ÚJV Řež, a. s.

Results of the Seventh Three-Dimensional AER Dynamic Benchmark Problem Calculation.

Solution with DYN3D and RELAP5-3D© Codes.

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VVER-440/213

The VVER is a Russian version of Pressurized Water Reactor (PWR), originally developed by Westinghouse.

Specific features:

- **Horizontal SG - probably the most specific feature of VVER (not usual at western PWR's)**
- **Direct ECCS connection to reactor vessel (HA, LPIS):**
- **Flow baffles around ECCS connection to DC**
- **Hexagonal fuel geometry**
- **Shrouded fuel assemblies**
- **Hot legs and cold legs open in the pressure vessel not on the same level**
- **Loops seals and isolation valves both in cold legs and hot legs**

VVER-440/213 – NPP Dukovany

Parameter	Unit	
Basic characteristics of NPP: - thermal power - number of loops - number of fuel assemblies	 MW - -	 1444 (1375) 6 349 (hexagonal geometry)
Basic pressure characteristics of NPP: - primary pressure (pressurizer) - secondary pressure (main steam header)	 MPa MPa	 12.3 4.5
HPIS (MPIS) pumps: - number - shutoff head - normal flow rate	 - MPa kg/s	 3 14.3 37.5
LPIS pumps: - number - shutoff head - normal flow rate	 - MPa kg/s	 3 0.7 111.0
Hydroaccumulators: - number - pressure - water volume - gas volume - ratio gas/total volume	 - MPa m3 m3 -	 4 3.5 (6.0) 40 30 0.43
Points of ECCS injection	-	CL, HL, UP, DC (flow baffles)

7th Dynamic AER Bechmark

VVER-440 pressure vessel coolant mixing by re-connection of an isolated loop

Benchmark definition: A. Kotsarev, M.Lizorkin and R. Petrin, 20th AER Symposium, Hanassari, Finland, 2010

- **Initiating event** – re-connection of coolant loop No.1 with coolant temperature 100°C.
- **Initial conditions** – the core is at the end of its first cycle with a power of 1196.25 MWt.
- **Reference plant** – VVER440/213, all participant use their own input data deck (geometry, neutronic related data).

  ÚJV→ NPP Dukovany input deck, Gd-2 fuel
- **Burn-up calculation** – calculation made at a nominal power level of 1375 MW until the critical boron concentration reaches the value of zero.

7th Dynamic AER Bechmark – cont.

Benchmark scenario:

- First the MIV of the hot leg opens, after that MCP is started.
- When the MCP reached full flow then the MIV of the cold leg starts to open.
- Water slug with lower temperature enters to core – it causes rapid increasing of reactor power.
- The reactor scram signal is activated when reactor power is higher then 110% Nom.
- Stuck rod in FA No. 293 is located in the sector with highest subcooling.
- Turbines are turned-off 10 s after scram signal.
- All MCPs remain in operation.

Reactor core configuration

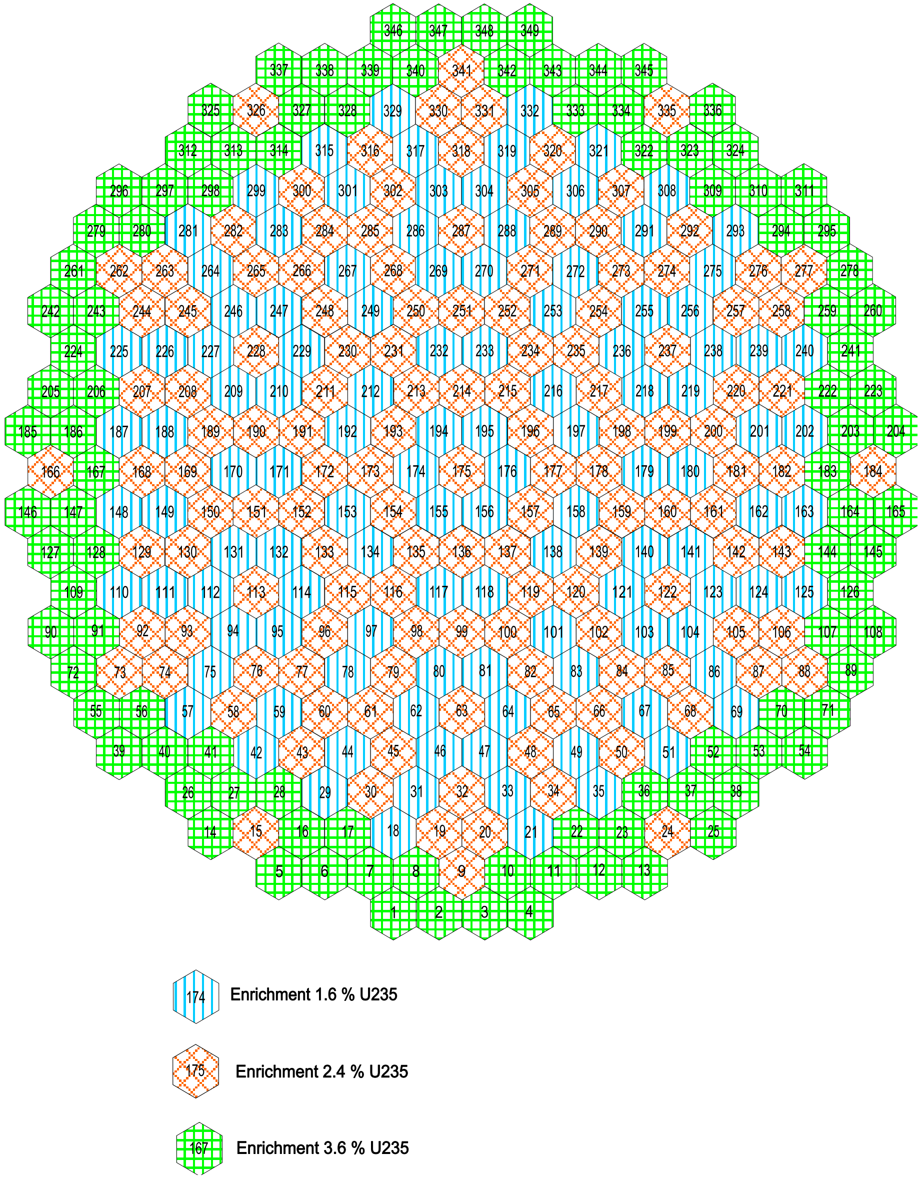


Fig. 1 Fuel assembly numbering

Reactor core configuration

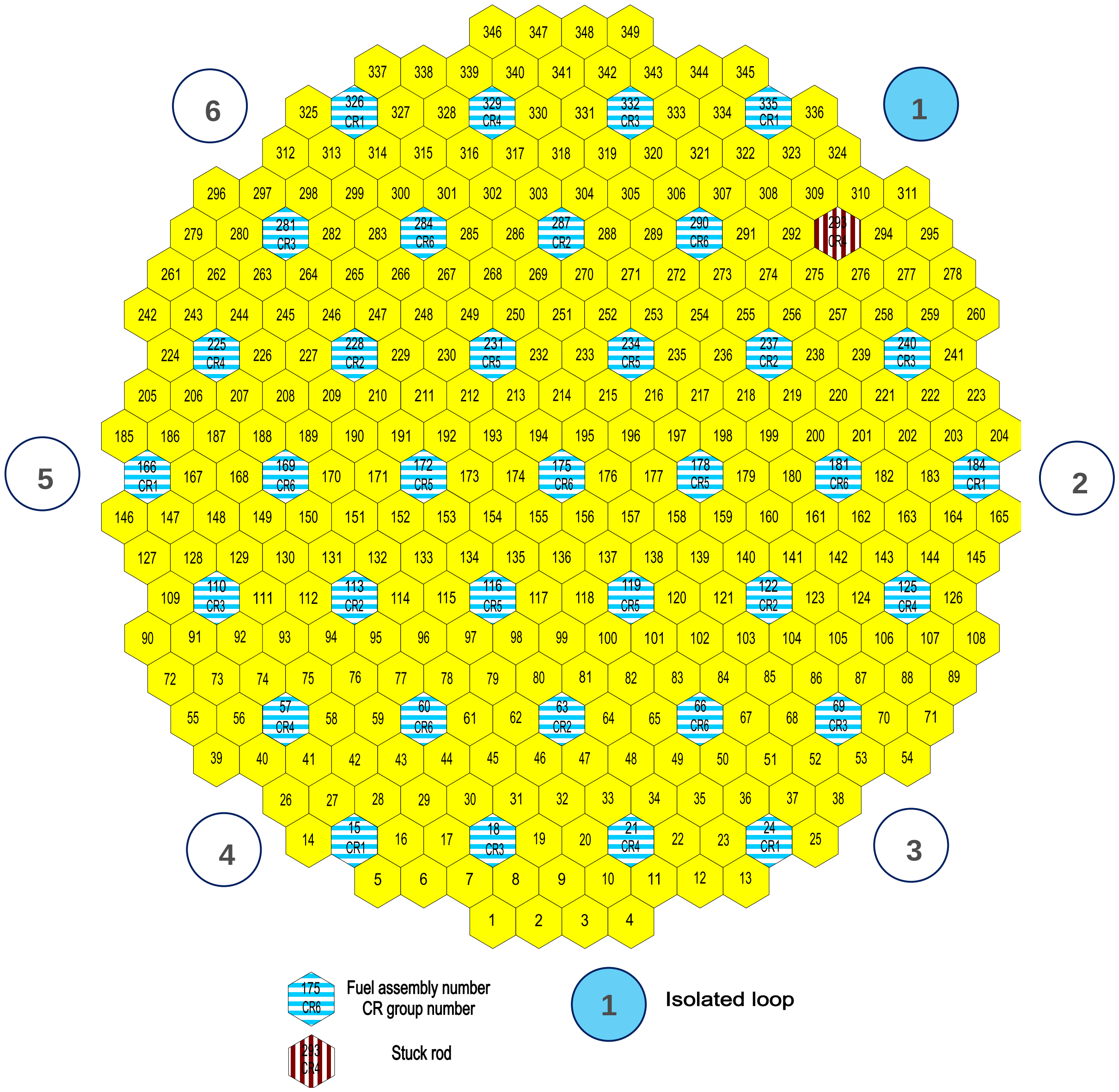
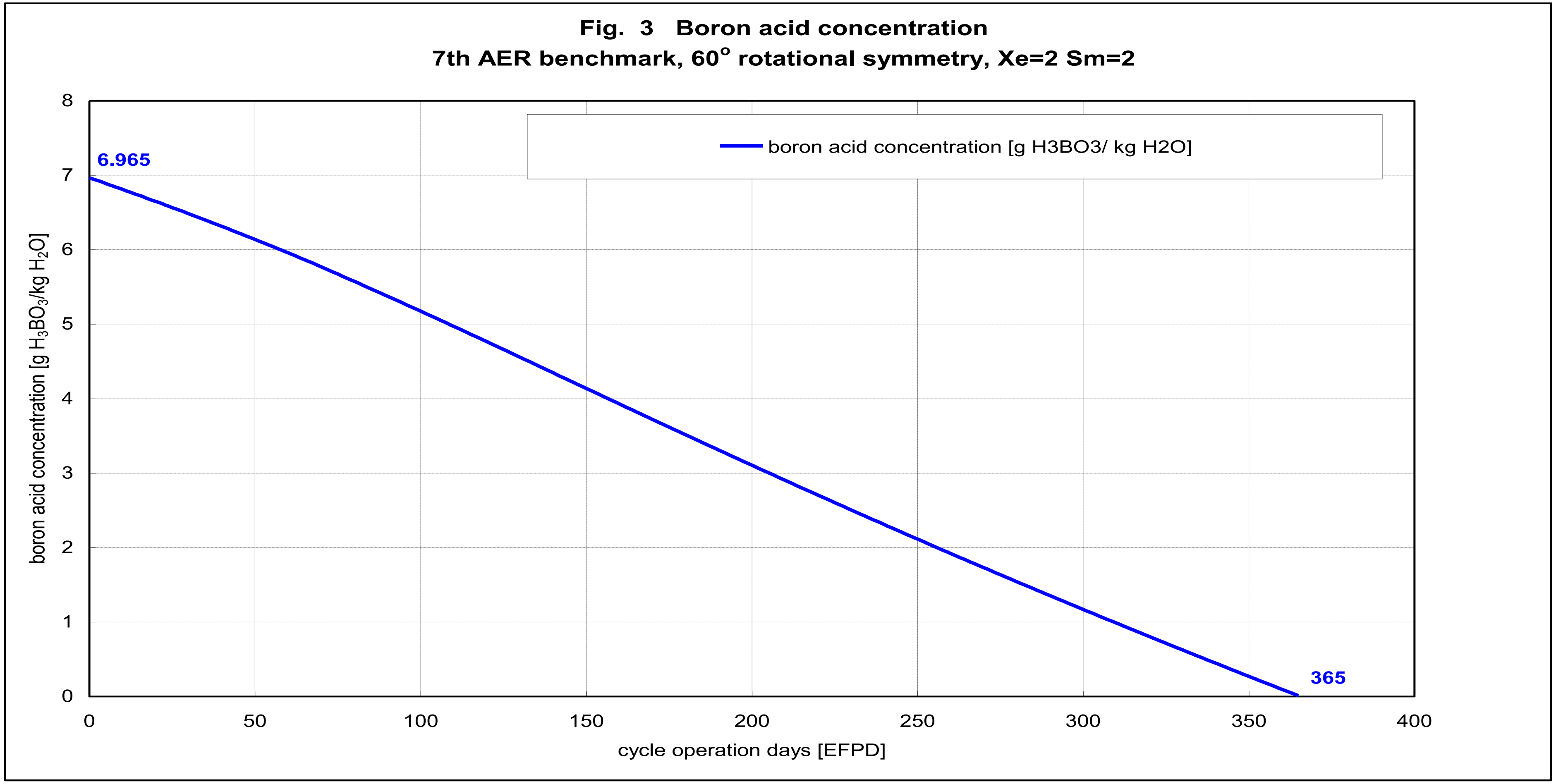


