ÚJV Řež, a. s.

In Vessel Retention Strategy VVER 1000/320

VVER 2013 Conference

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Presentation content

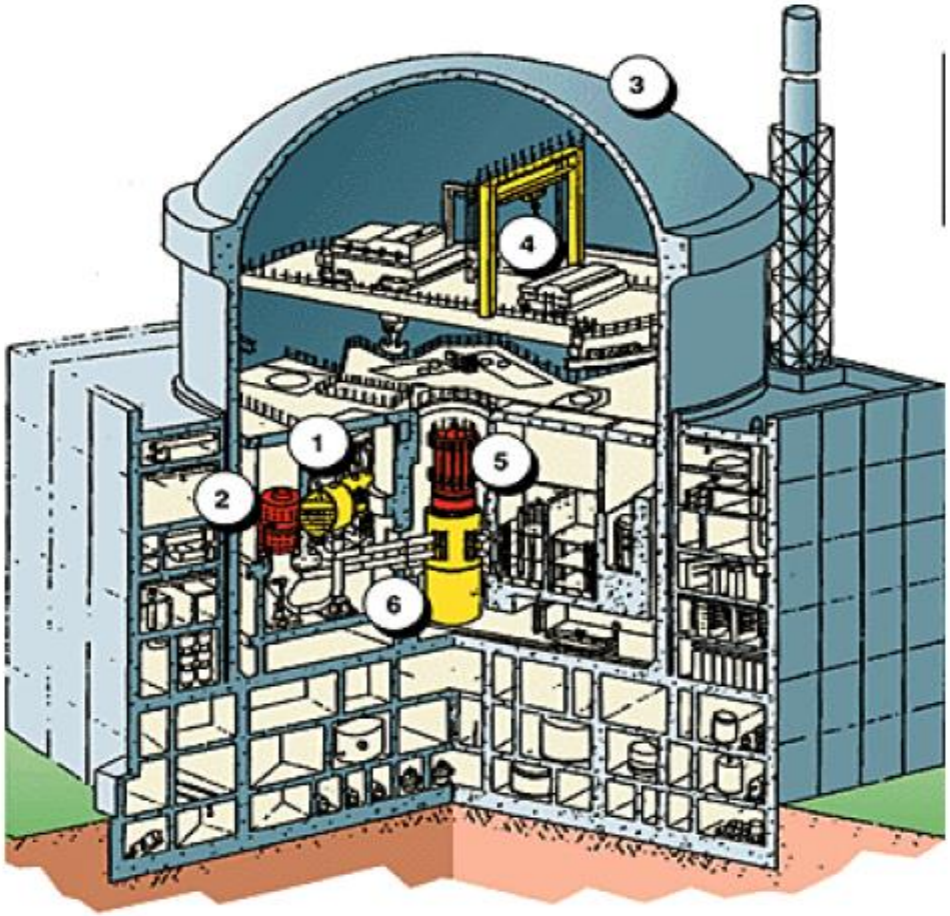
- Background of SA issues
- VVER 1000/320 Containment and RPV Cavity Configuration
- IVR Strategy for VVER 1000/320 Status and Needs
- Conclusions

Background

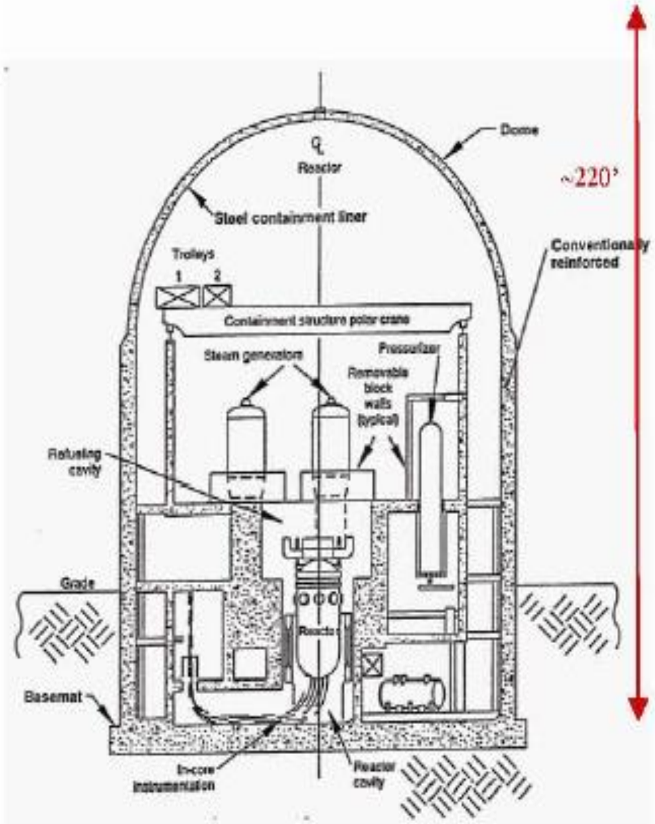
- **UJV provides both Czech NPPs with support in several SA issues**
  - SAMG validation, analytical support to design of PAR layout, SA initiated in spent fuel pool or in different operational conditions (full power x shutdown)
- **Solutions of SAM strategies – melt localization as example**
  - Analytical and experimental investigation of feasibility for both potential strategies
    - In-Vessel Retention with External Reactor Vessel Cooling
      - Scope of this contribution
    - Ex-Vessel Coolability
      - Corium cooling during MCCI and/or proposal for specific core catcher

Containment VVER

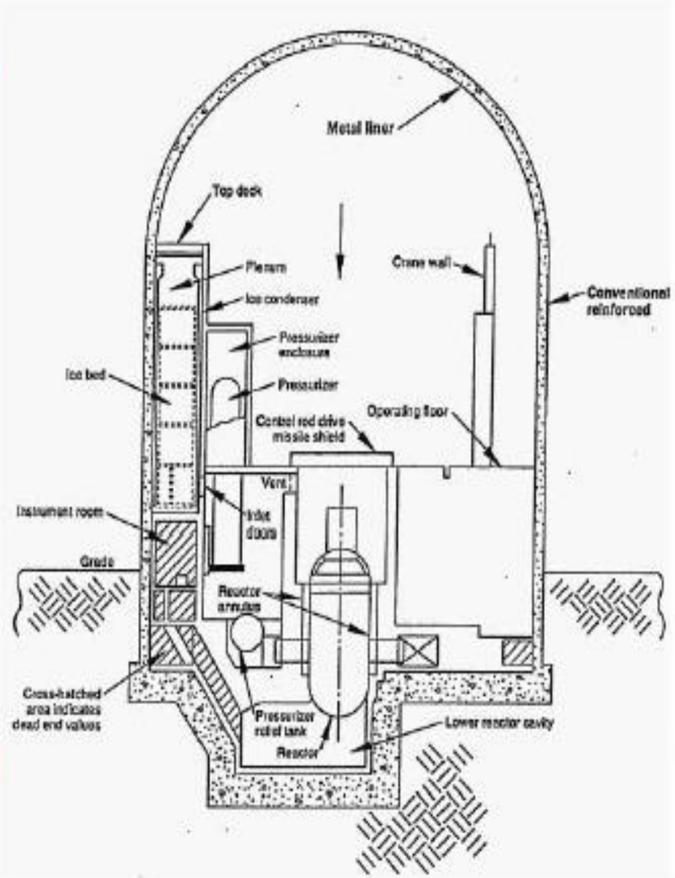
It is important to realise key configuration. The RPV is above the ground.



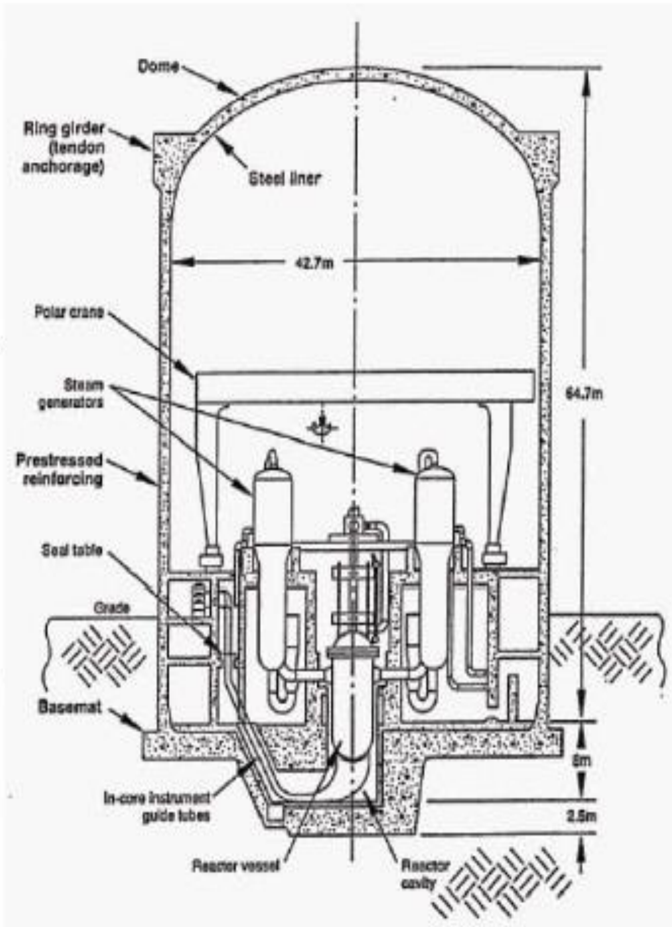
PWR Type of Containments, RPVs are on the ground



