Effect of passive safety systems on typical beyond-design accidents for WWER-1000/V-392 reactor plant

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Introduction (1/2)

The Russian regulatory documents for nuclear power plant safety (OPB-88/97) contain the requirement on the necessity of the beyond-design-basis accidents (BDBA) consideration as the events and scenarios participating in the formation of the relevant safety systems design basis.

In particular, the list of such accidents have to be composed, the acceptance criteria are to be formulated and the realistic analysis of BDBAs have to be made.

Introduction (2/2)

The designer should tend to the estimated probability of the limiting radioactivity release less than 10^{-7} per reactor-year, and the estimated probability of severe core damage derived on the PSA basis should not exceed 10^{-5} per reactor-year.

Main characteristics of power unit

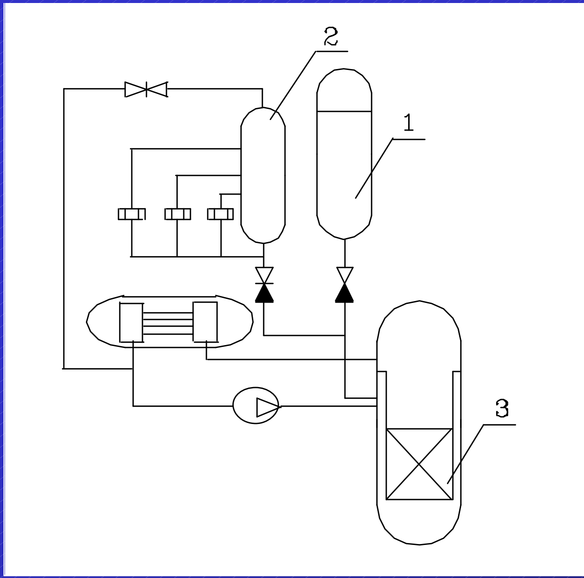
Core rated power	3000 MW
Coolant pressure at core outlet	15,7 MPa
Coolant flow rate through reactor	86000 m^3/h
Steam pressure at steam generator outlet	6,27 MPa

Examples advancements in the safety increasing area are as follows:

- advanced reactor WWER-1000;
- passive system of residual heat removal (SPOT);
- passive system for core flooding under loss-of-coolant accidents (HA-2);
- passive system of quick boron supply to reactor;
- primary coolant pump preventing coolant leak under long-term station blackout.

Brief description of new passive systems (HA-2)

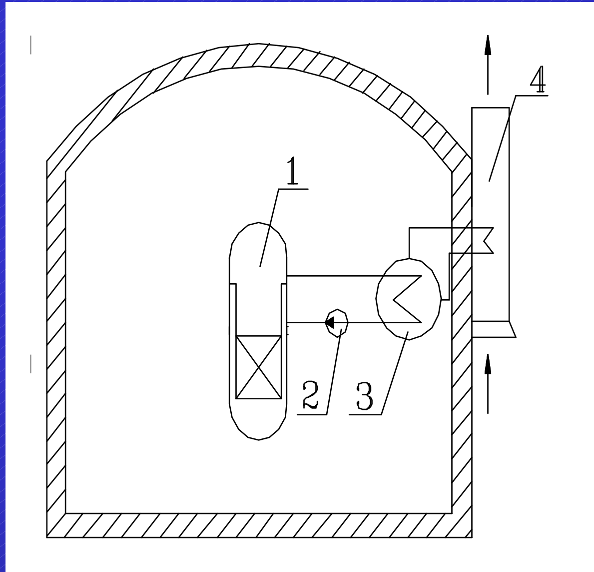
The HA-2 system (JNG50-80) is intended to supply the boron solution to reactor with the purpose of long term (up to 24 h) cooling of the fuel during LOCAs of different size with active ECCS failure. The HA-2 system consists of four groups (four channels) of the tanks with 16 g/kg boron solution being under atmospheric pressure.



