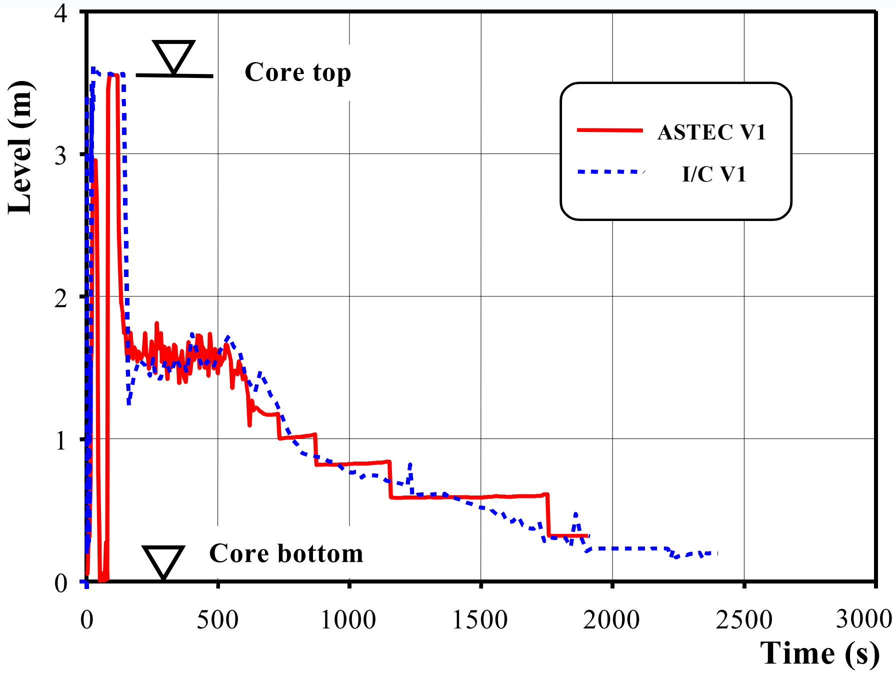
- Very similar nodalization of the RCS for the considered codes.
- The same nodalization of the core for the considered codes.
- Using of identical or very similar modeling approaches from alternative ones existing in the considered codes.
- Using the same value for similar criteria in the code models.
- Tuning of the uncertain thermalhydraulic parameters in the best-estimate code against measured data on NPP.
- Tuning of the uncertain thermalhydraulic parameters in the integral code against the best-estimate code calculation results.

Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000

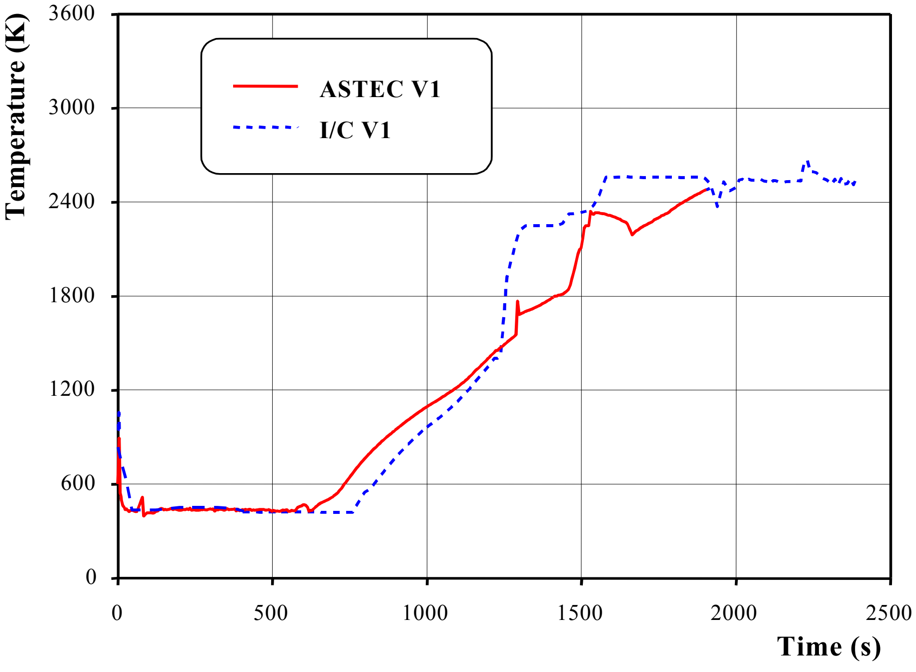
Pressure Losses in the Primary Circuit of the VVER-1000