Subatmospheric



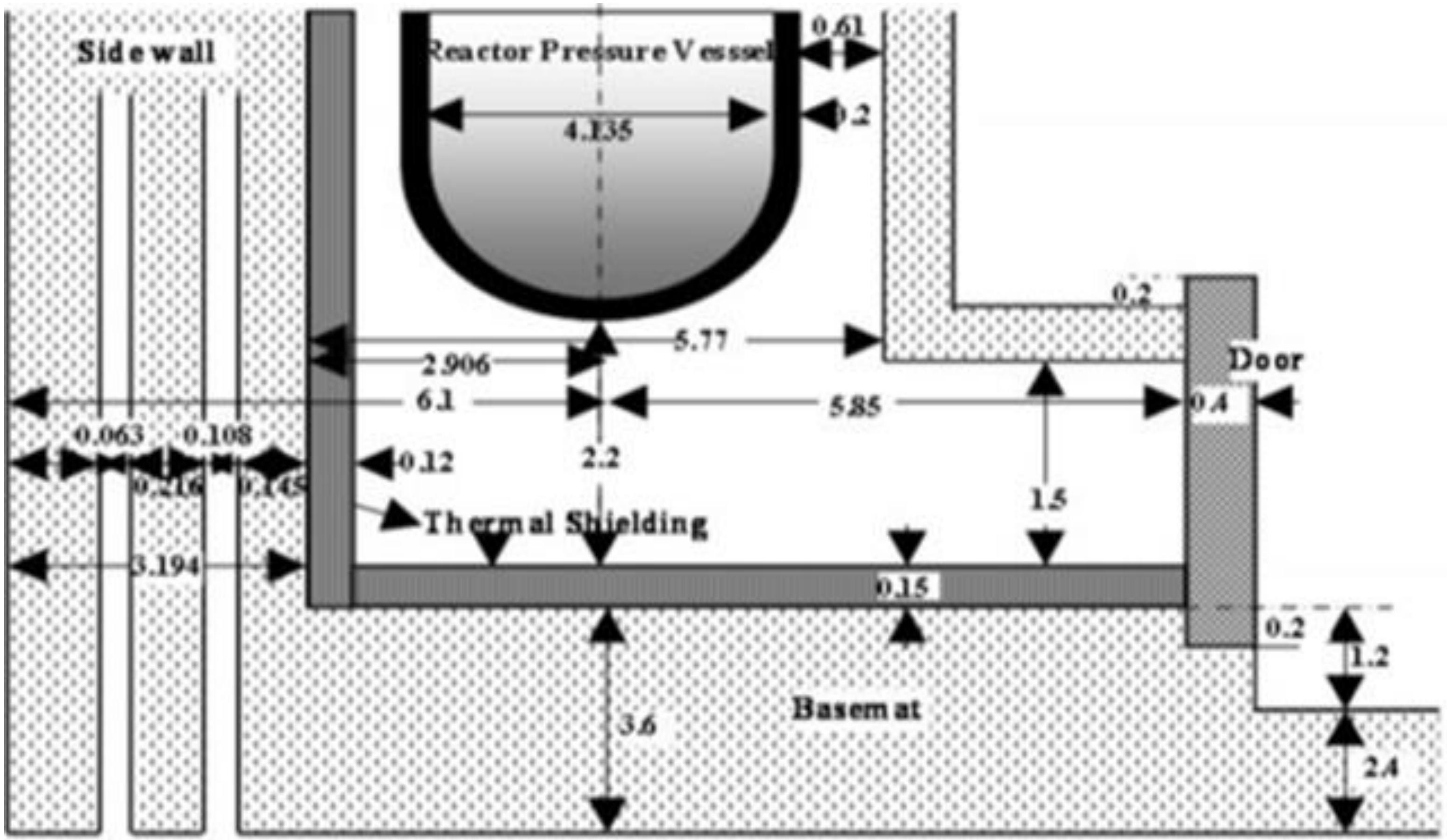
Ice Condenser



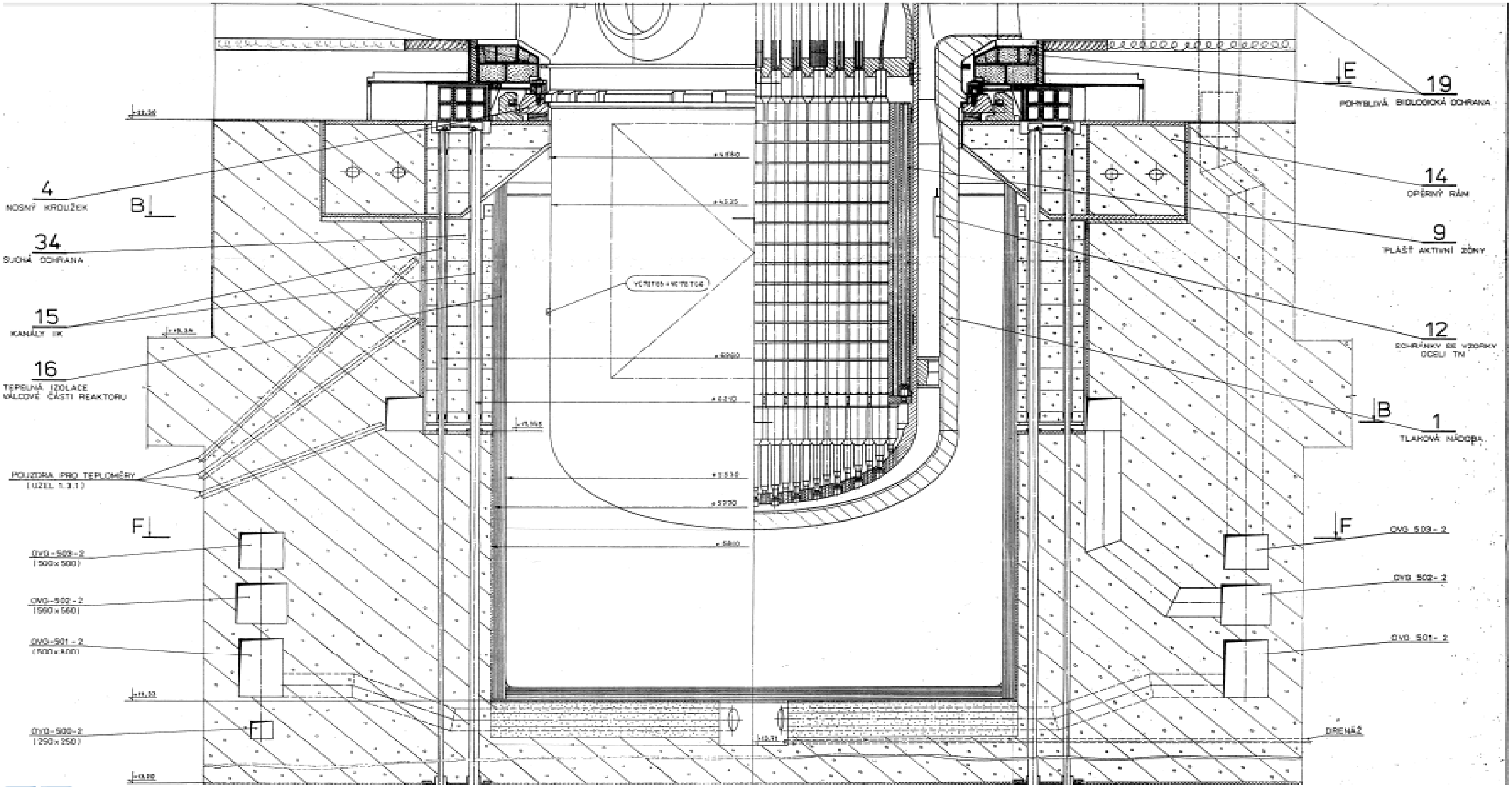
(Large, Dry)

Cavity VVER 1000

- Configuration details of the RPV cavity. Note the ionization channels and dimensions of the walls and cavity floor



Details on the VVER 1000/320 Cavity, Cooling and ionization channels



IVR Strategy Status and Needs

- Following part of presentation will describe:
- Calculation results by Kurchatov Institute for IVR
- Experimental work present and future
- Cooling strategy
- Deflector feasibility
- Cold spray (HVPC) feasibility

New INSAG Document Recommendations

- Containment boundary penetration by molten core needs to be prevented by stabilization the corium. Such stabilization is essential for reaching a safe and stable state.
- The choice of an appropriate strategy depends on many factors, in particular the reactor power, the reactor type, the size and shape of the reactor cavity, and the availability of water and injection system for flooding.
- If the in-vessel retention of the corium by external vessel cooling is chosen as the safety concept, an issue to be evaluated is a possibility of steam explosion when there is a risk of failure of the concept.
- In following presentation key issues with respect to the IVR strategy are discussed

Kurchatov Institute Calculations

- **Based on long term cooperation agreement with Kurchatov Institute, following slides provides latest calculation results to support the IVR strategy**

IVR Process Modeling for VVER-1000/V-320 Using SOCRAT and ASTEC Codes

- Russian SOCRAT V1 code: heat transfer to the water modeled as boundary condition, detailed modeling of the melt.
- West European ASTEC V2.0 rev2 code: model of 2-phase hydraulics for external cooling, simplified (point) simulation of melt structure.
- Uncertainty and Sensitivity studies: variation of code uncertain parameters (initial melt temperature, mass of the melt, melt composition, decay heat decrease due to FP release, etc..)