Fig. 2 Control rods location

Burnup calculation

- DYN3D code in combination with HELGD05 neutronic library (Dukovany NPP)



X-S library creation

Homogenized 2 group X-S for given reactor core configuration and burnup were extracted from HELGD05 neutronic library and attached to RELAP5-3D© through USER option.

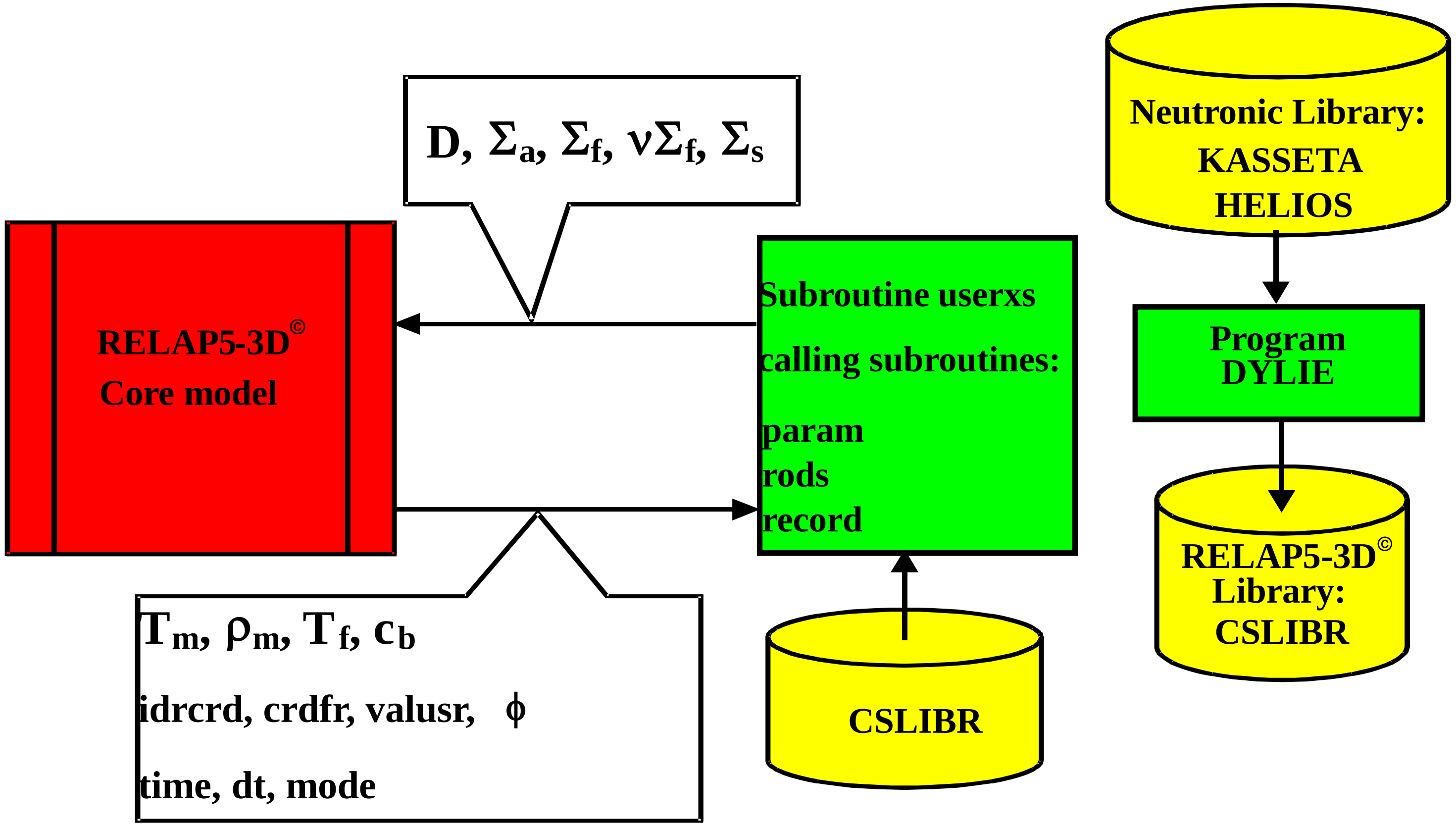


Fig. 4 Neutronic data preparation

RELAP5-3D© model

- RELAP5-3D (ver. 2.4) model is based on RELAP5/Mod3 input developed in UJV (P. Král, J. Krhounková)
- 3-D reactor pressure vessel model has been validated on available transient data from NPP Dukovany (e.g. asymmetrical loop cooling).

- Pressure vessel consists of 1 three-dimensional (MULTID) object:
  - 8 azimuthal sectors
  - 4 radial sectors
  - 17 axial levels
  - Some volumes (related to core and reactor head) are disabled (by setting flow areas = 0)
  - Normal one-dimensional equations are used on each of the coordinate direction (MULTID → Word 7 = 1 on Card CCC0001)
- Core (including reflector) is simulated by bundle of 1-D channels (pipes) connected to the multidimensional lower plenum and upper plenum