1 - ECCS hydroaccumulator (HA-1)
2 - HA-2 tank (2 pcs.)
3 - reactor

Brief description of new passive systems (SPOT)

The passive heat removal system (JNB50-80) is intended for the long term residual heat removal under condition with complete loss of feedwater supply to SG in case of intact primary circuit. This system can also facilitate to the residual heat removal under certain scenarios of a loss of coolant accident.



1 - reactor; 2 - MCP;
3 - steam generator;
4 - air heat exchanger

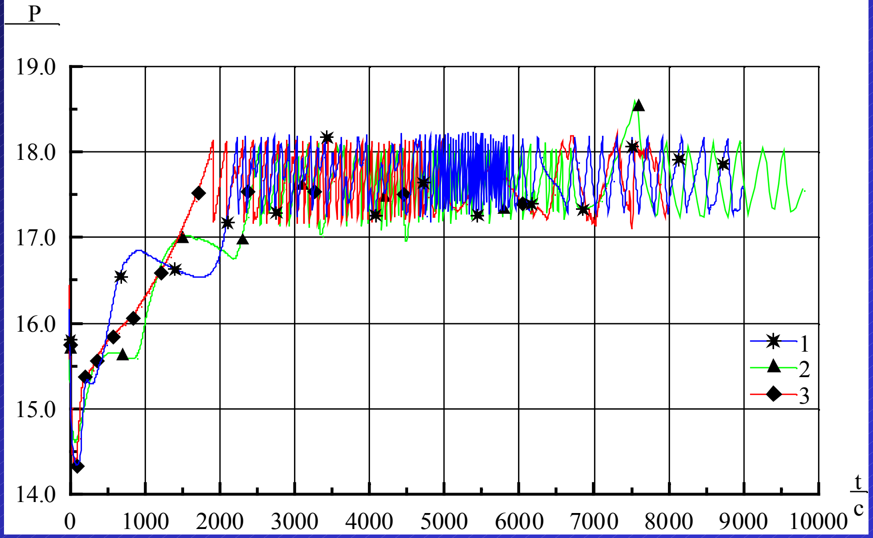
Beyond-design accidents without new passive systems

The following typical beyond-design accidents that essentially determine the design basis of the above passive systems are considered in this paper:

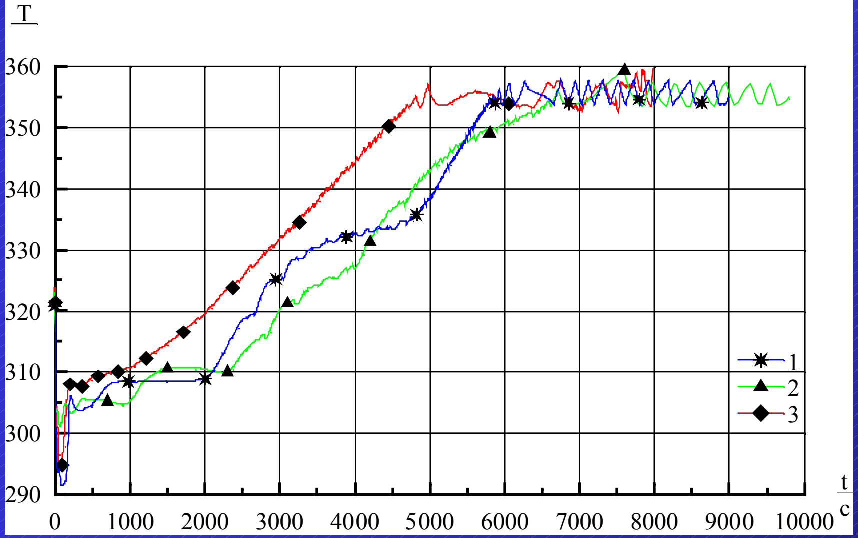
- station blackout with intact primary circuit;
- LB LOCA (double-ended cold leg break 850 mm diameter) with 24 h station blackout.

The “best estimate” approach is used when performing the calculations.