SCENARIO OF PRELIMINARY CALCULATION

The LB LOCA scenario - the earliest core degradation and melt transfer to the reactor vessel lower head (maximal decay heat power)

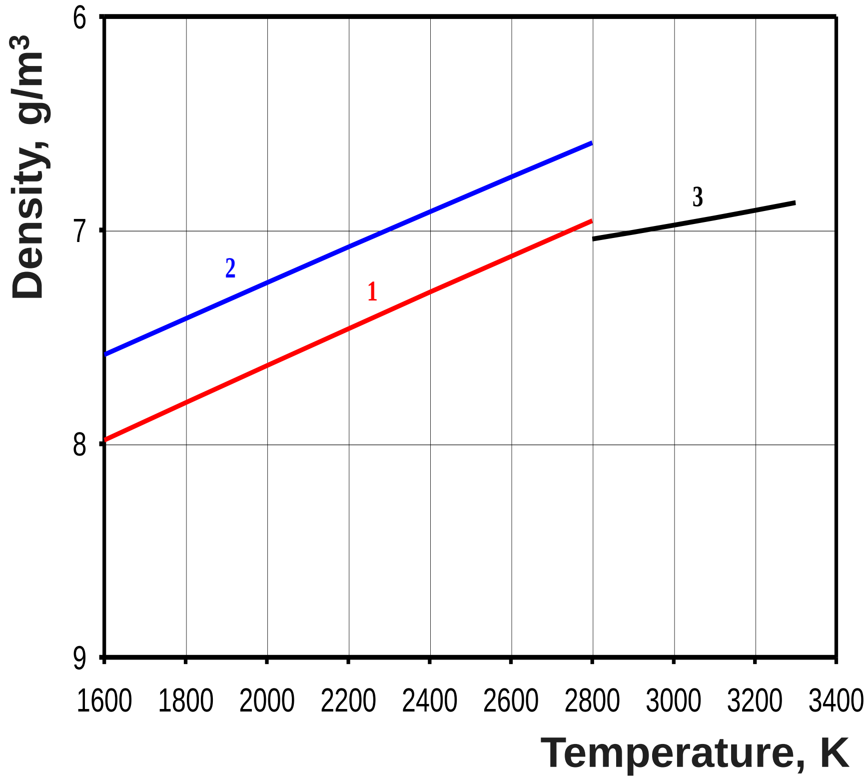
Break location:	**In the cold leg near the reactor inlet (2×850 mm)**
Power supplies:	**Simultaneous loss of the off-site power supply**
Water supply into the reactor vessel:	**From SITs only**
Measure on severe accident management:	**In-vessel melt retention (Flooding the reactor cavity and transferring the decay heat through the wall to external water. Cooling mode is a pool boiling)**

Expected Structure of the Molten Pool for VVER-1000 Reactor

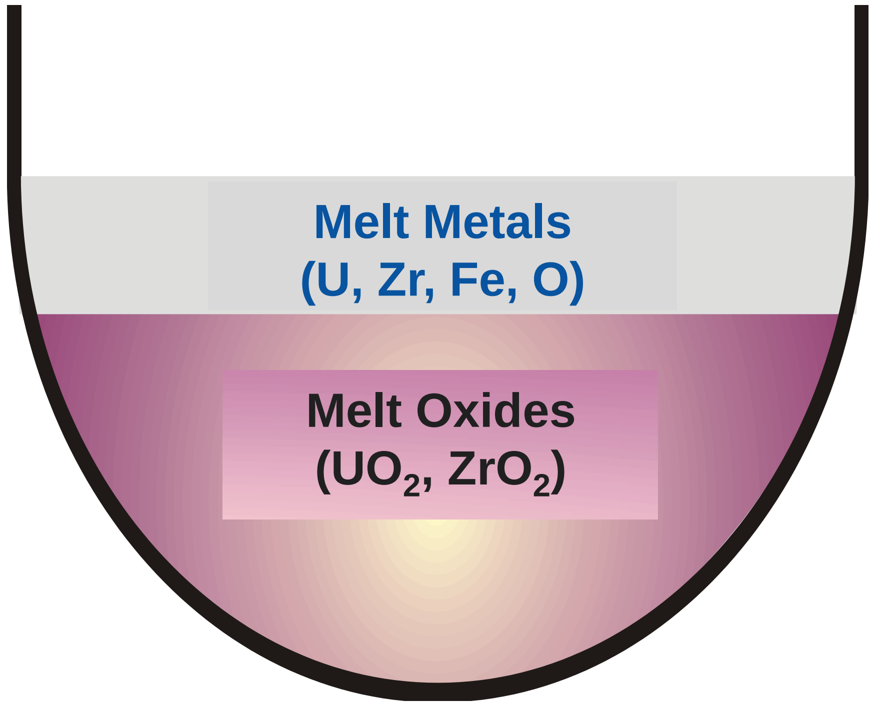
Dependence of density on temperature:

1 / 2 – Metal layer C-30 / C-70

3 – Oxide layer



Molten pool configuration
on the reactor vessel bottom
for VVER-1000



Assessment of the Molten Pool Characteristics

Core properties:

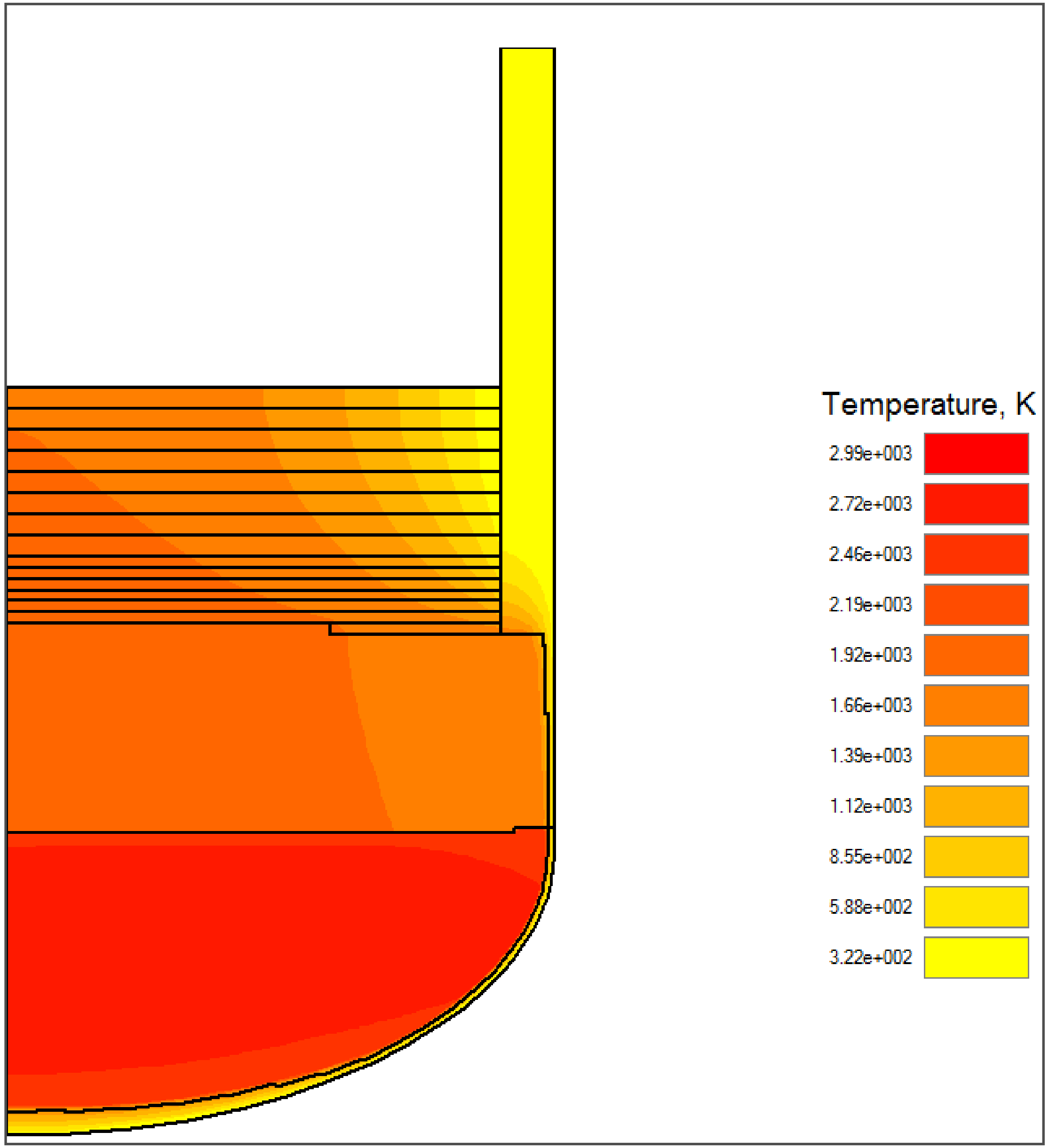
- Oxide layer density for temperature range 2700 - 2900 K.
  ρ = 7,04 g/cm^3
- Metal layer density for temperature range 2500 - 2800 K.
  ρ = 7,11 g/cm^3 for corium oxidation rate C-30
  ρ = 6,91 g/cm^3 for corium oxidation rate C-70

For inner diameter of the VVER-1000 reactor vessel about 4.2 m the height of each layers of the molten pool equals about 1 m.