Element of the RCS	Values measured on NPP (10^5 Pa)	Values calculated by ICARE/CATHARE V1 (10^5 Pa)	Values calculated by ASTEC V1 (10^5 Pa)
Downcomer	1.93 ± 0.12	1.94	1.88
Core	1.69 ± 0.14	1.69	1.63
Upper plenum	0.80 ± 0.04	0.81	0.75
Hot leg	0.27 ± 0.01	0.28	0.28
Steam generator	1.35 ± 0.12	1.35	1.28
Cold leg	0.11 ± 0.03	0.11	0.11

Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000



Collapsed Water Level in the Core

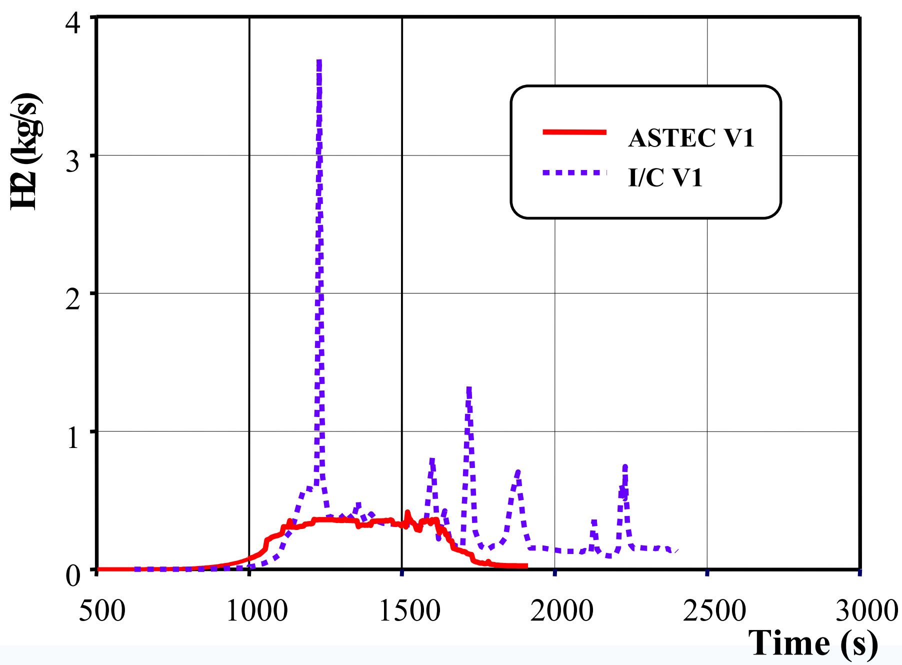


Fuel Rod Cladding Temperature

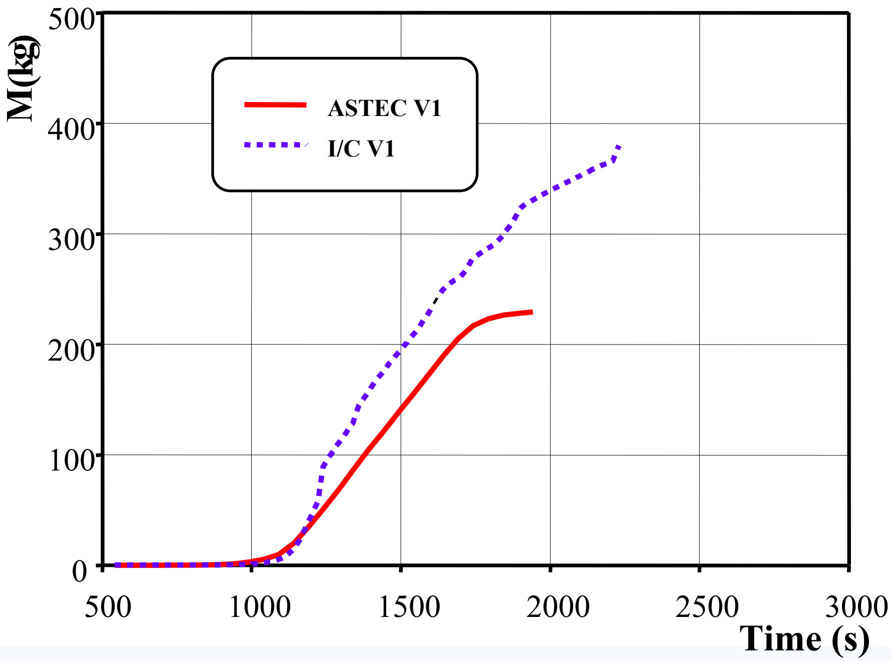
Radial Ring Number 5 (R=1.5 m, Z=1.9 m)

Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000

Total H_2 & H_2 production rate versus time

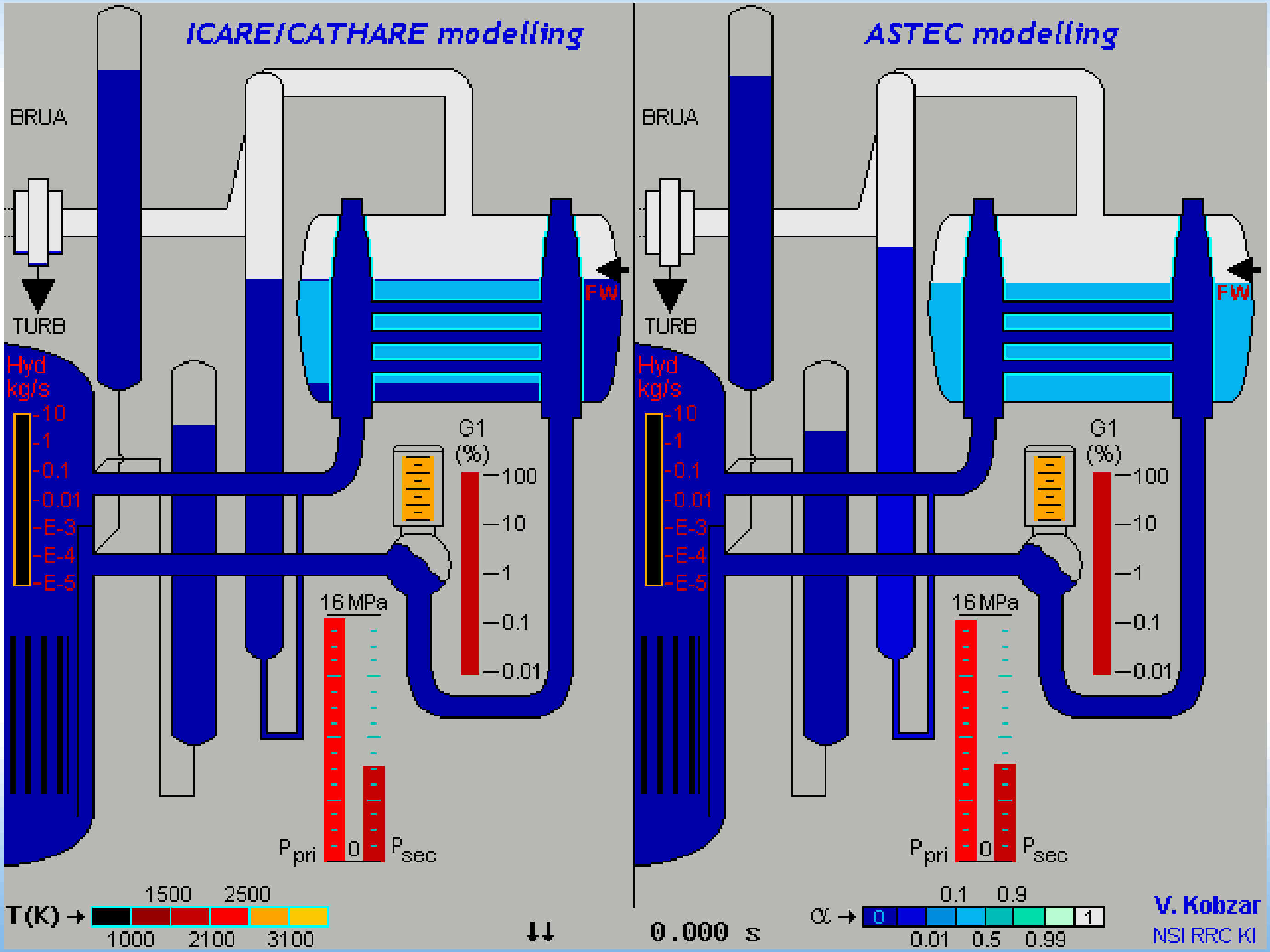


Hydrogen production rate



Total mass of hydrogen generated

Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000



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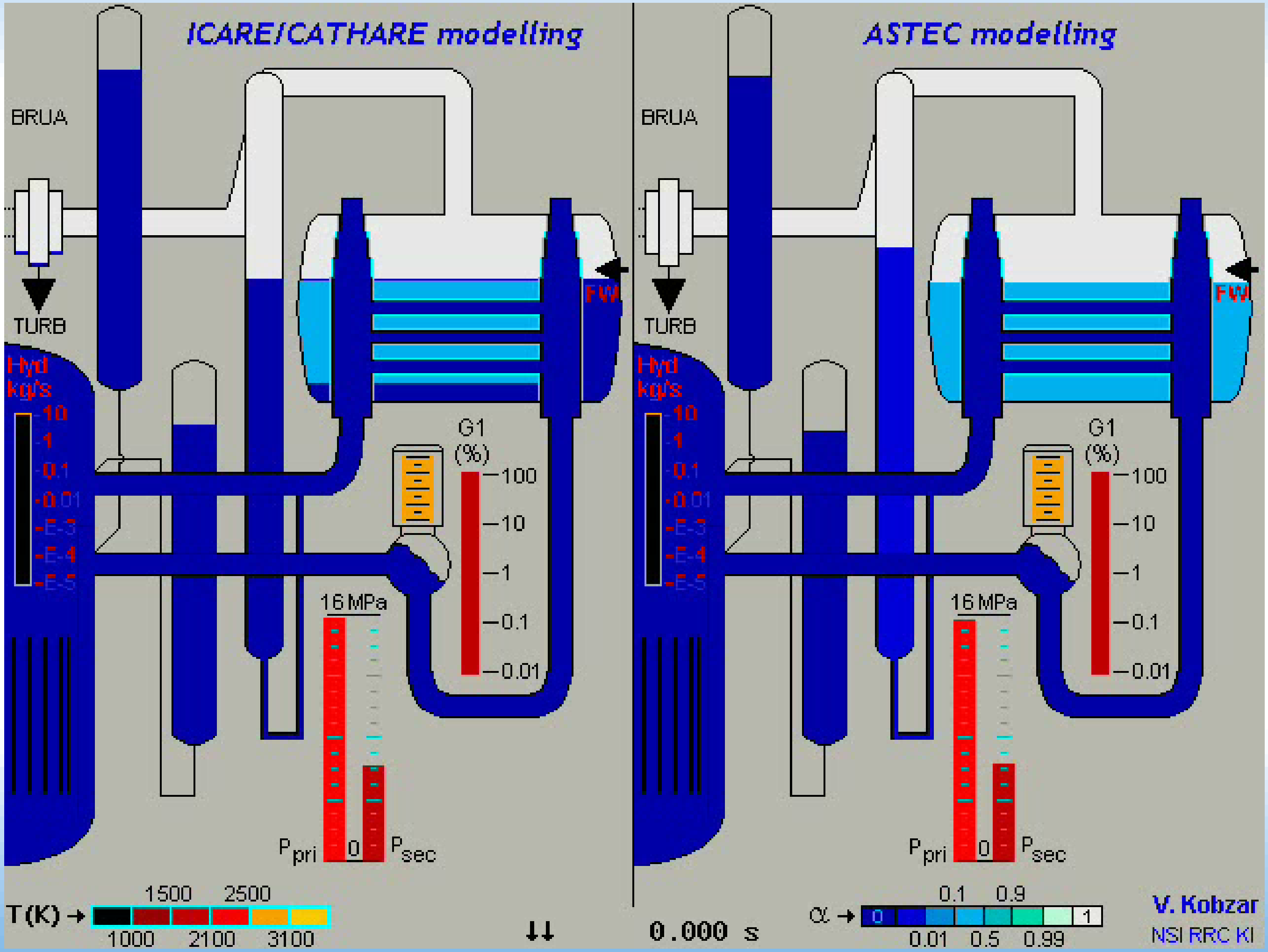
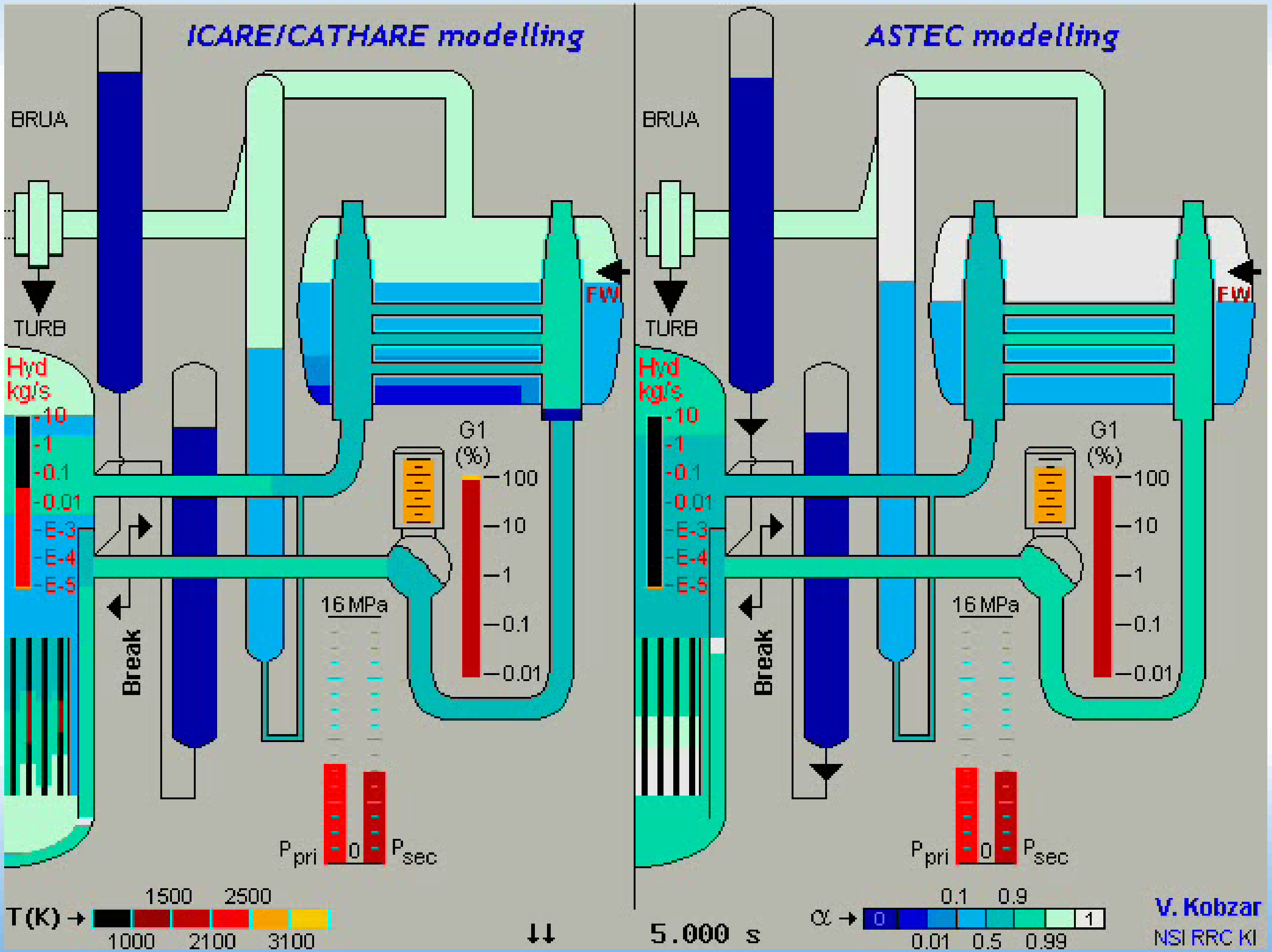
Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000



Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000



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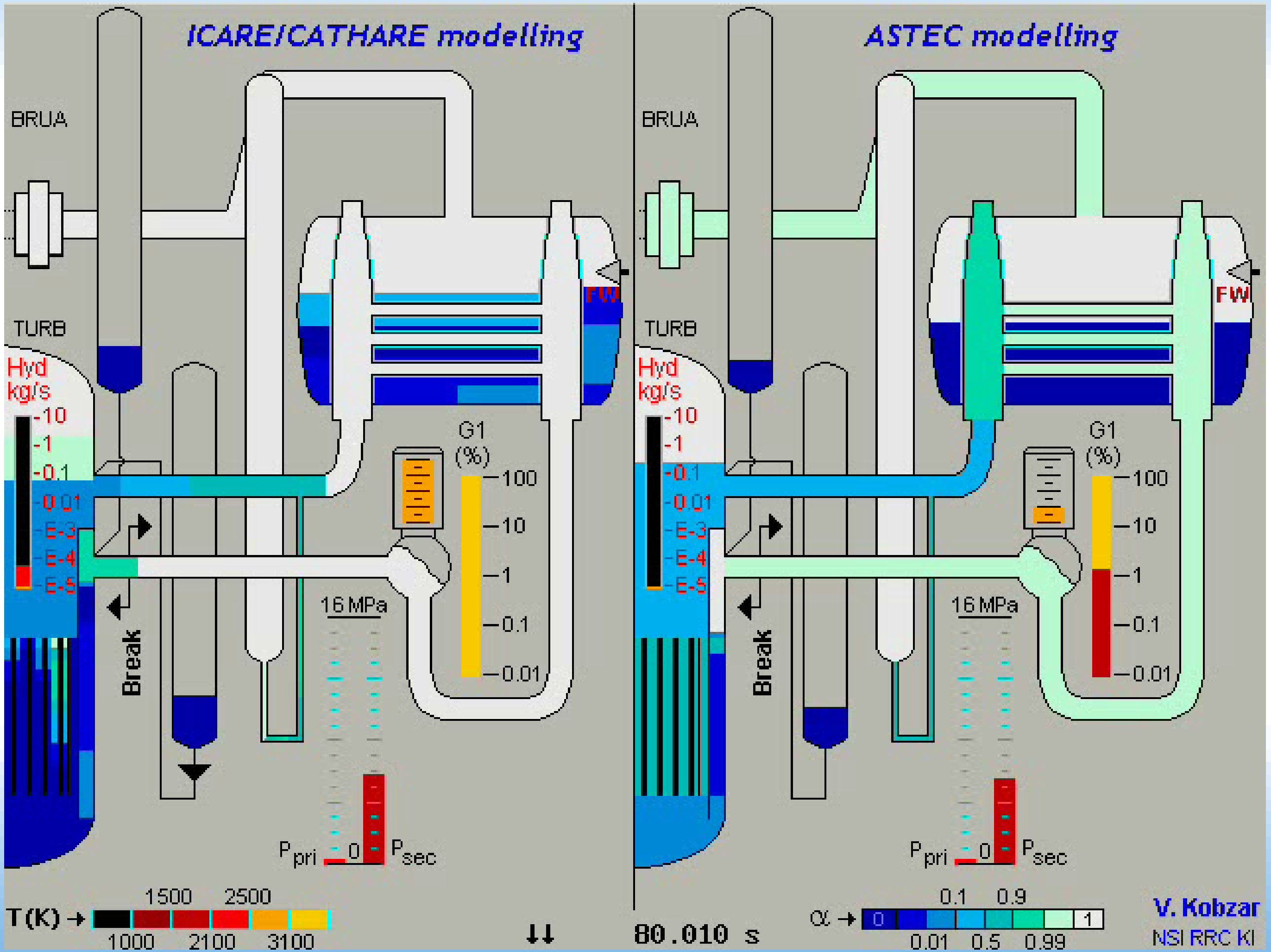