Station blackout (1/3)



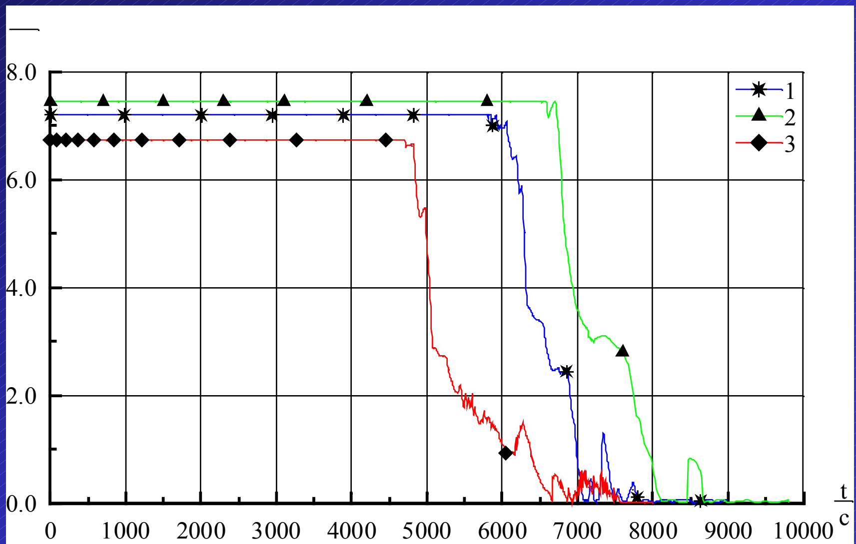
Pressure at the core outlet



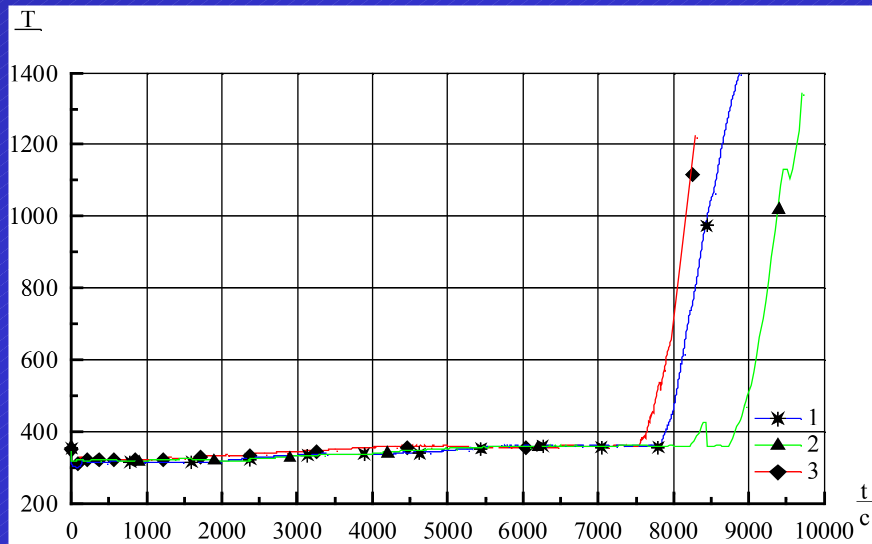
Coolant temperature at the reactor outlet

1 – ATHLET 1.2A; 2 – RELAP5/MOD3.2; 3 – DINAMIKA-97

Station blackout (2/3)