Characteristics of the molten pool for VVER-1000

Corium oxidation rate	Mass of layer, t		Volume of layer, m^3		Height of layer, m	
	Oxide	Metal	Oxide	Metal	Oxide	Metal
C-30	85,26	110,19	12,11	15,50	0,96	1,23
C-70	111,13	87,19	16,08	12,62	1,28	1,00

RESULTS OF SOCRAT PRELIMINARY CALCULATION



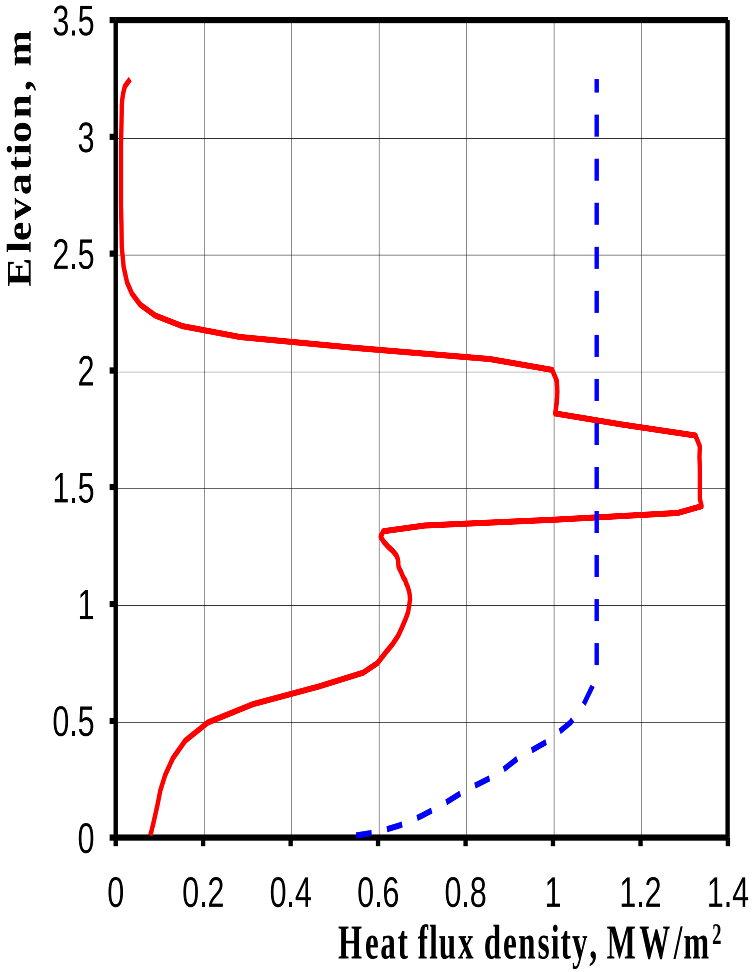
Temperature field in quasistationary state

SOCRAT and ASTEC PRELIMINARY CALCULATIONS

Heat flux distribution along the RPV height

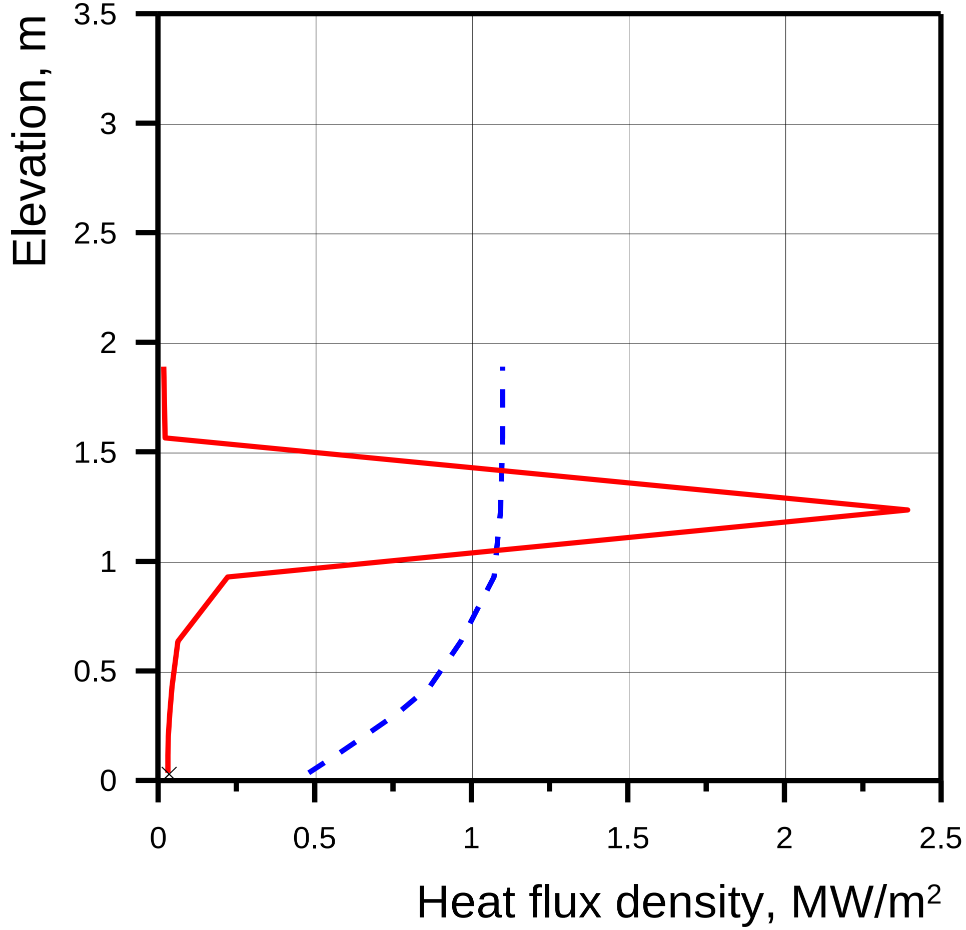
SOCRAT calculation results

Time = 9030 s



ASTEC calculation results

Time = 9728 s



LIST of SOCRAT VARIANT CALCULATIONS

Variants of the calculation	Supply of water into the vessel	Release of volatile fission products	Presence of deflector
Preliminary calculation	NO	NO	NO
Variant calculation #1	YES	NO	NO
Variant calculation #2	NO	YES	NO
Final calculation	YES	YES	YES

SOCRAT and ASTEC Preliminary and Final Calculations

Chronology of main events of simulated accident

Events /sec/	Preliminary simulation		Final simulation	
	SOCRAT	ASTEC	SOCRAT	ASTEC
SIT injection period	5,5-54	7-76	5,5-54	7-76
First cladding creep rupture	1050	1253	1380	1358
Beginning of oxidation in the core	1160	1214	1480	1315
First total core uncover	2290	3778	3020	-
First material slump in the lower plenum	3250	4278	3860	6812
Reactor vessel lower head failure	8900	9694	-	-
IVR success	-	-	+	+
The margin to heat transfer crisis	-	-	24 %	13 %

SENSITIVITY STUDY with SOCRAT CODE

Varying parameters

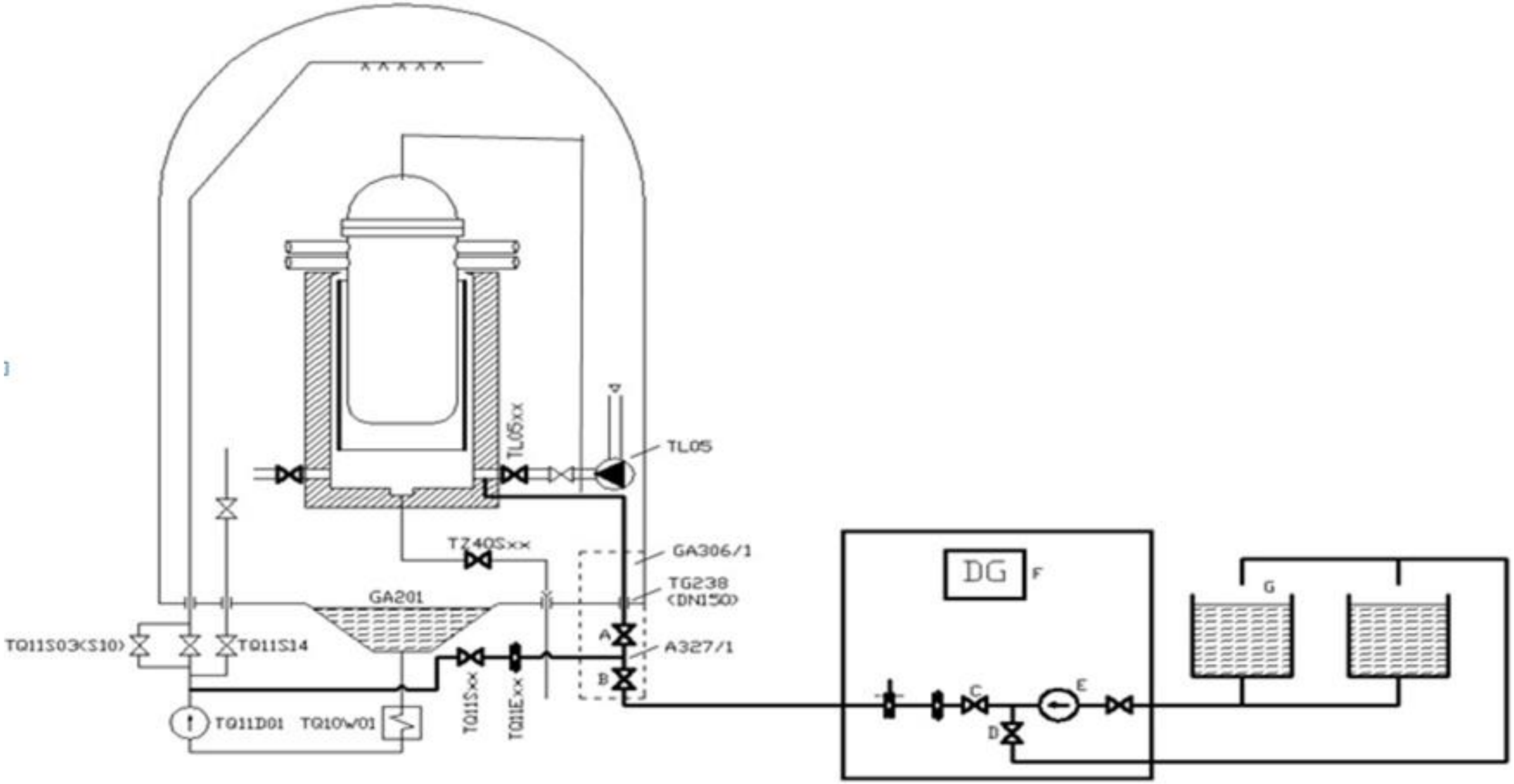
14 sensitivity study calculations were performed with variation of (for example):