RELAP5-3D© model

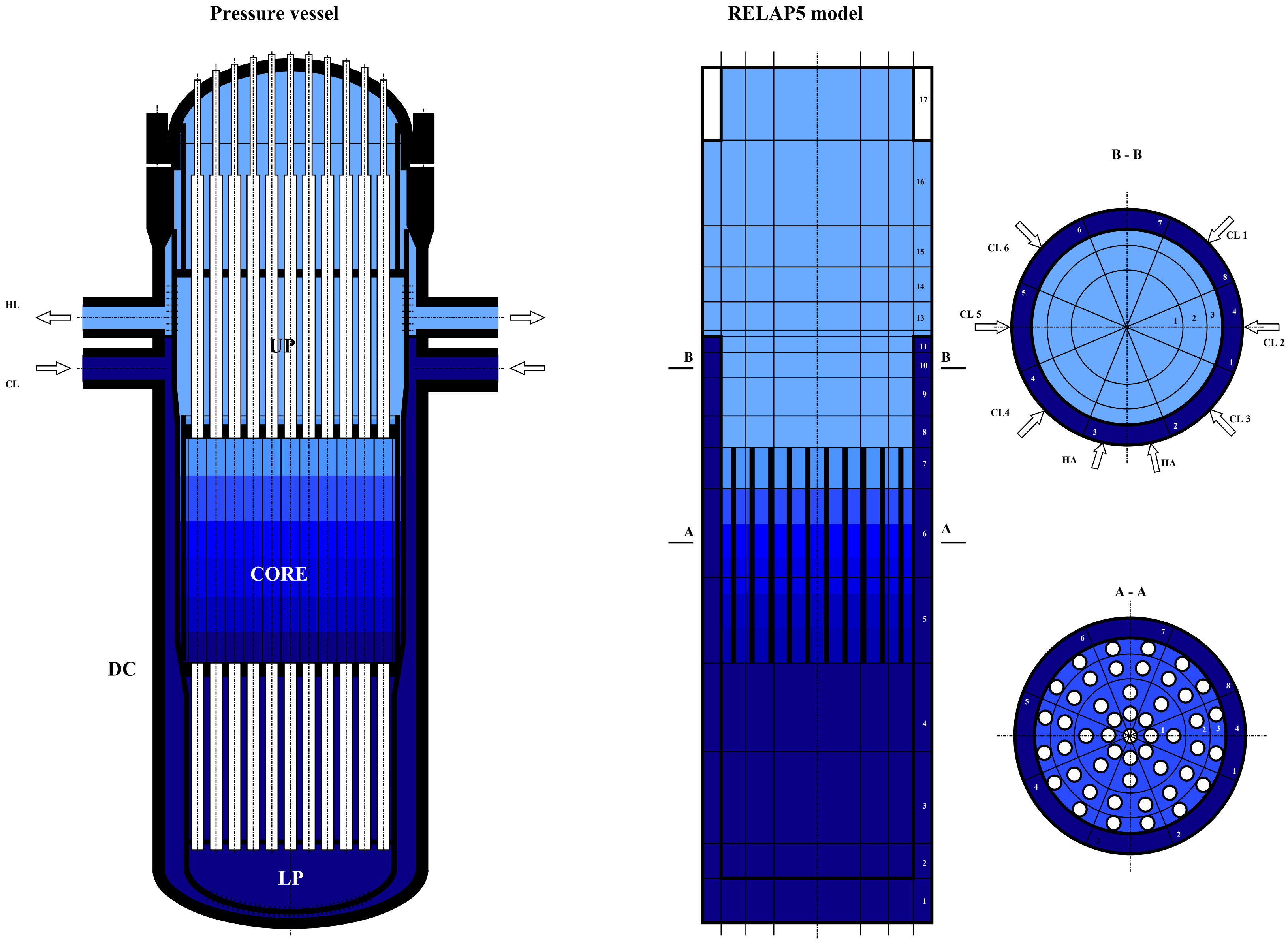
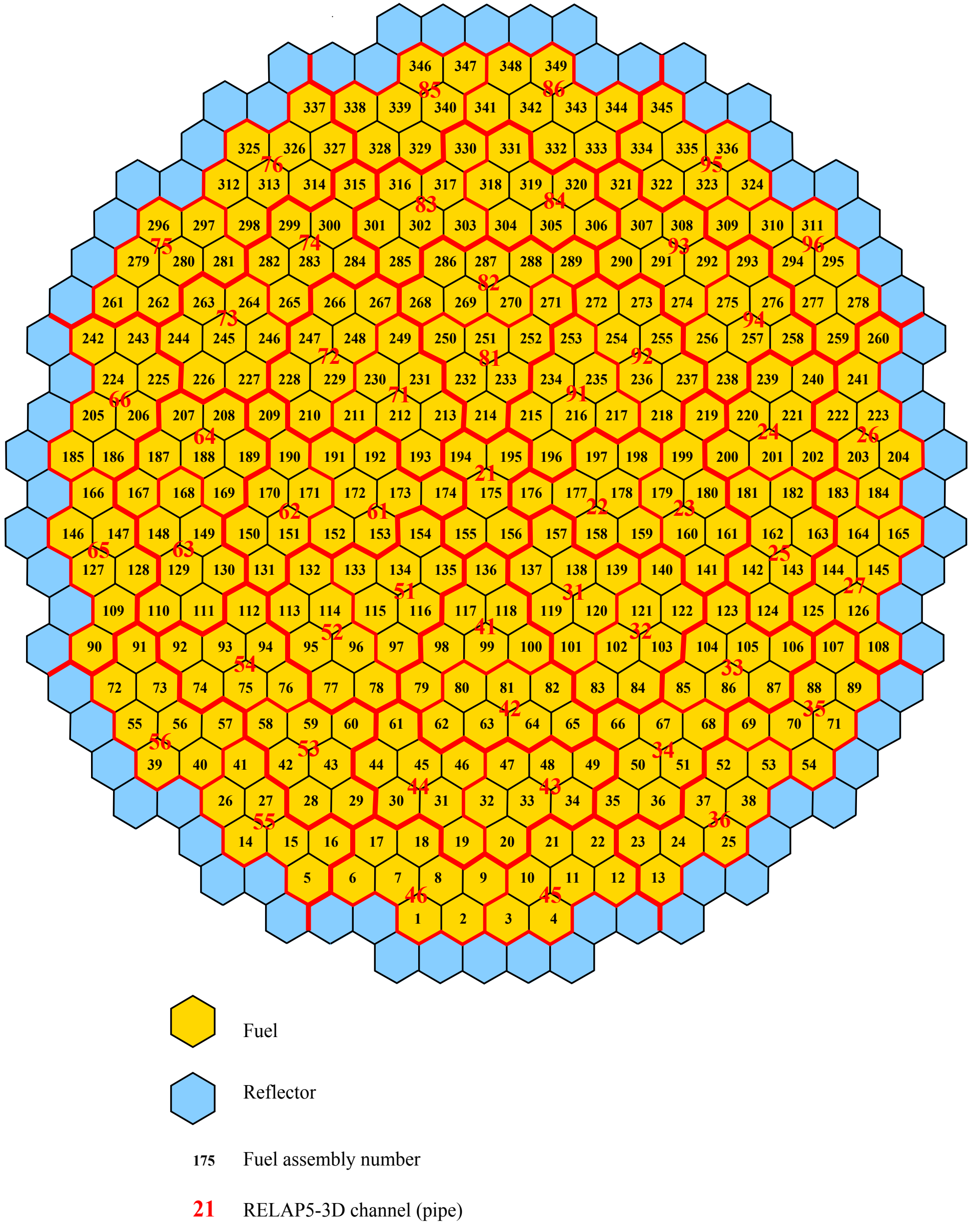


Fig. 5 Reactor vessel nodalization

RELAP5-3D© model



349 fuel assemblies

49 core TH channels (1D pipes)

8 reflector channels (1D pipes connected to the 3rd radial sector of MULTID object)

Every fuel channel has 12 axial volumes:

- **1 non-heated volume - lower reflector**
- **10 active core volumes**
- **1 non-heated volume – upper reflector**

Fig. 6 TH core model and coupling with 3-D NK

RERELAP5-3D© nodalization

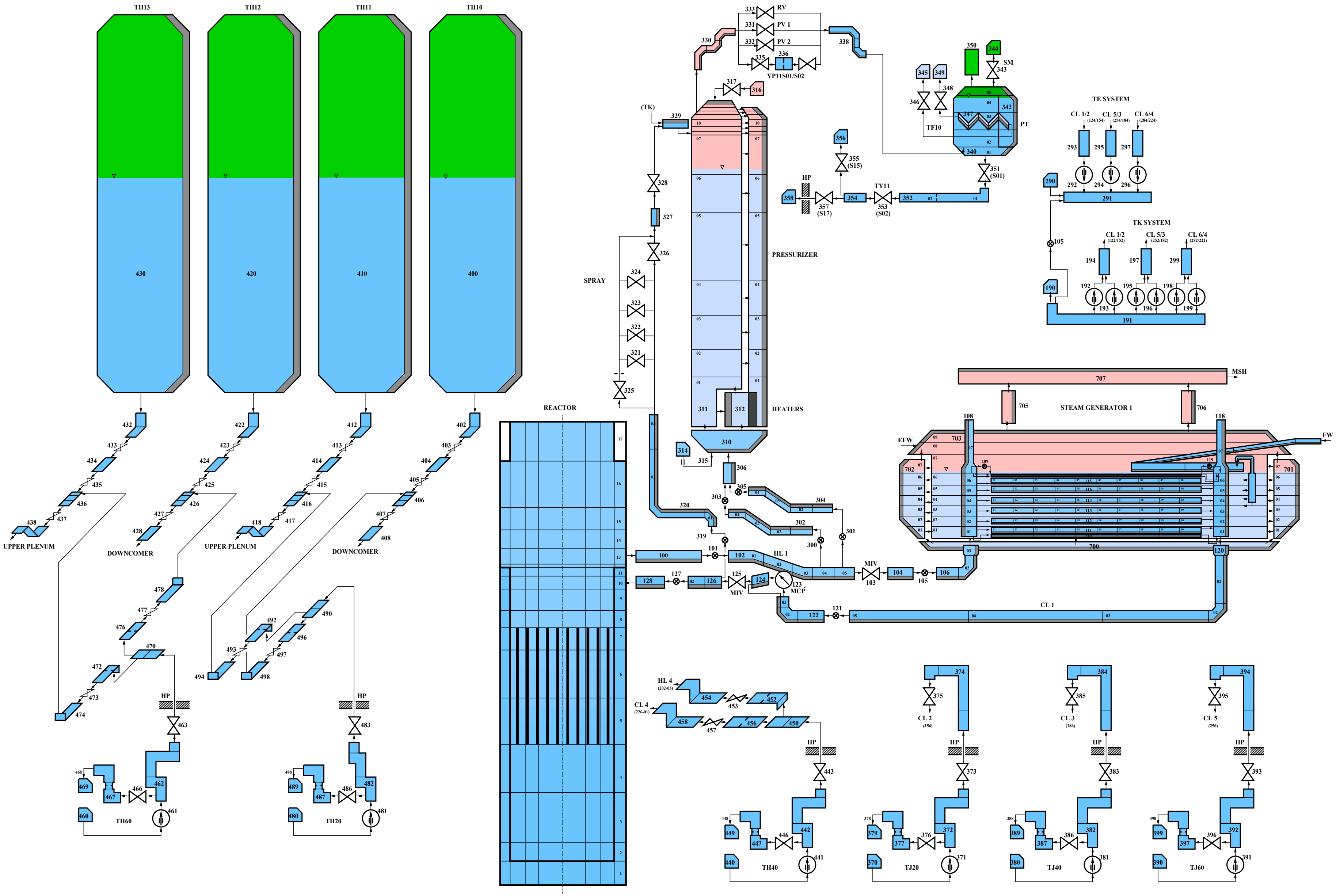


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Fig. 7 Primary circuit nodalization

Initial steady-state conditions

	Proposed conditions	Calculated conditions
Primary circuit		
Reactor power [MW]	1196.25	1196.25
Upper plenum pressure [MPa]	12.26	12.27
Core inlet temperature [°C]	267.4	267.6
Loop No. 1 cold leg temperature [°C]	100.0	101.0
Loop mass flow rate [kg/s]	1470.0	1464.6-1469.8
Core bypass mass flow rate [%]	3	3
Pressurizer collapsed level [m]	5.97	5.97
Secondary circuit		
Pressure at SG outlet [MPa]	4.63	4.61- 4.67
Feed water temperature [°C]	220.0	220.0
Feed water mass flow rate [kg/s]	124.5	127.6-130.3
SG collapsed level [m]	2.015	2.015

Transient results

Sequence of main events:

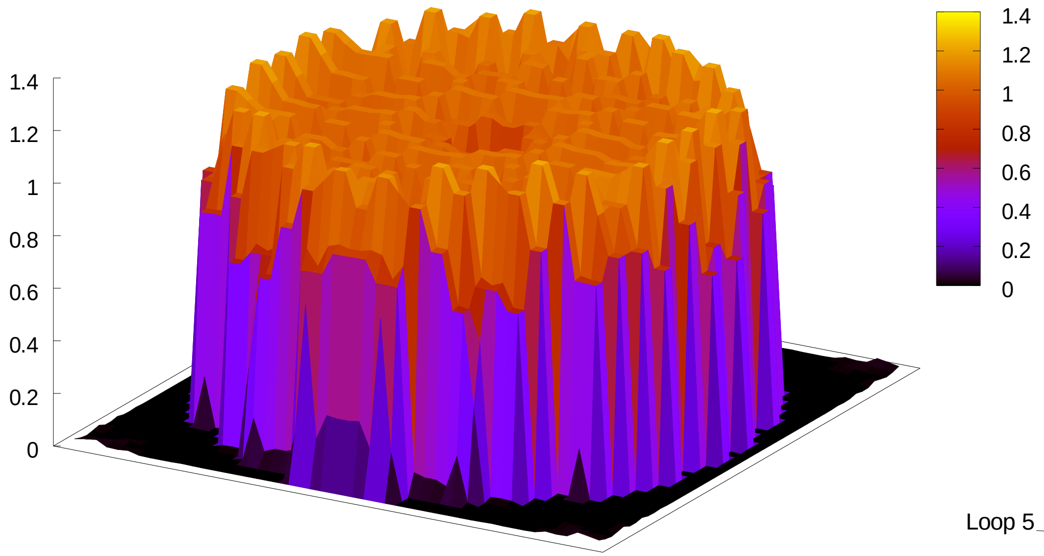
Event	Time [s]	
	UJV	HZDR[1)]
MIV of the hot leg No.1 starts to open	0.0	0.0
MCP No.1 starts	2.0	5.0
MIV of the cold leg No.1 starts to open	20.0	20.0
1-st TK pump starts	29.0	39.8
SCRAM – power level of 110 % of the nominal value	29.7	38.8
Maximum core power (= 1729.1 MW)	30.4	39.4
Closing of turbine isolation valves starts	39.7	48.8
2-nd TK pump starts	69.0	79.8
End of calculation	500.0	215.0