Collapsed level in upper plenum



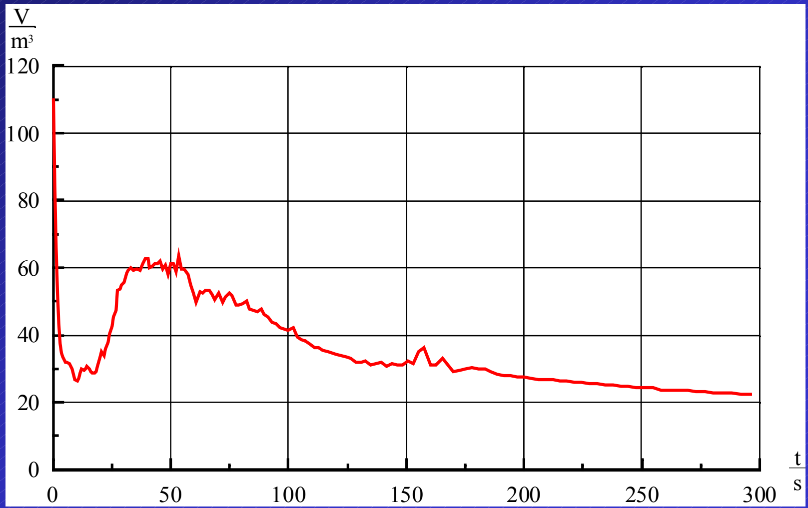
Maximum temperature of fuel rod claddings

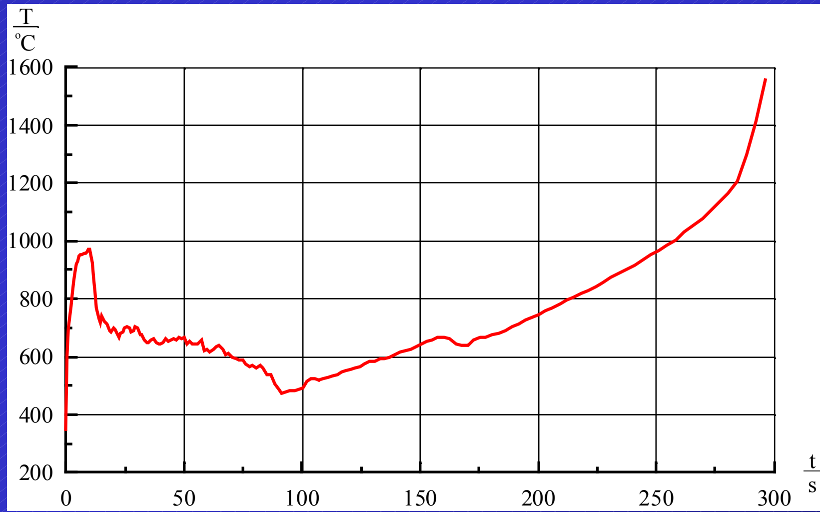
1 – ATHLET 1.2A; 2 – RELAP5/MOD3.2; 3 – DINAMIKA-97

Station blackout (3/3)

Event	Time, s		
	DINAMIKA-97	RELAP5/ MOD3.2	ATHLET 1.2A
Beginning of the PRZ SV operation	1920	2550	2240
Steam generators emptying	7500	6400	6200
Beginning of the upper plenum boiling	4830	6600	5900
Termination of the natural circulation	6000	7200	6600
The maximum cladding temperature reached 1200 °C	8280	9500	8680

Main coolant pipeline break at reactor inlet (2x100% CL LOCA) with station blackout *(1/2)*