- Corium oxidation degree
- Mass of steel in the molten pool
- Initial temperature of corium
- Degree of power reduction due to volatile fission products
- Heat transfer coefficient on upper surface of the molten pool
- Vessel steel heat conductivity
- Molten pool chemical composition
- Power distribution between molten pool layers
- Eutectic temperature of (Fe, U, Zr) – SS interaction

Summary of activities to support the IVR strategy applicability

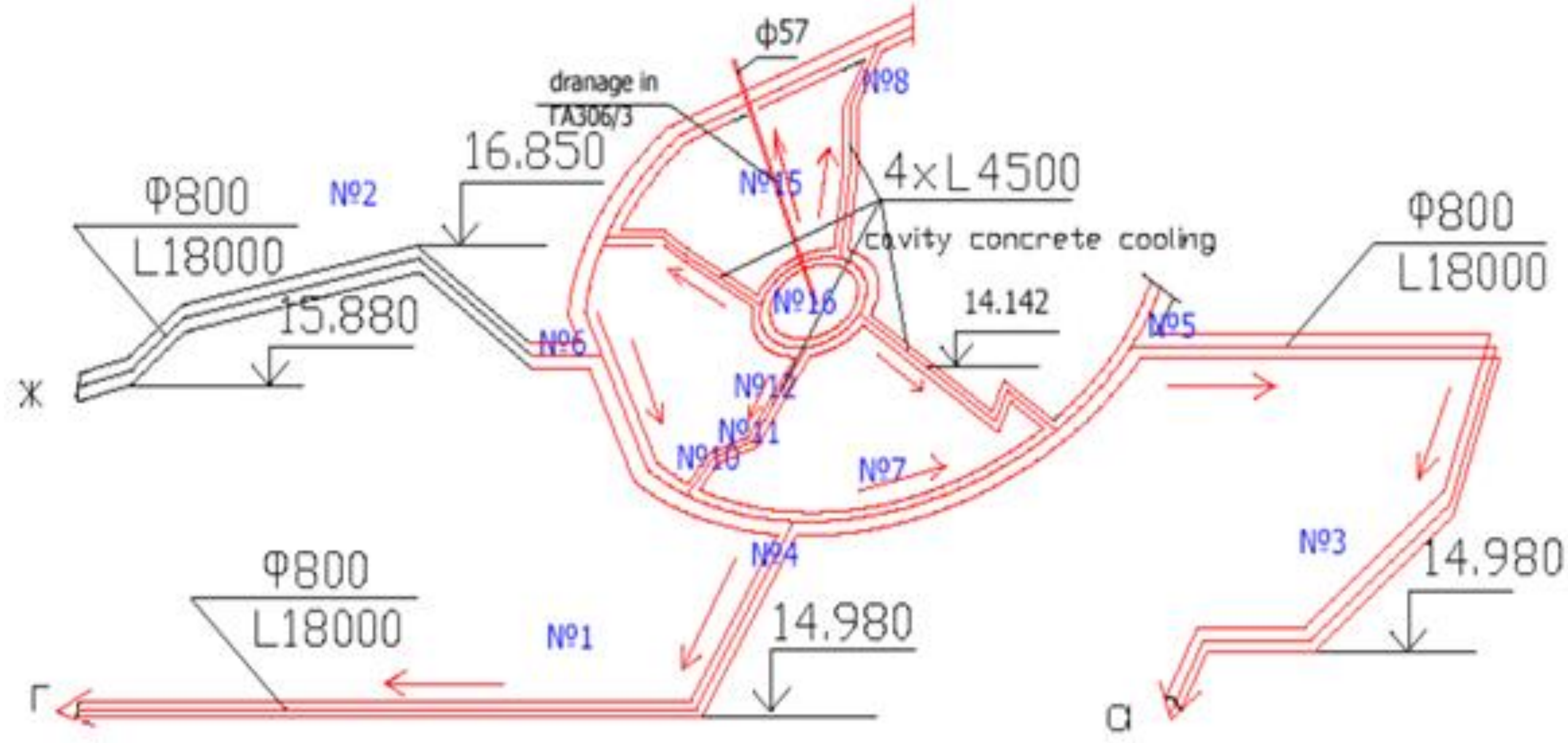
- Active and passive cooling possibilities
- Deflector feasibility study
- Experiments to support long term coolability

Active Cooling



Schematic view of the active cooling system

Cooling media intake through TL



Cavity air cooling channels available for cavity water intake under the RPV

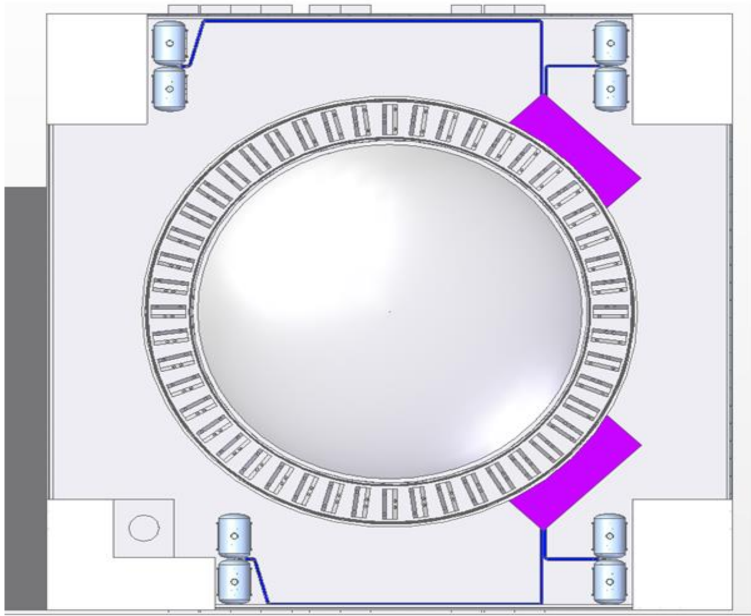
Parameters for Active Cooling

Active cooling system design parameters with storage tanks located outside containment

Number of boric acid tanks	2
Volume of boric acid	500 m^3 per tank
Time for initial flooding of the cavity	30 minutes
Time to saturate coolant in the cavity	3.5 hour
Initial cavity water supply (30 min)	~300 m^3/hour
Long-term water supply (12 hours min)	~50 m^3/hour
12 hours water supply can be extended as needed by enlarging capacity of tanks	
Long/term cavity evaporation rate	5-7 kg/s
Water supply to the reactor vessel	3-4 kg/s

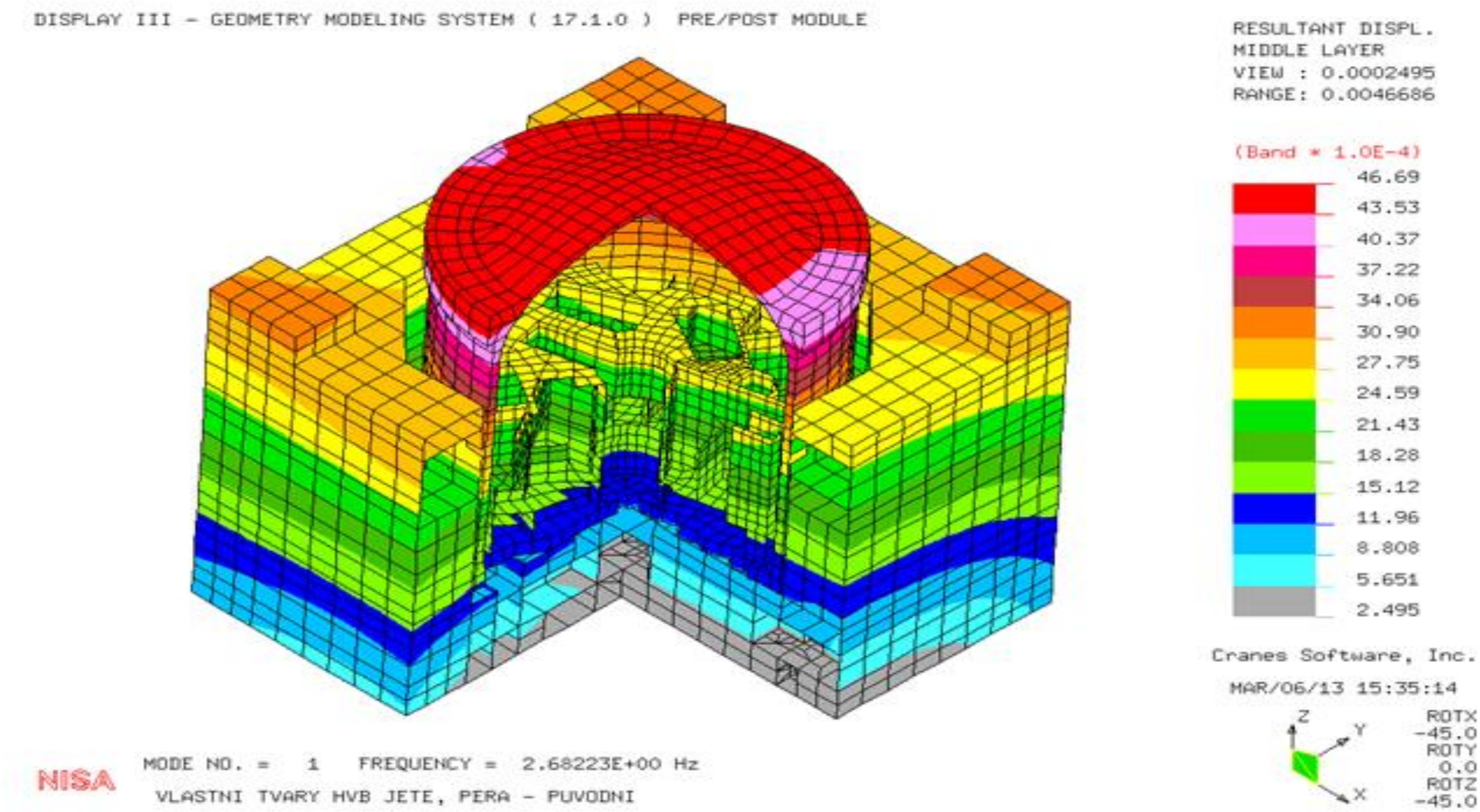
Passive Cooling Strategy

Photo of the containment surrounding building during the containment tendon maintenance