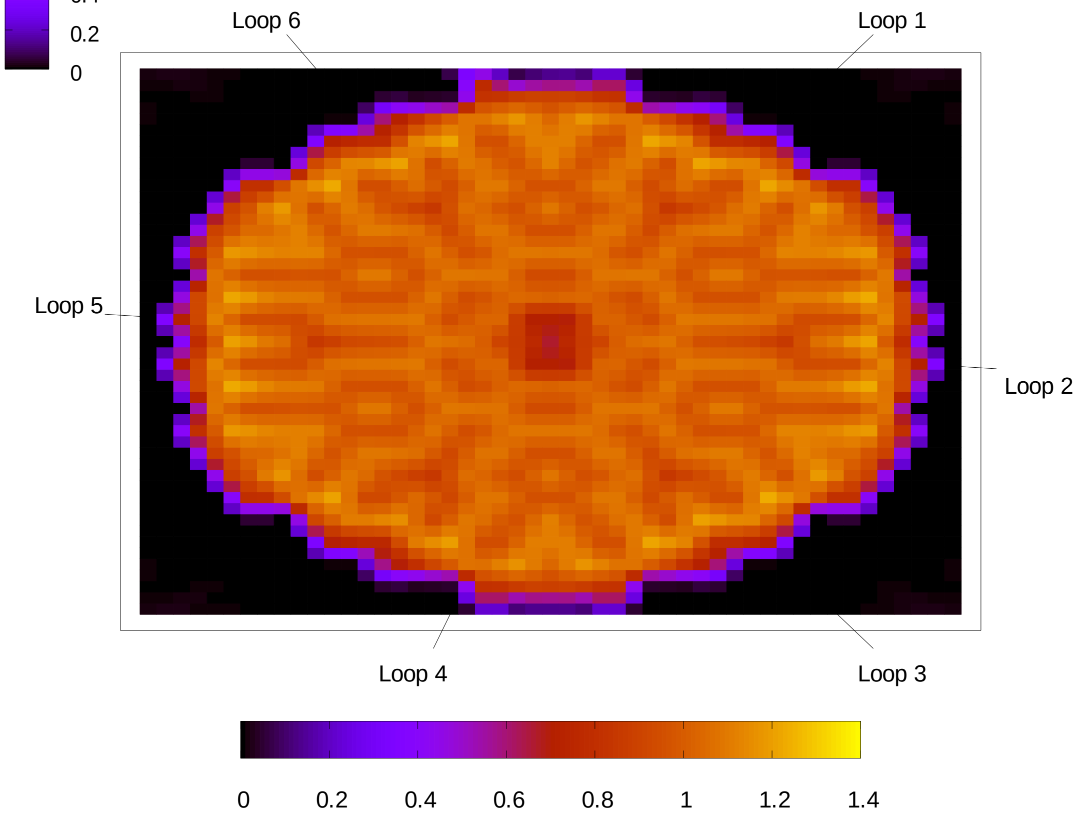
[1)] Y. Kozmenkov, S. Kliem, Helmholtz-Zentrum Dresden-Rossendorf, Germany

Externally coupled codes DYN3D/ATHLET (DYN3D and coupling developed in HZDR, ATHLET in GRS, Germany)

The 3D core model includes all 349 fuel assemblies (assembly-by-assembly approach).

Transient results

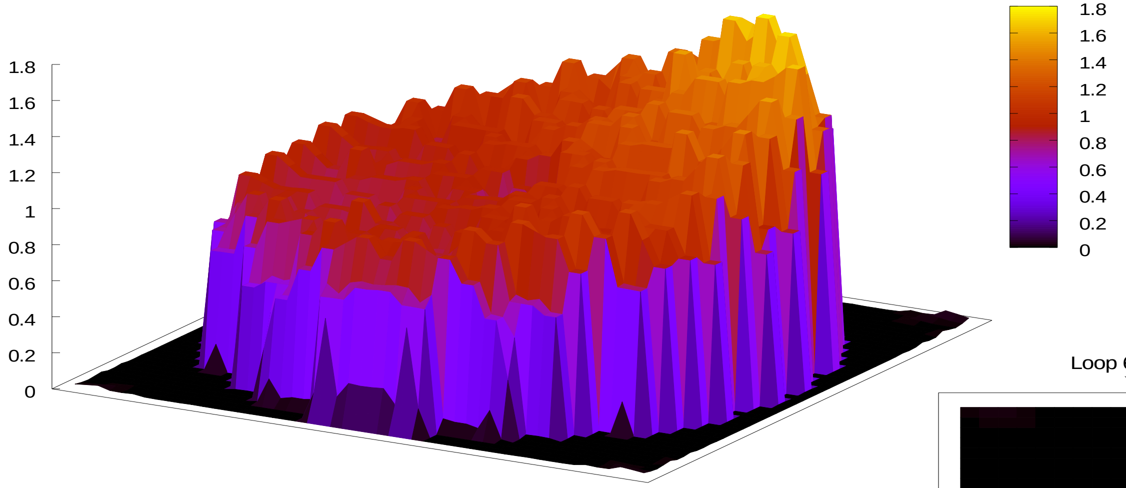




Total power = 1196.25 MW, Fission power = 1117.53 MW

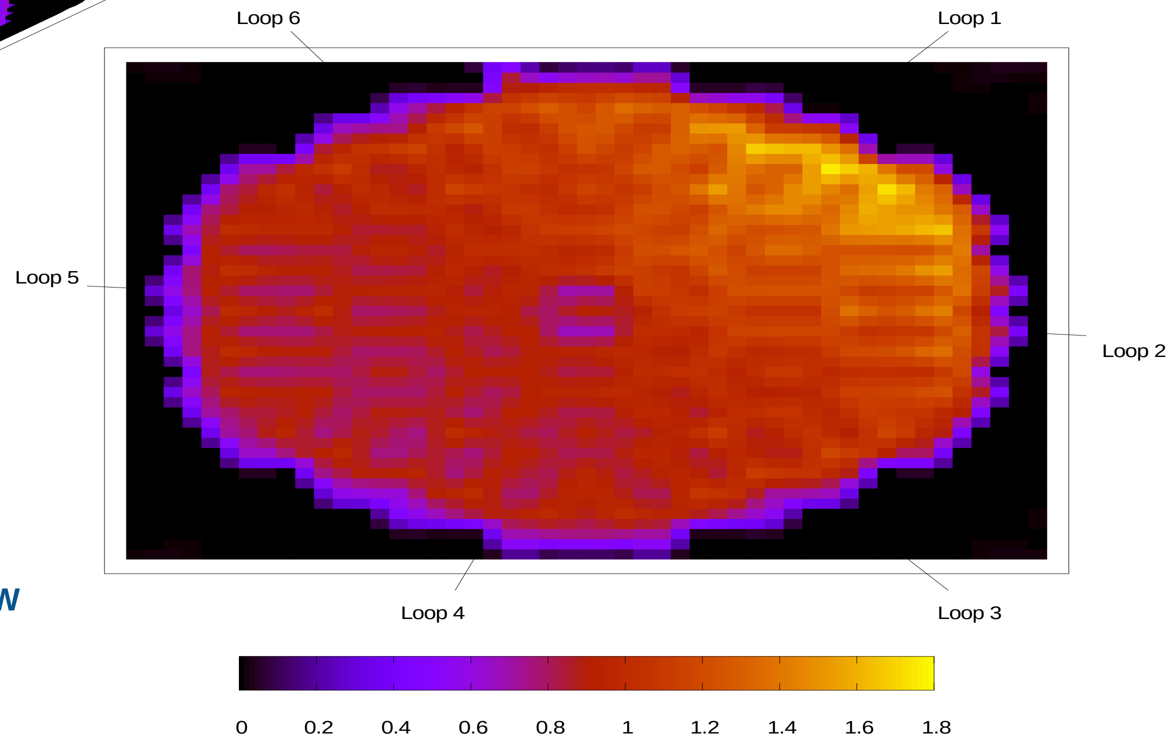
Fig 8 Normalized fission power at 0 s (transient initialization)

Transient results



Main events:

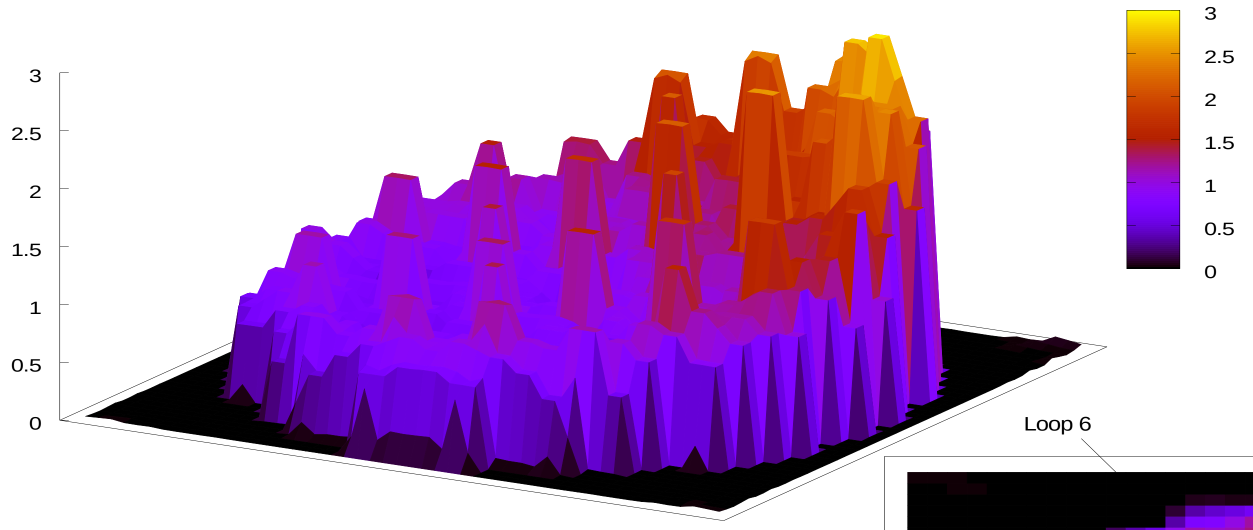
- **SCRAM at 29.7s**
- **Control rods start to drop at 30.2 s**
- **Maximum power at 30.4 s**