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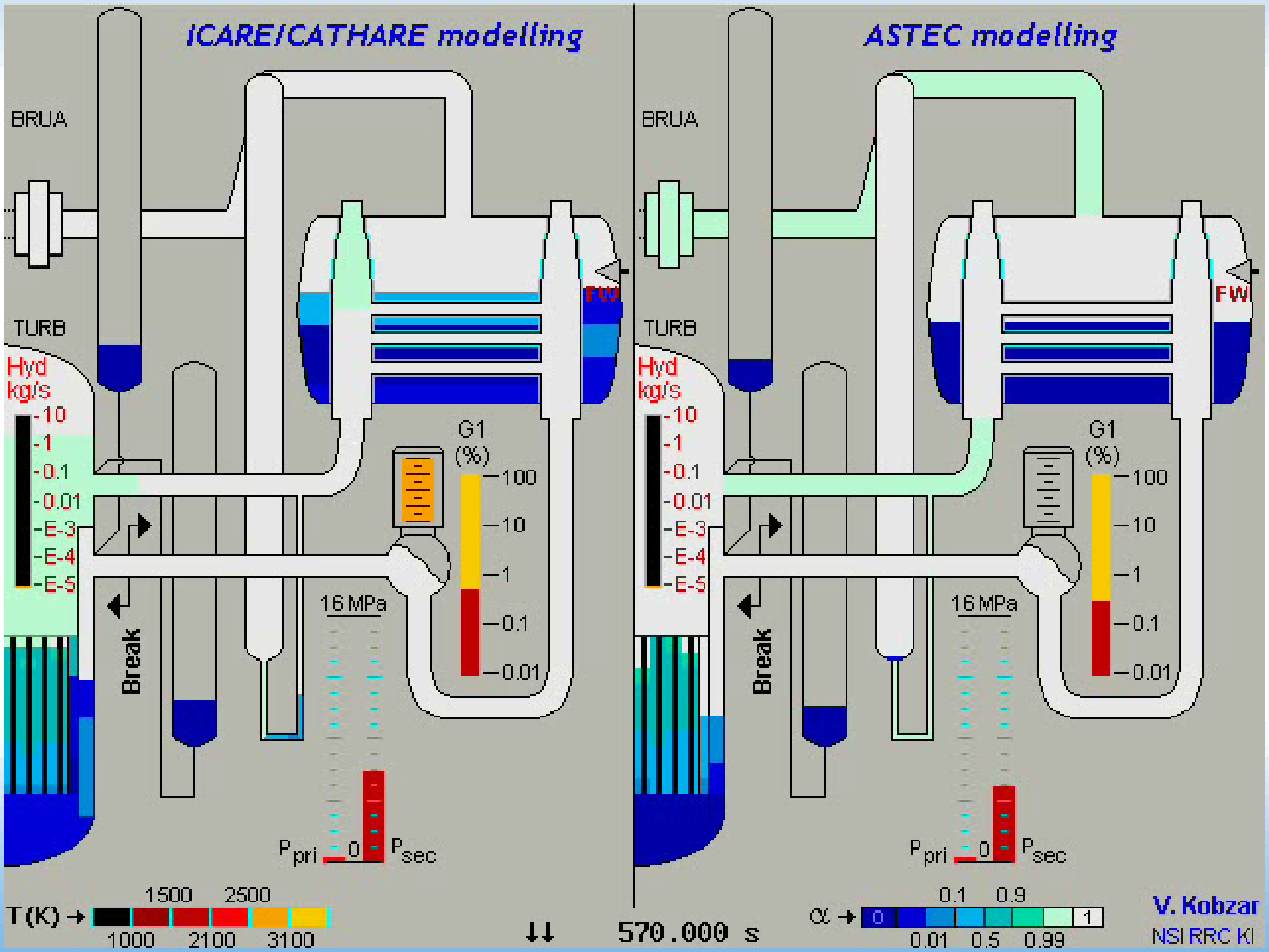
Benchmark between ASTEC and ICARE/CATHARE codes for LB LOCA scenario on a VVER-1000