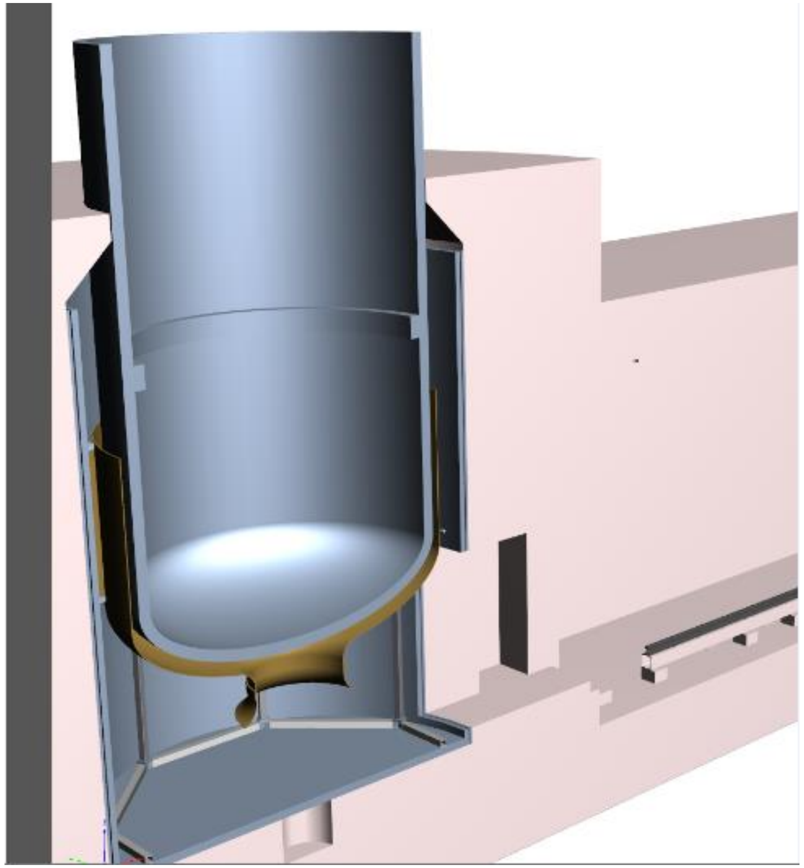


Storage tanks location as one of several design options

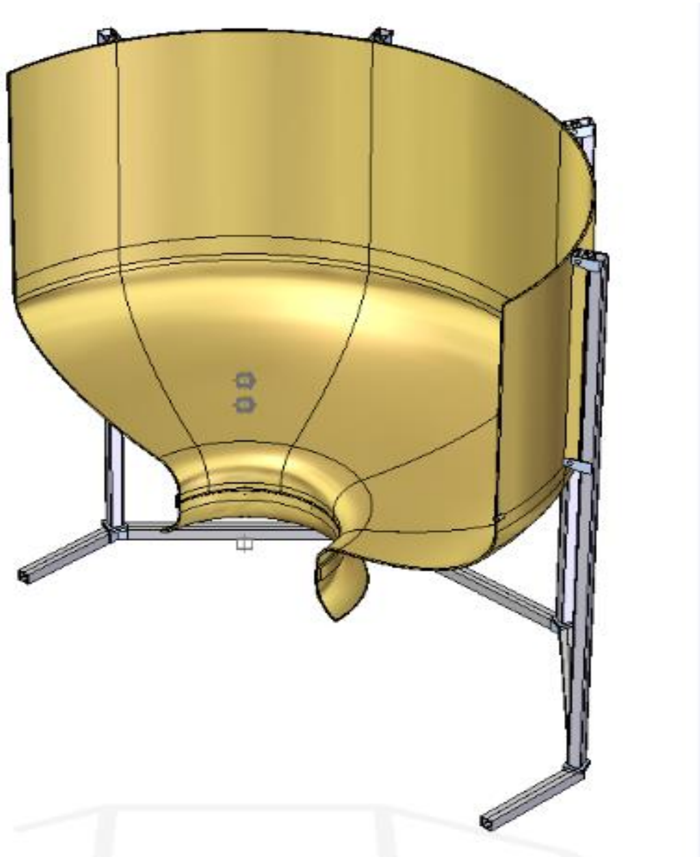
Calculation model to justify passive cooling tanks