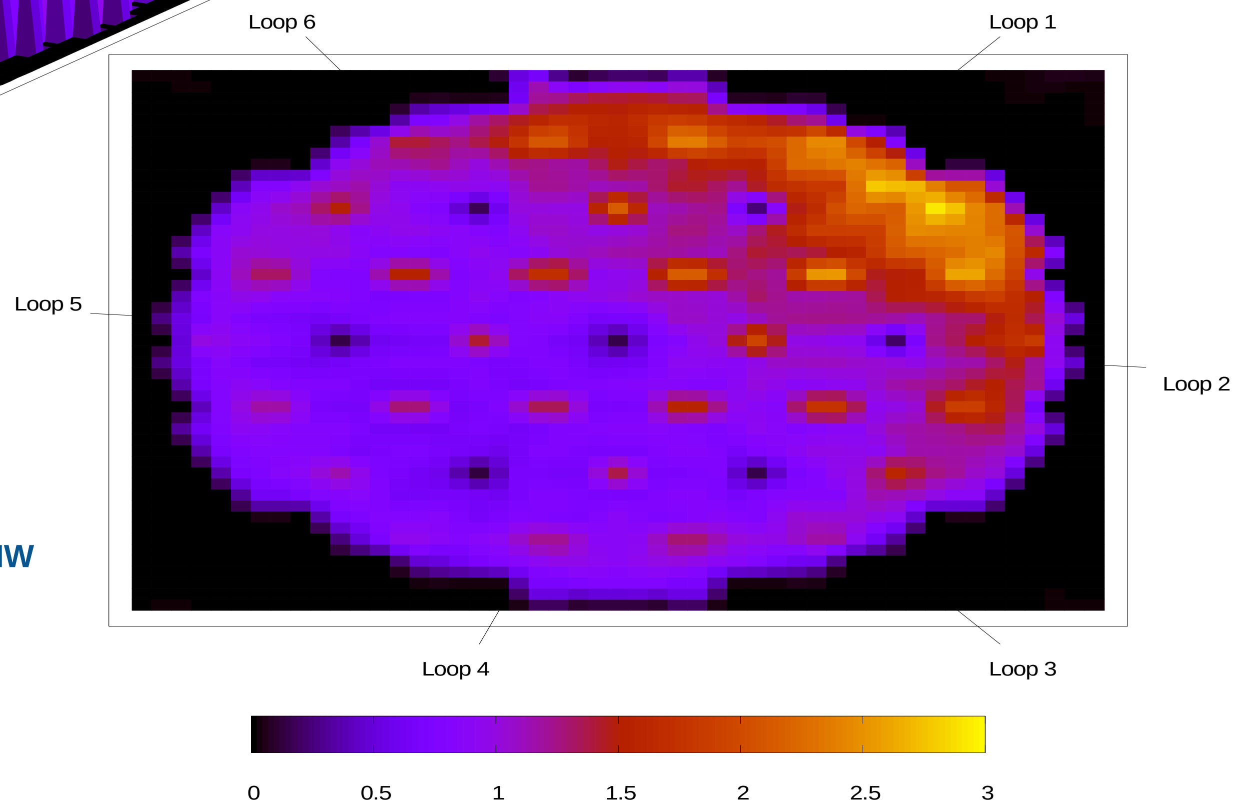
Total power = 1729.1 MW, Fission power = 1647.2 MW

Fig. 9 Normalized fission power at 30.4 s (maximum core power)

Transient results



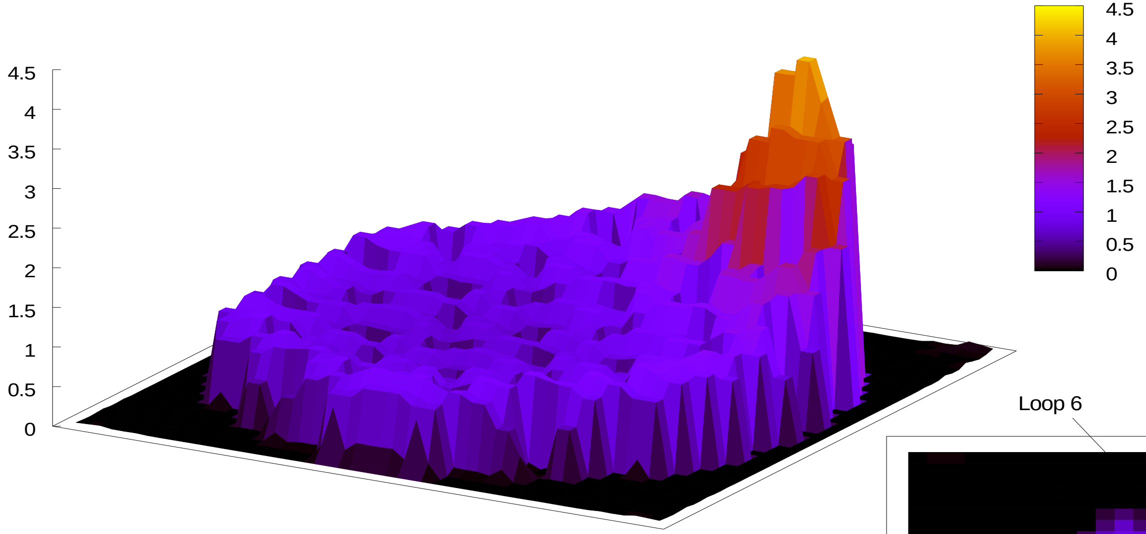
Group K6 fully inserted



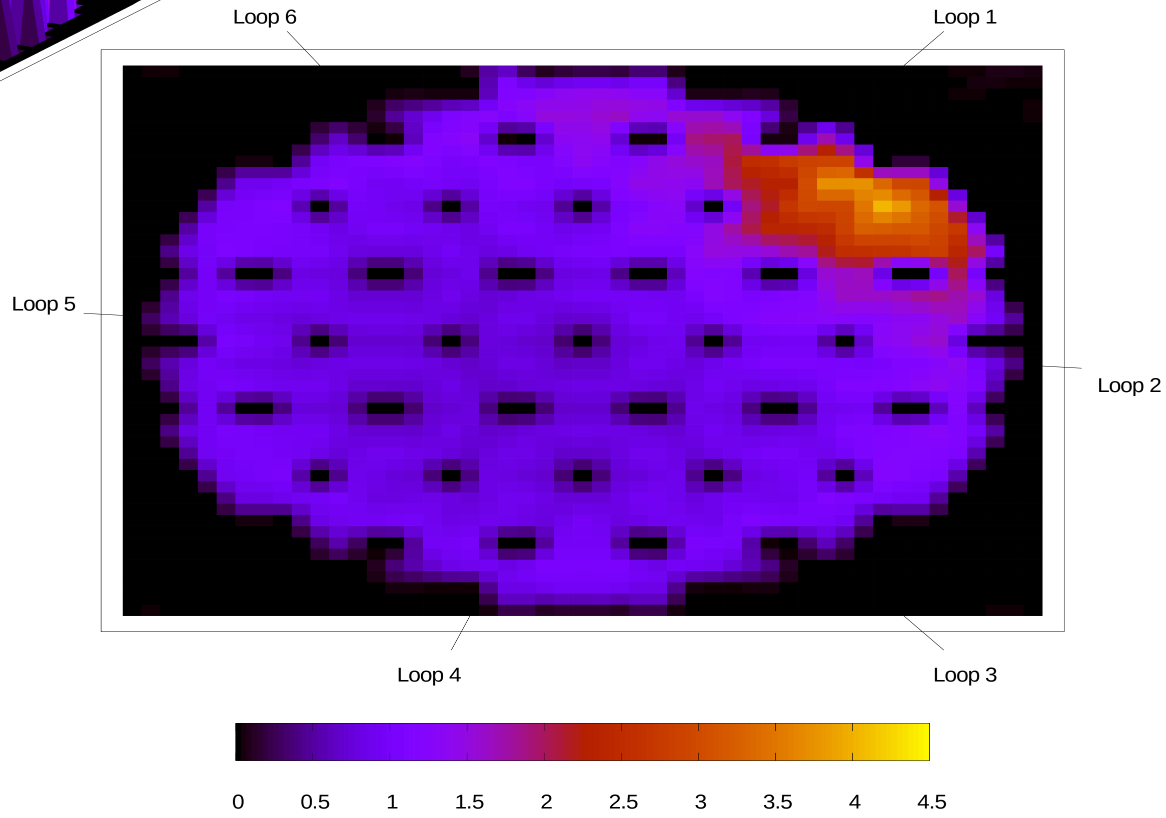
Total power = 279,6 MW, Fission power = 207,9 MW