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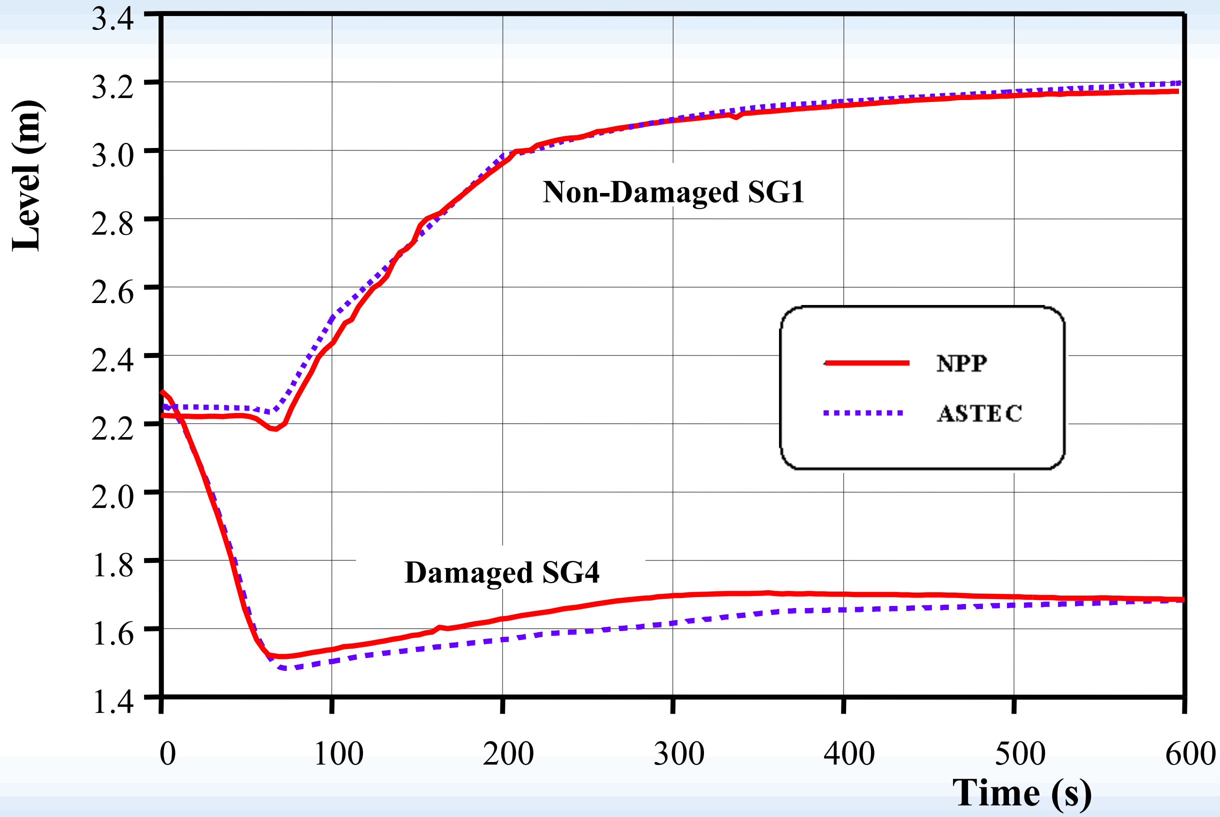
Simulation of the real incidents on the NPPs with VVER

Incident	Module of the ASTEC code
1. Incident with stop of feedwater supply to the SG on the Unit #1 of the Kalinin NPP with VVER-1000 (Russia)	CESAR
2. Incident with cleaning tank on the Unit #2 of the Paks NPP with VVER-440 (Hungary)	ICARE2*