Deflector Feasibility Study

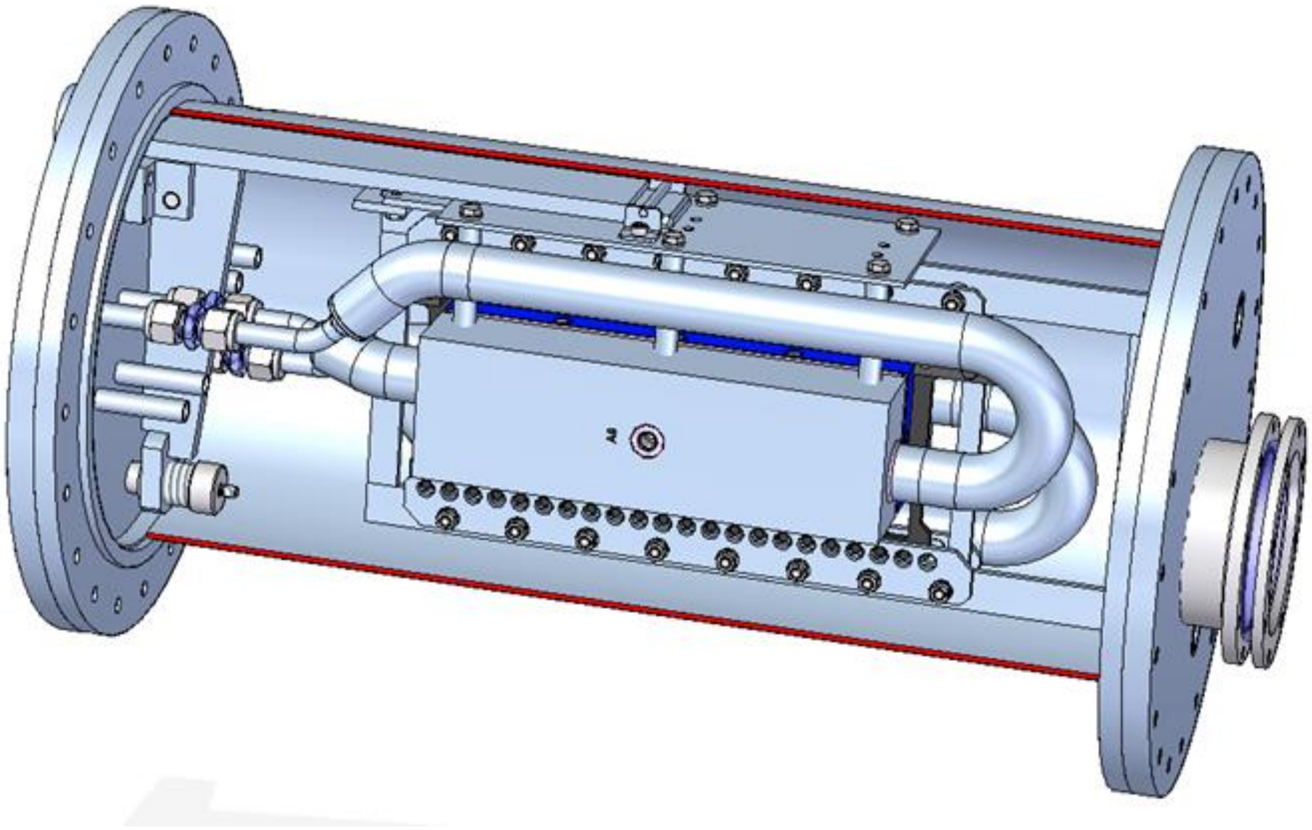


Deflector position under the RPV in the RPV cavity



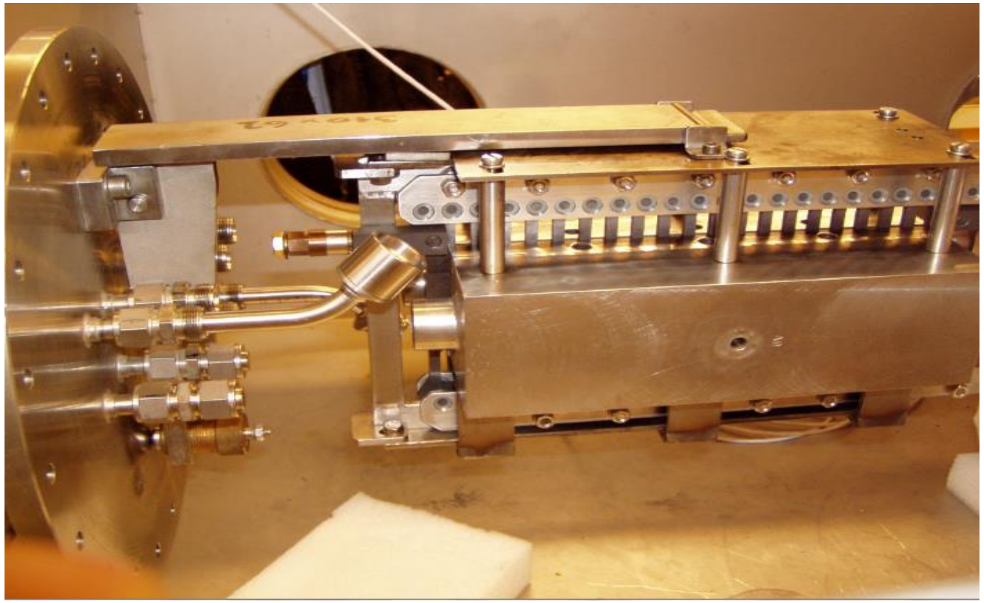
Detail view on deflector segments

Experiment BESTH 1

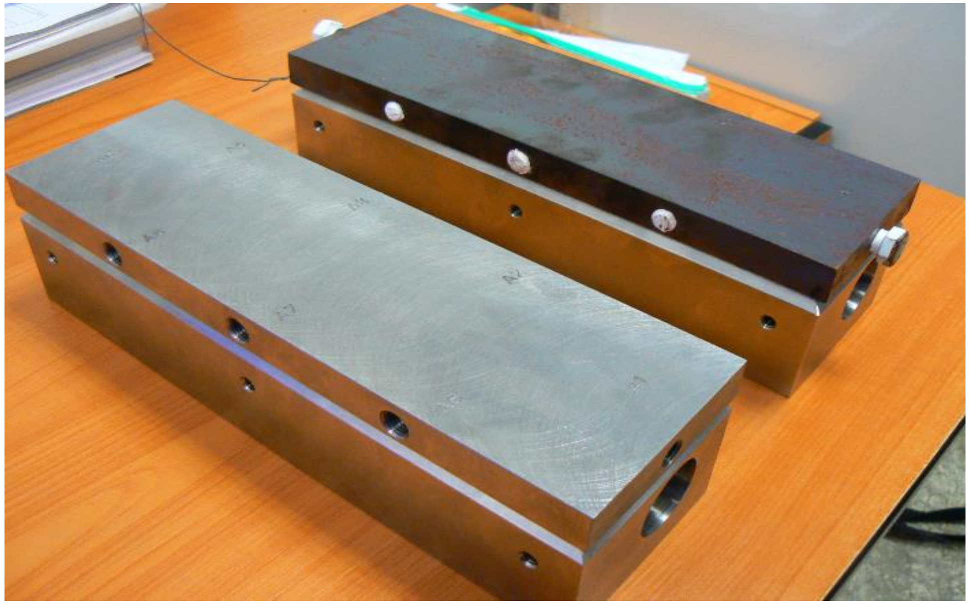


Experimental chamber

BESTH 1 Heater and Test samples



Detail photo with samples positions and heating element in the middle



Samples with clean and corroded surface

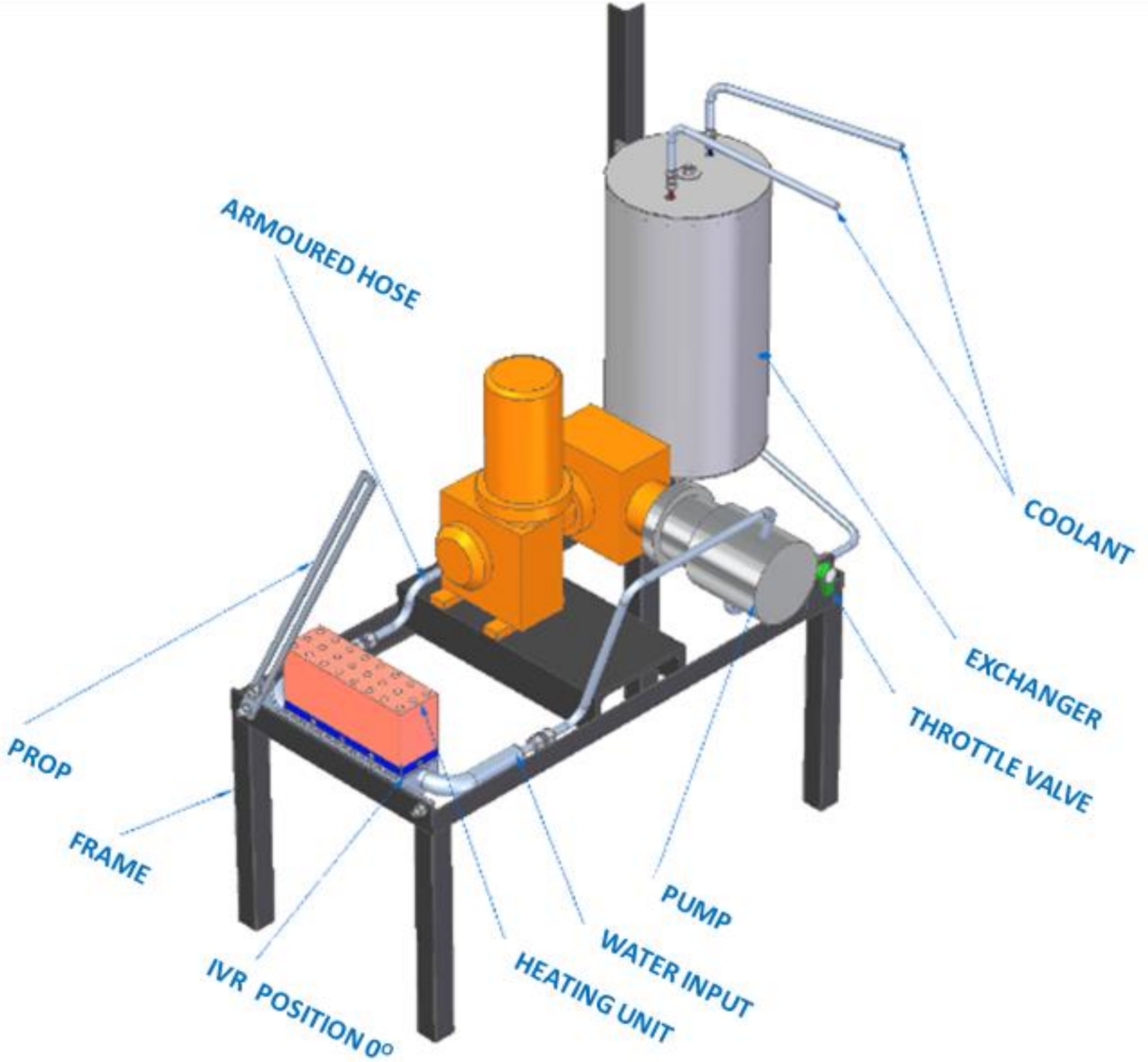
BESTH 1 Results

Summary of test results

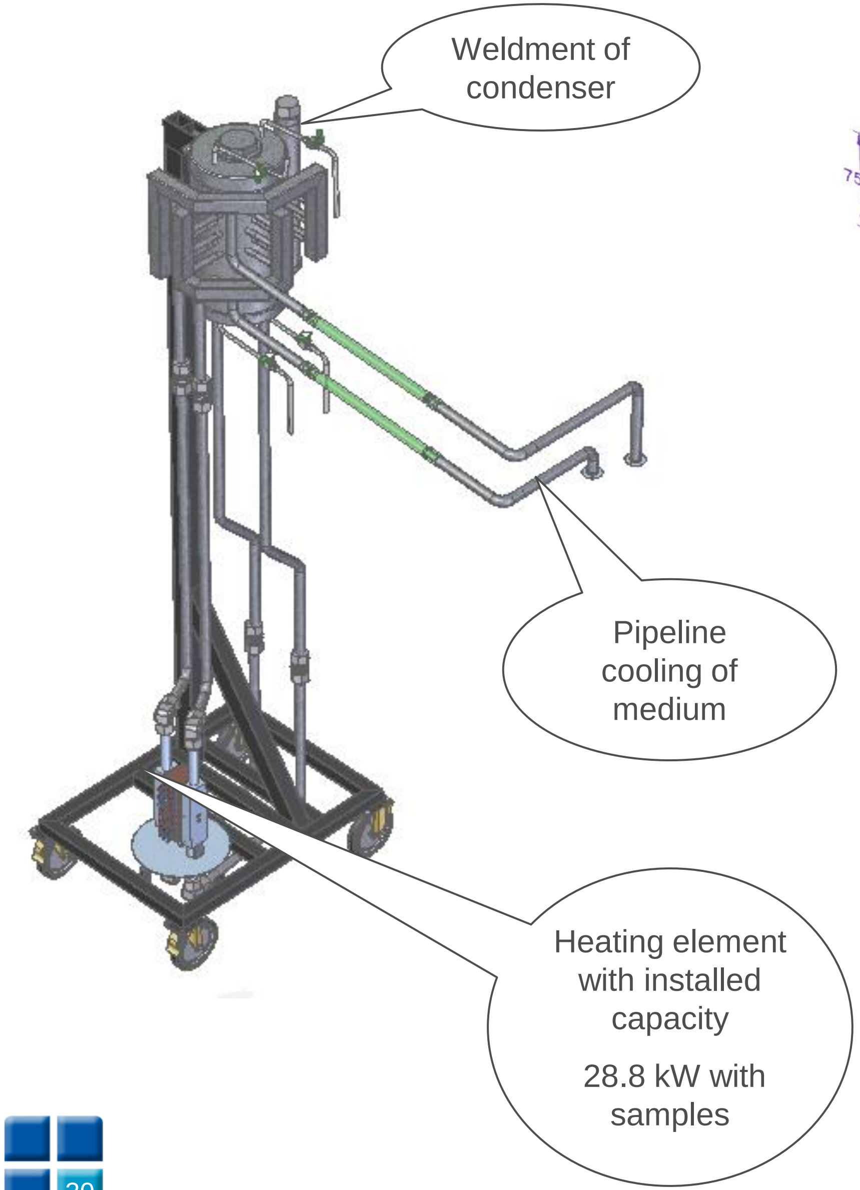
	Unit	1	2	3
Heating – electric power	kW	24,7	**27,5**	23,9
Heating – thermal power (95% of el. power)	kW	23,5	**26,13**	22,7
Max temperature measured – spec. A, corroded	^oC	335,6	**420,5**	386
Max temperature measured – spec. B, “clean”	^oC	349	**397,8**	358
Max temperature of coolant – spec. A	^oC	66,2	**68,2**	66,3
Max temperature of coolant – spec. B	^oC	65,3	**67,6**	65,8
Average pressure of cooling circuit	kPa	270,9	281	**312**
Duration of experiment	Min	**498**	290	150