Fig. 10 Normalized fission power at 37 s

Transient results



All control rods fully inserted ⇨



Total power = 90.1 MW, Fission power = 29.5 MW

Fig. 11 Normalized fission power at 50 s

Transient results

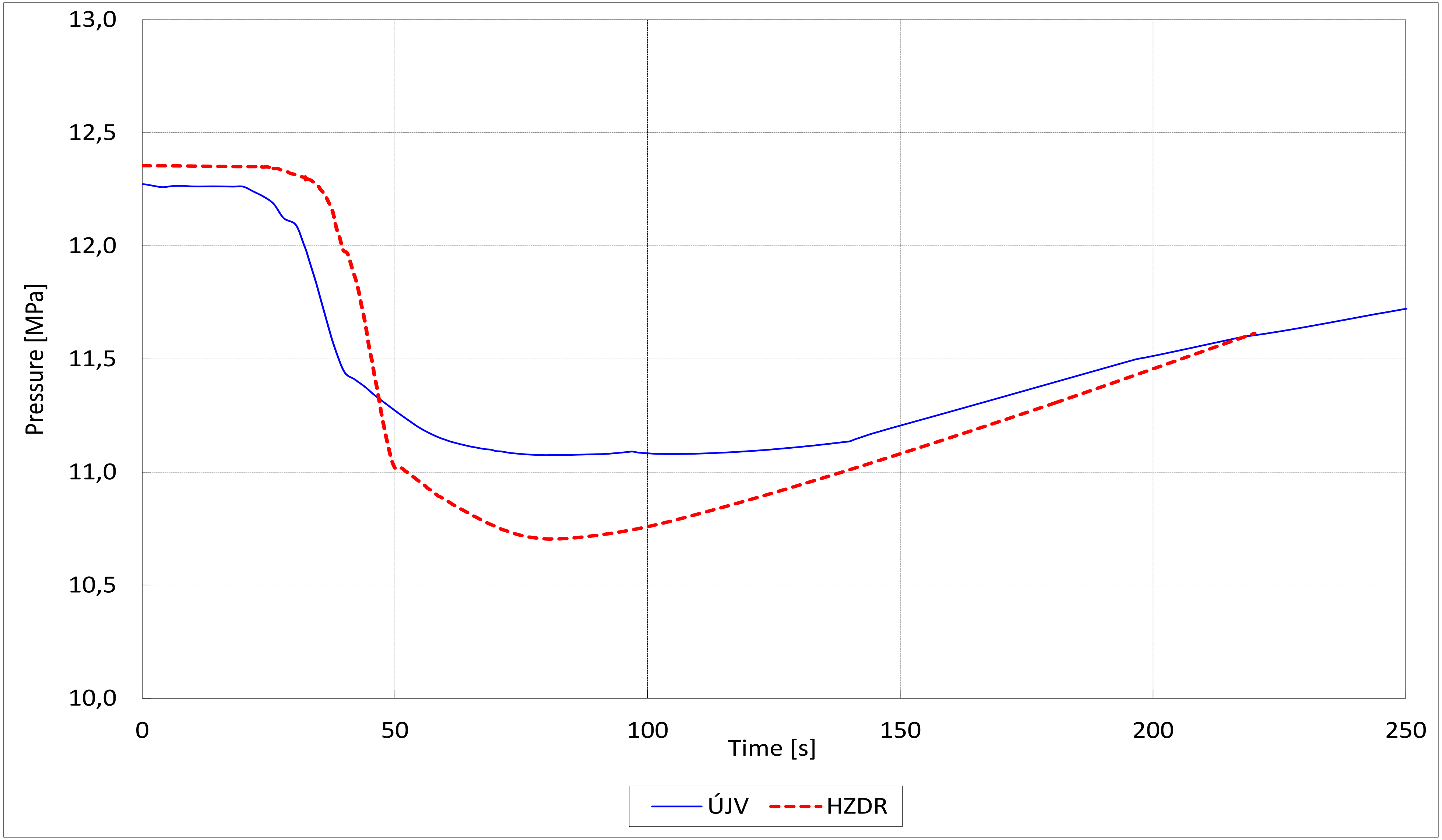


Fig. 12 Primary pressure – upper plenum

Transient results

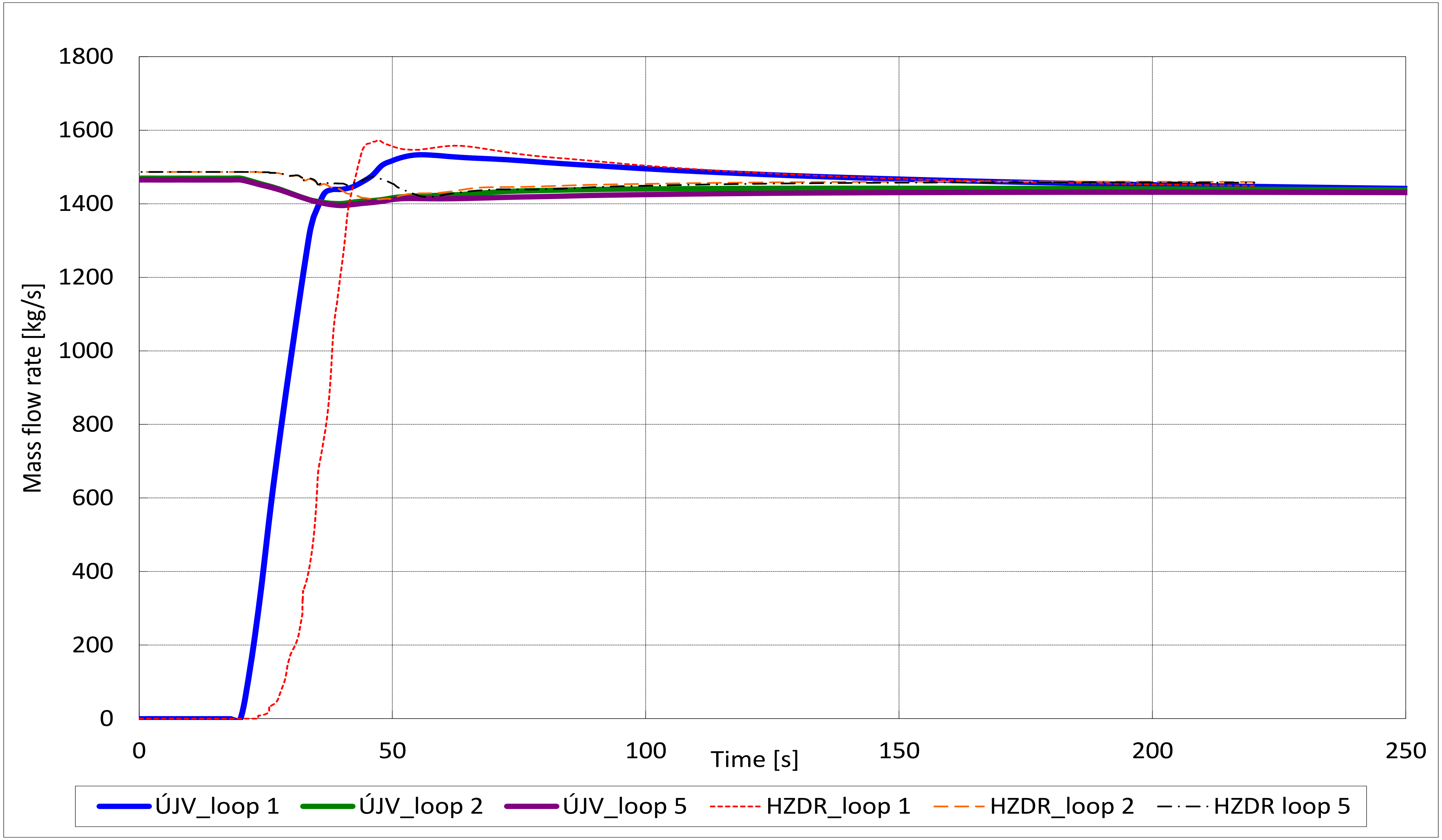


Fig. 13 Loop mass flow rate

Transient results

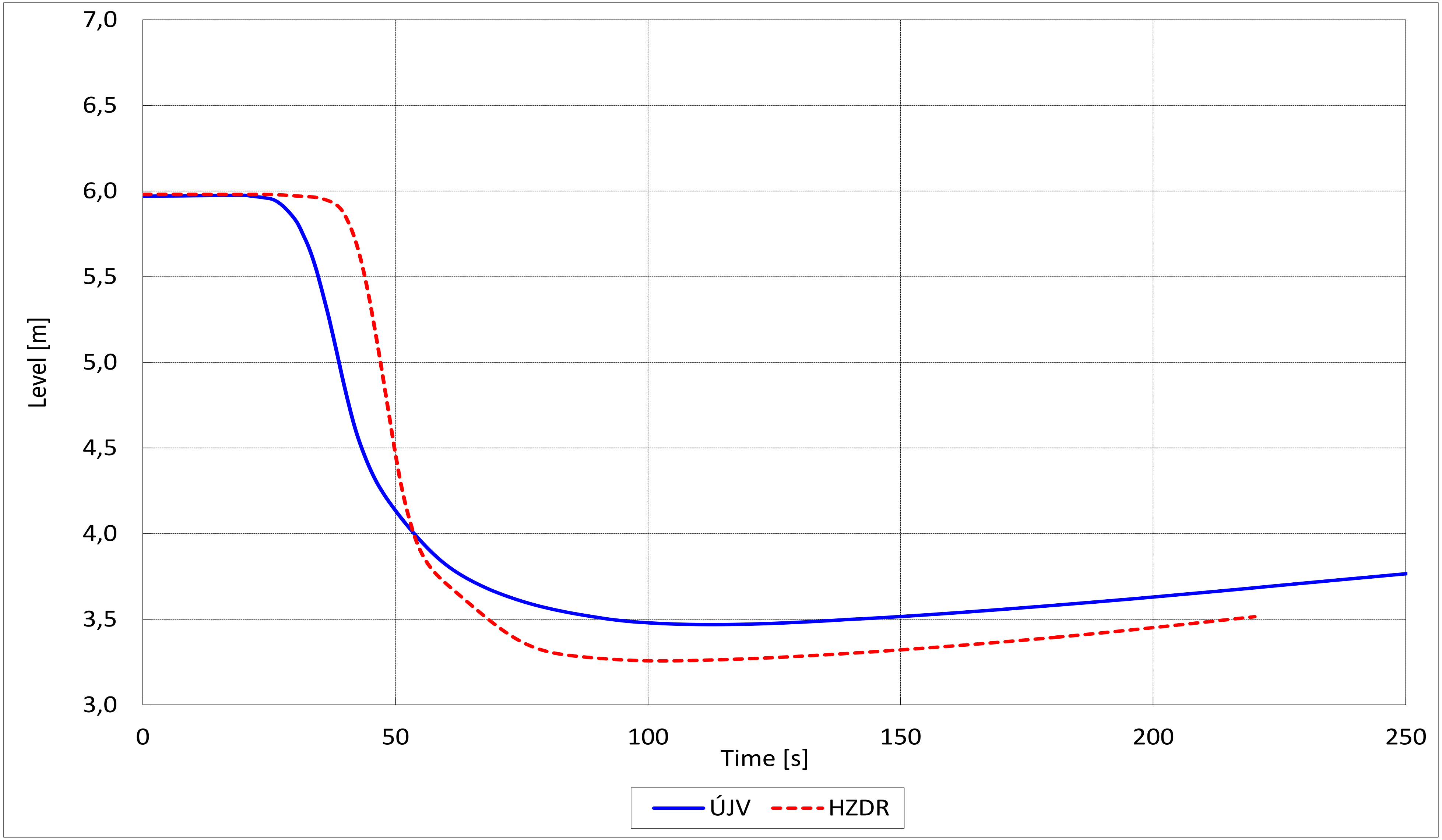


Fig. 14 Pressurizer collapsed level (from the bottom)