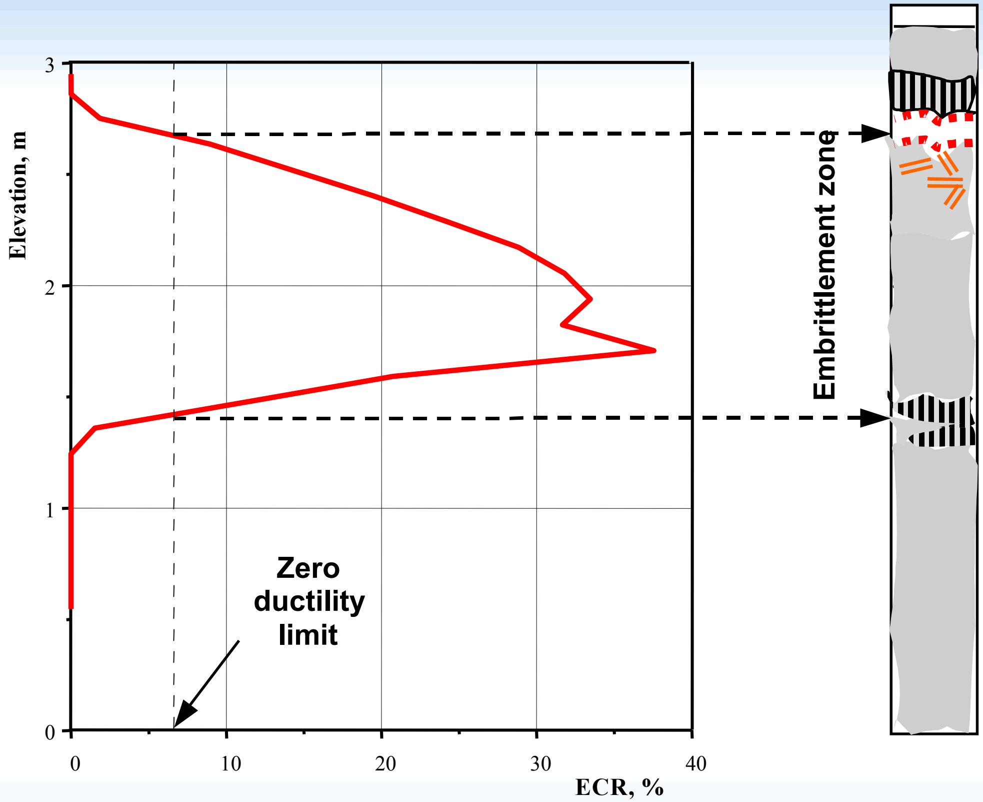
*) – ICARE2 is planned to be used in the ASTEC code for modeling of the core degradation instead DIVA module

CESAR simulation of the incident on Kalinin NPP

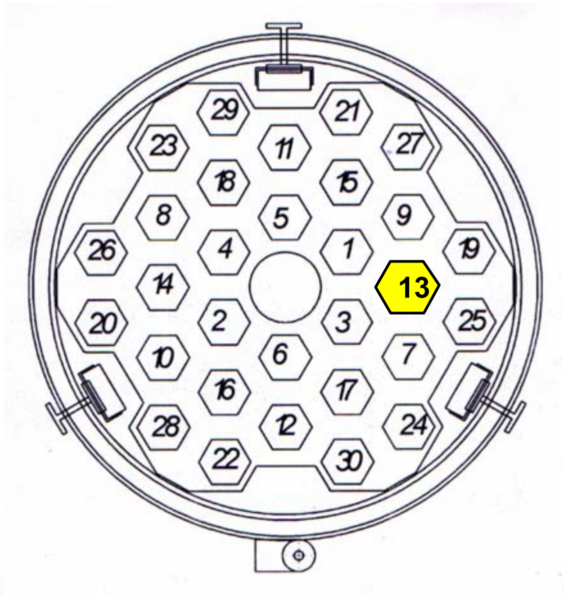


Evolution of the collapsed water level in the steam generators

ICARE2 simulation of the incident on Paks NPP



Reconstruction of the assembly #13 appearance



Fuel assembly arrangement in the cleaning tank

Assessment of cladding embrittlement zone for fuel assembly #13 (Second ring)

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Conclusions (1)

- A first stage of the work in collaboration between NSI RRC KI and IRSN has been successfully achieved through the transfer of the ASTEC code to NSI RRC KI, the users' training and first applications to VVER.
- The validation matrix for all main phases of the severe accident progression based on the experiments specific to VVER conditions was developed.
- The applications of ASTEC code to hypothetical severe accident sequences on the VVER-1000 and to real incidents on NPPs with VVER-1000 and VVER-440 show the code acceptability and functionality for calculations.
- The next stages of the collaboration will consist to complete the modeling specifications of VVER safety systems, and in parallel to work on validation and reactor applications of the modules under development of the next version of the ASTEC code.
- That would be fruitful to continue above work on ASTEC code adaptation to VVER in collaboration with SARNET Network where similar work on ASTEC code will be done.

Conclusions (2)

After completion of the ASTEC code adaptation to VVER it can be used for:

- **Safety analysis of NPPs with VVER;**
- **Cross verification of Russian severe accident codes;**
- **Prolongation of the existing NPPs with VVER operation beyond the design limit;**
- **Development of severe accident management procedures for new design of the NPPs with VVER.**