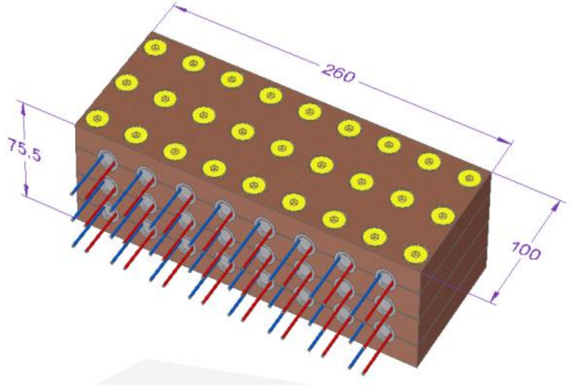
BESTH 2 Experiment with natural circulation

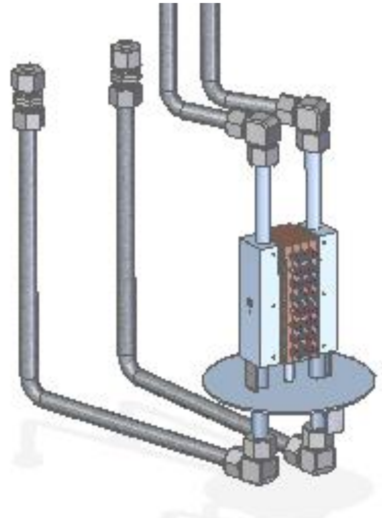
Principal view of the new facility



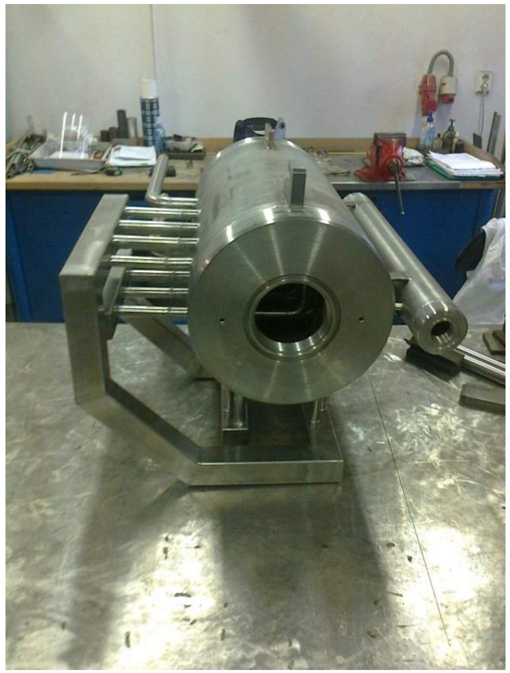
BESTH 2 Experiment







Weldment of condenser



Summary of Key Activities Needed(1)

1.Steam Generation and Steam Removal

1.1. Estimation of the steam generation

1.2. Steam condensation, volume and possible locations

1.3. Could we utilize existing cooling channels openings in the in different height of the cavity for the steam removal

1.4. To optimize the steam removal, deflector shape has to be optimized

1.5. The OKB proposal is to drill several holes with proposed diameter and height. Details should be matched with other possibilities

Summary of Key Activities Needed(2)

2.Cooling water storage tanks and piping

2.1. Tanks outside containment

2.2. Use of existing cavity GA xxx for the RPV Internals

2.3. Tanks located on the roof at 43 m around containment

2.4. Assessment of best configuration or combination of all above options including DG, Pumps and Piping needed

Summary of Key Activities Needed(3)

3. Deflector

3.1. Deflector profile optimization for the steam removal

3.2. Connection on cavity floor intake

3.3. Deflector position with respect to the NDE manipulator

3.4. Deflector manufacturing, transportation, vibration resistance

3.5. Deflector removal and storage

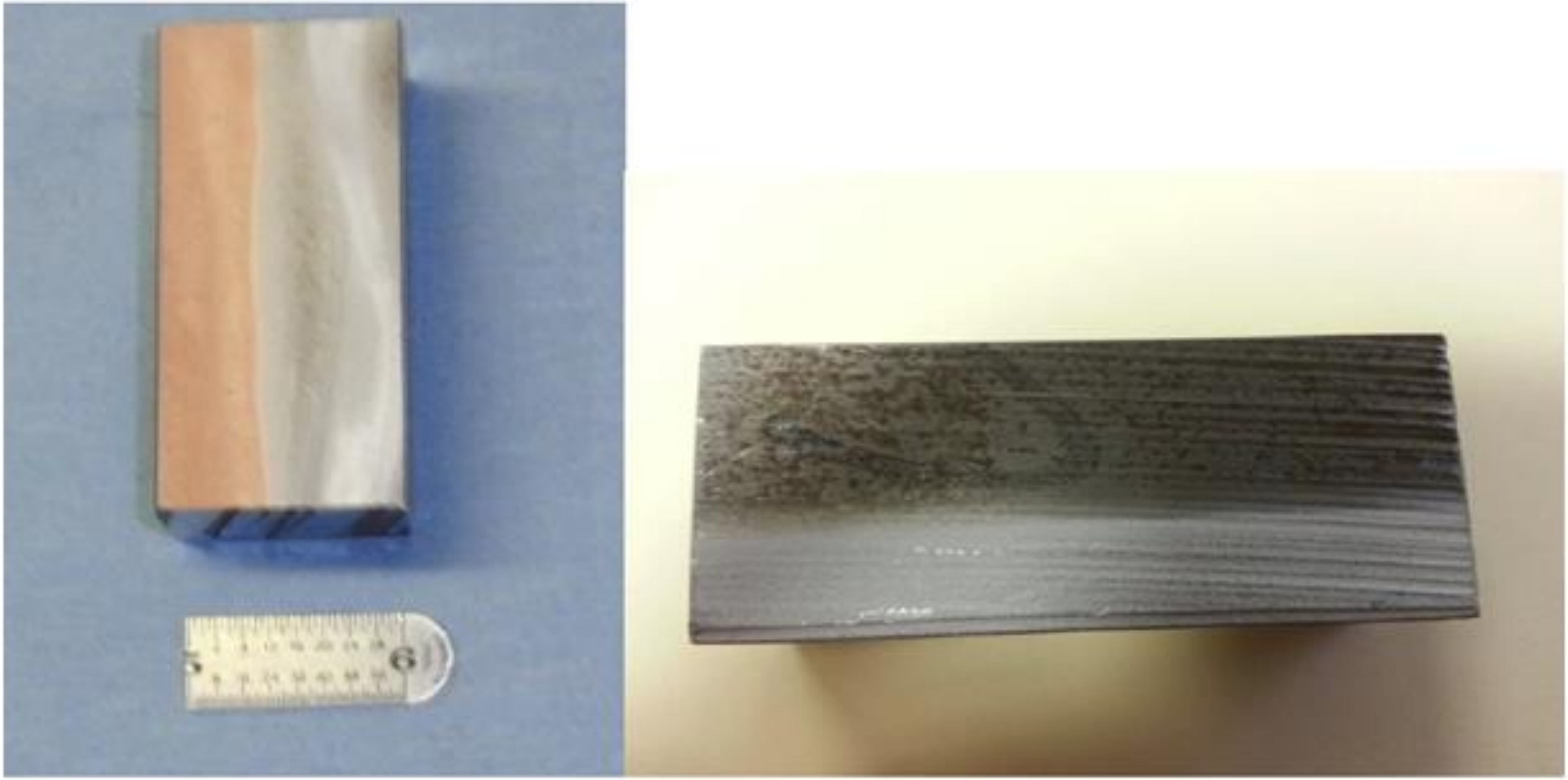
3.6. Assessment of dose rates under the RPV

3.7. Based on above, decision on manipulator need and function

Summary of Key Activities Needed(4)

- Cold spray (HVPC)
- At present first feasibility study started on possible application of High Velocity Particle Coating „ cold spray“ technology with final goal to significantly improve the heat transfer from the RPV surface to the cooling media.
- The HVPC technology if proved, could significantly increase the margin to the CHF value and further justify the IVR strategy for VVER 1000/320 units
- Possibility to use manipulator for coating under investigation

First successful HVPC cooper(left) and aluminum(right) coatings on the RPV samples



Project Milestones „IVR Feasibility“

1. Results from KI analytical calculations. Technical report received, internal assessment: 10/2013
2. International „Benchmark calculation“ by SA Codes with agreed input data
   start : 11/2013, finished: 11/2014
3. Experiments on BESTH facility on samples without „cold spray“ to identify CHF: 4/2014
4. Experiments on BESTH facility on samples with „cold spray“ to increase the CHF: 6/2014
5. Meeting with AEP Moscow: 12/2013

Many thanks

- Many thanks to all participants
- Questions are welcome