Transient results

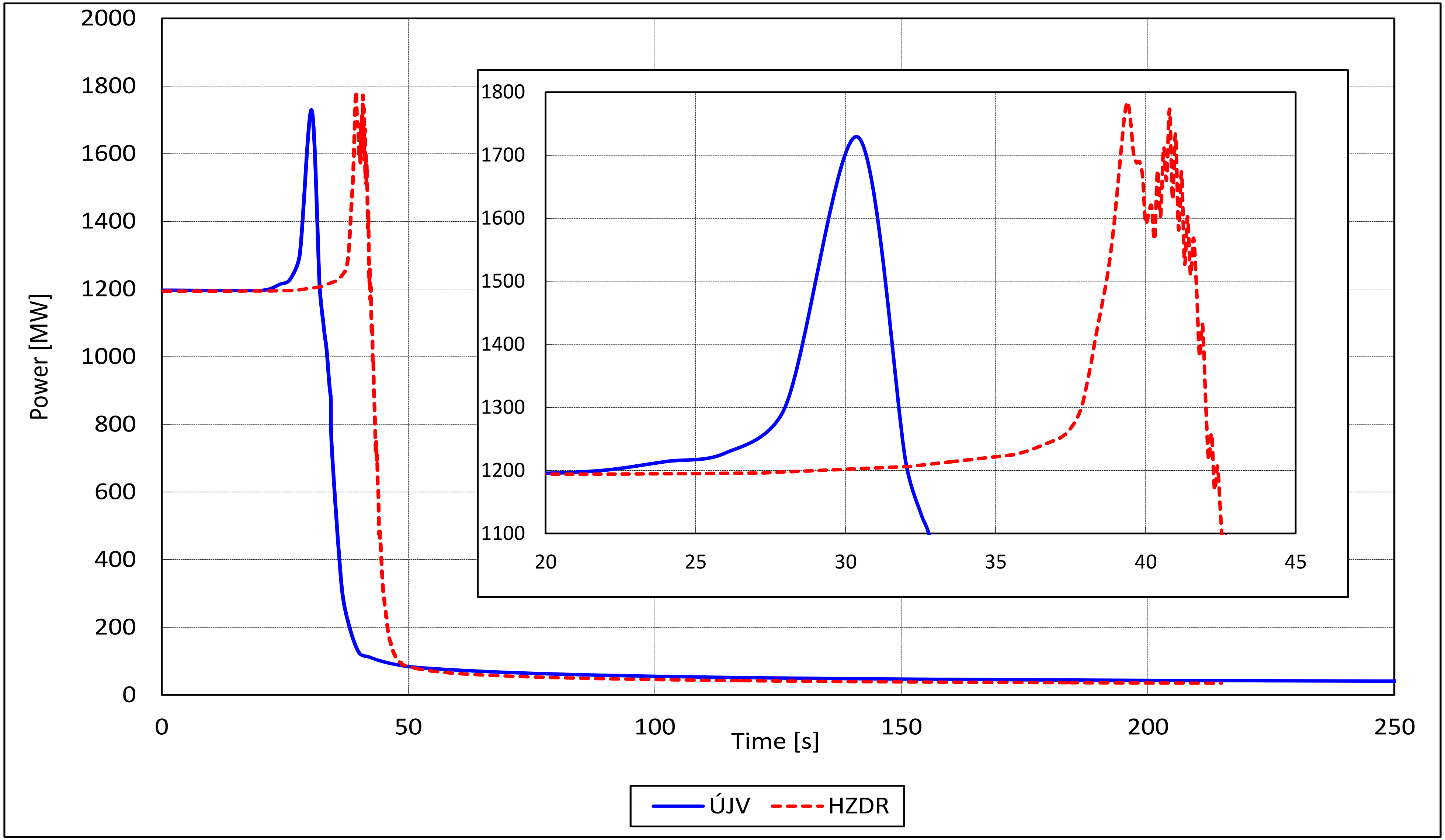


Fig. 15 Core power

Transient results

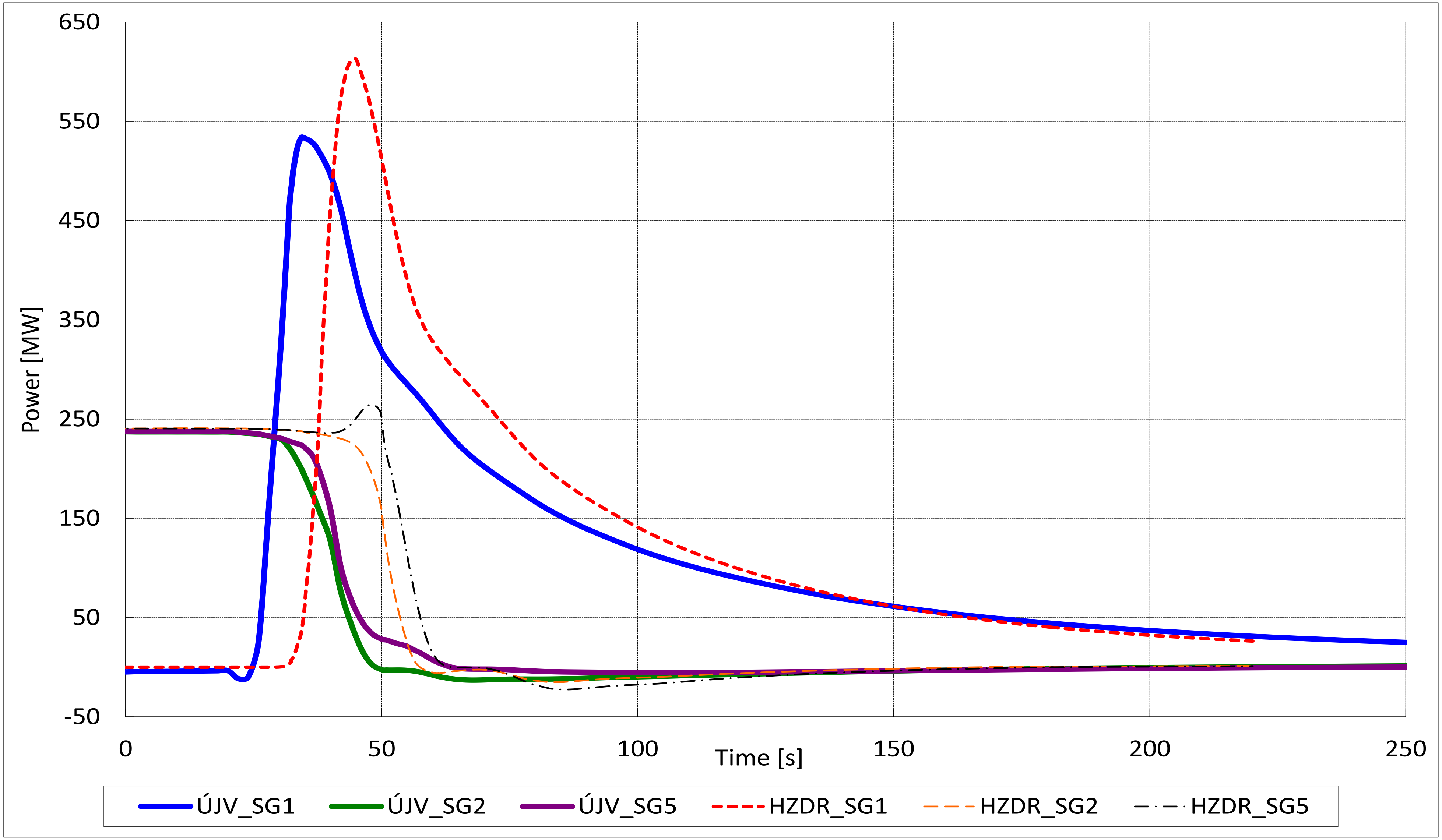


Fig. 16 Power transfered to SG

Transient results

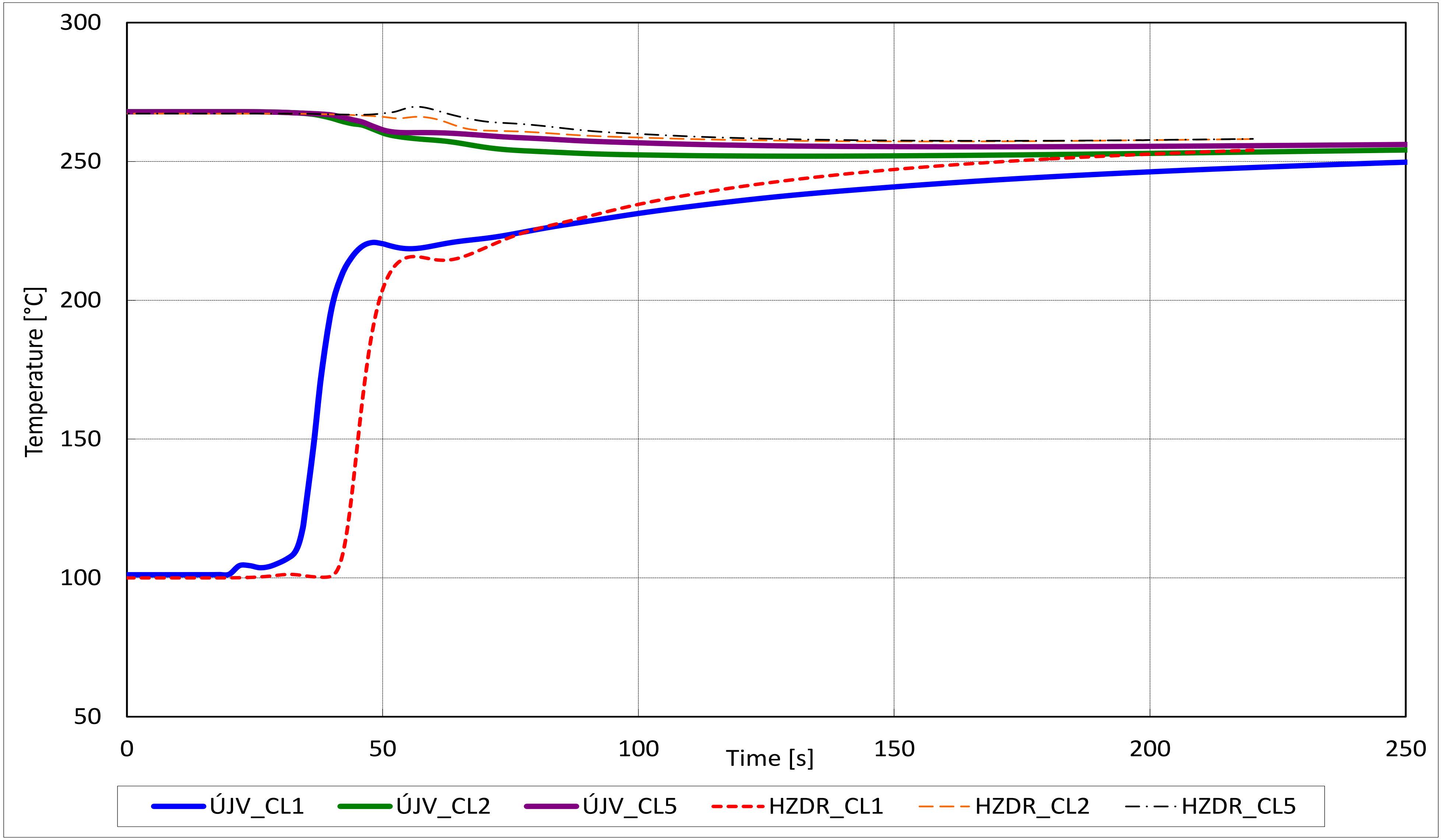


Fig. 17 Cold leg temperatures – loop seal

Transient results

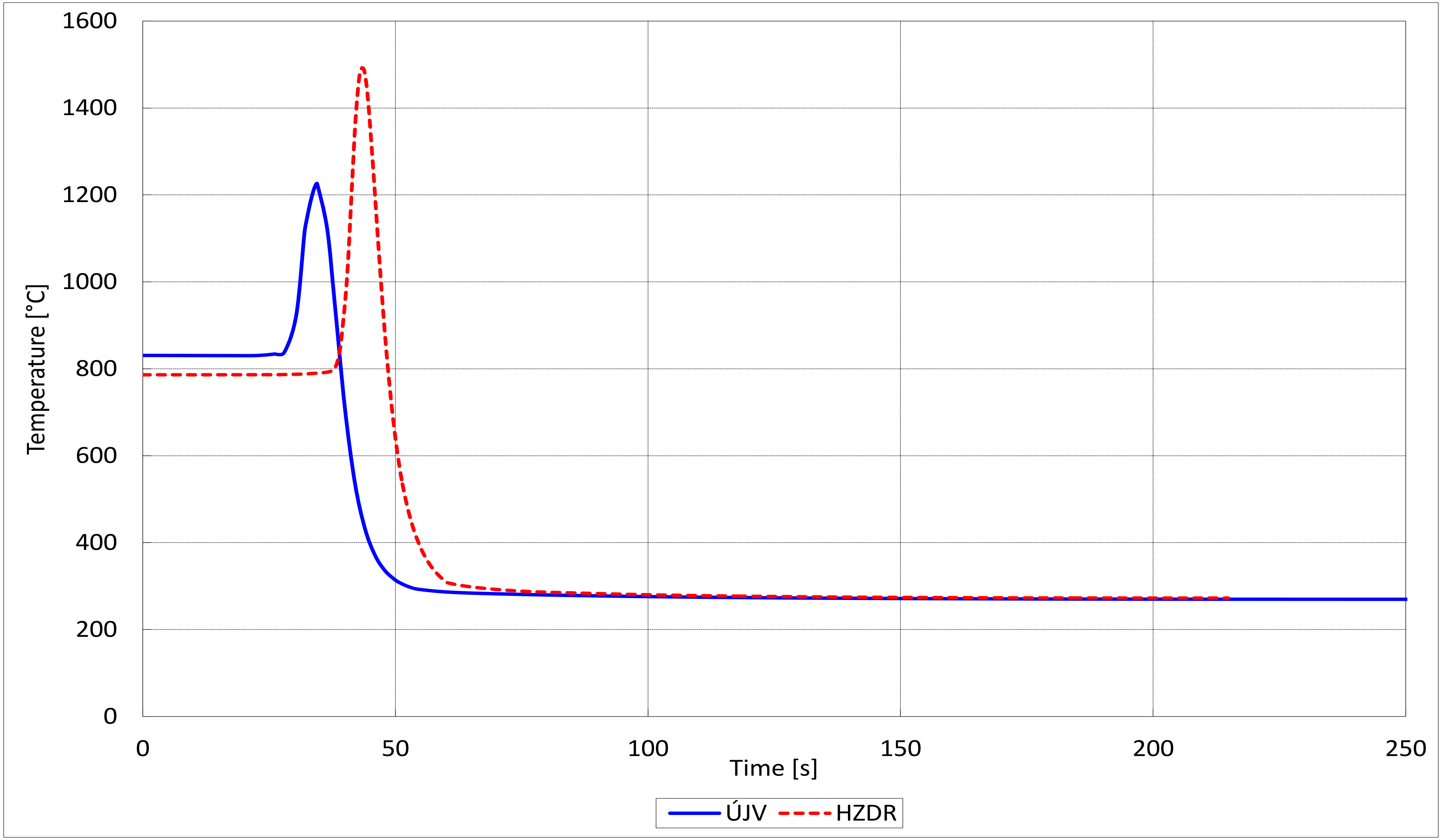


Fig. 18 Maximum fuel temperature

Transient results

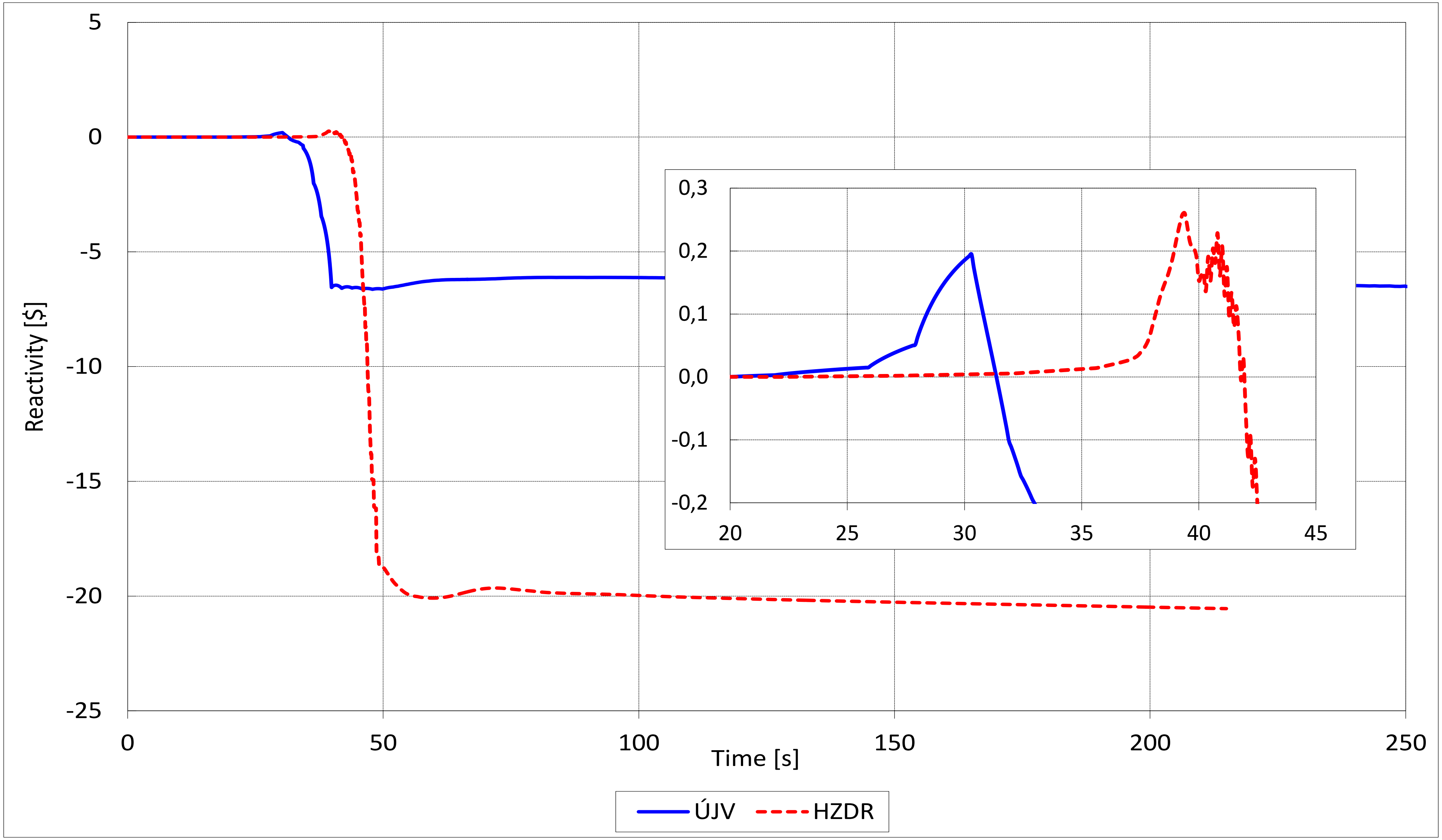


Fig. 19 Reactivity

Transient results

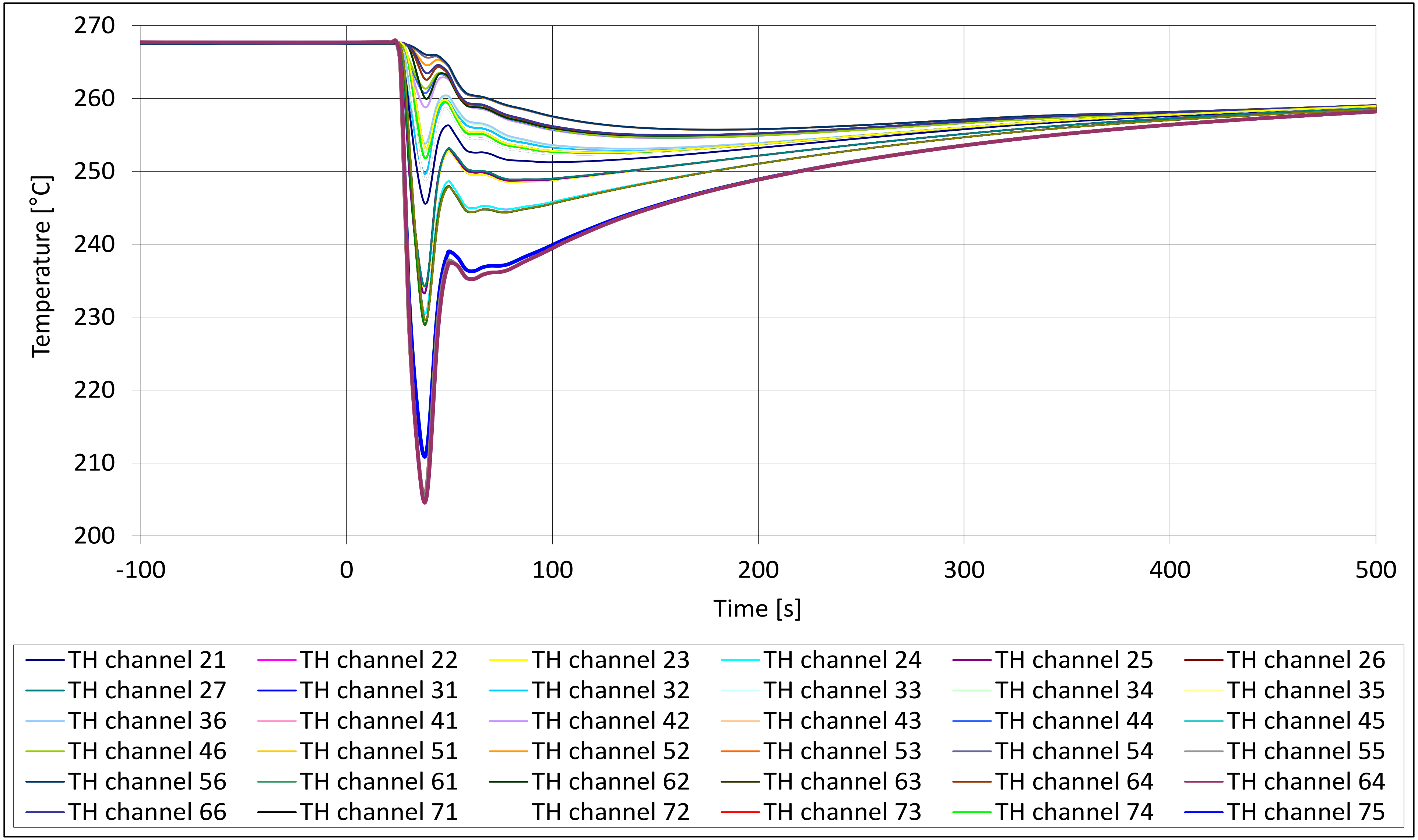


Fig. 20 Core inlet temperatures

Conclusions

- UJV has prepared input model of VVER-440 for RELAP5-3D©.
- Calculation of 7-th dynamic AER benchmark was performed.
- Comparison of UJV and HZDR calculation:
  - The trends of main calculated parameters are very close
  - Faster start of mass flow in reconnected loop in UJV calculation (different MIV and/or MCP characteristic ?)
  - Higher maximum fuel temperature in HZDR calculation (more detailed core nodalization)