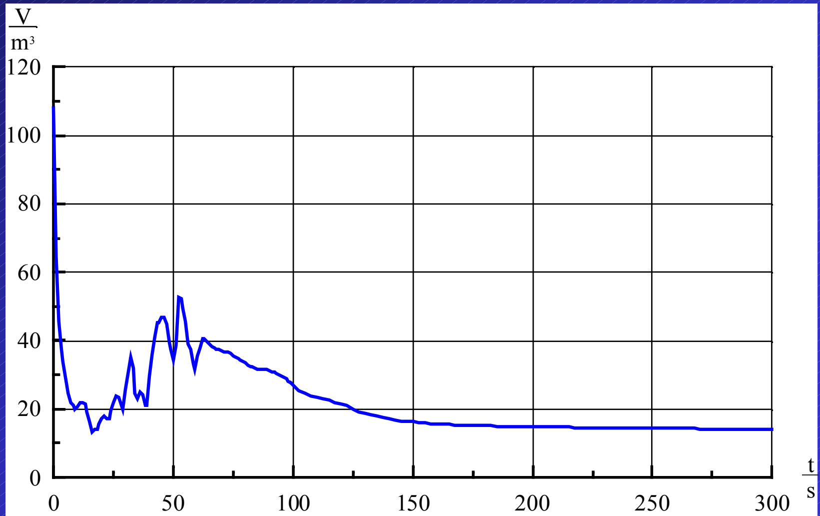


Water inventory in the reactor

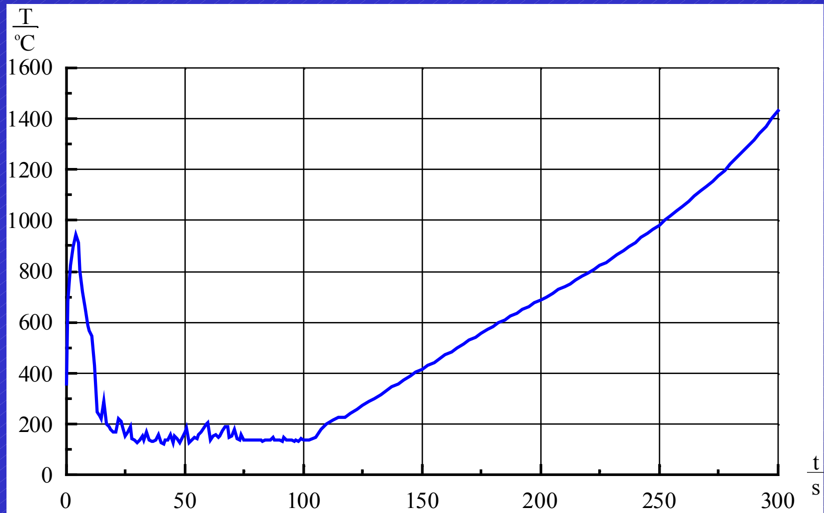
Maximum temperature of fuel rod claddings

TECH-M-97 code (without HA-2 and SPOT)

Main coolant pipeline break at reactor inlet (2x100% CL LOCA) with station blackout *(2/2)*



Water inventory in the reactor



Maximum temperature of fuel rod claddings

RELAP5/MOD3.2 code (without HA-2 and SPOT)

Beyond-design accidents with new passive systems

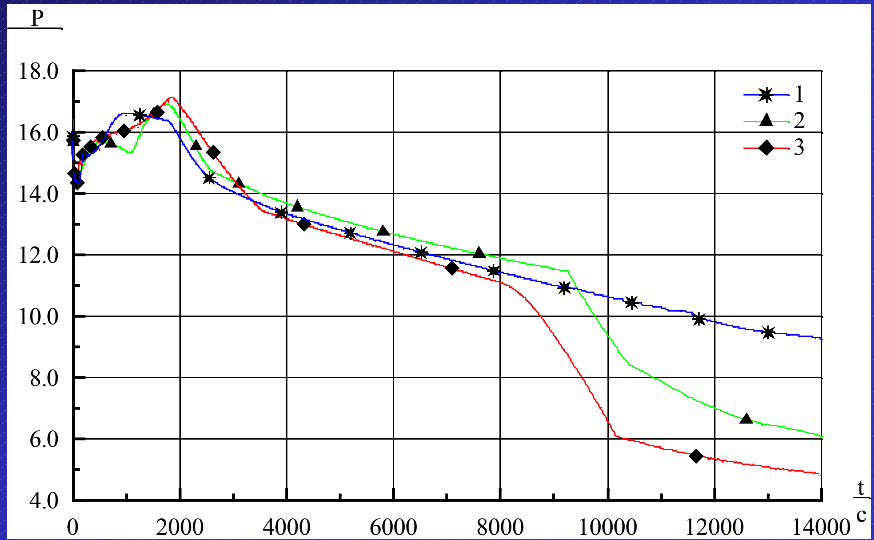
The results of the typical BDBA considered above indicate the necessity to provide for additional engineered features, intended to prevent the progression of a BDBA into severe accident.

In the present chapter, the calculation results of the same typical BDBAs, but with new passive systems (HA-2, SPOT) operation are shown. It was assumed that all four channels of this systems in operation.

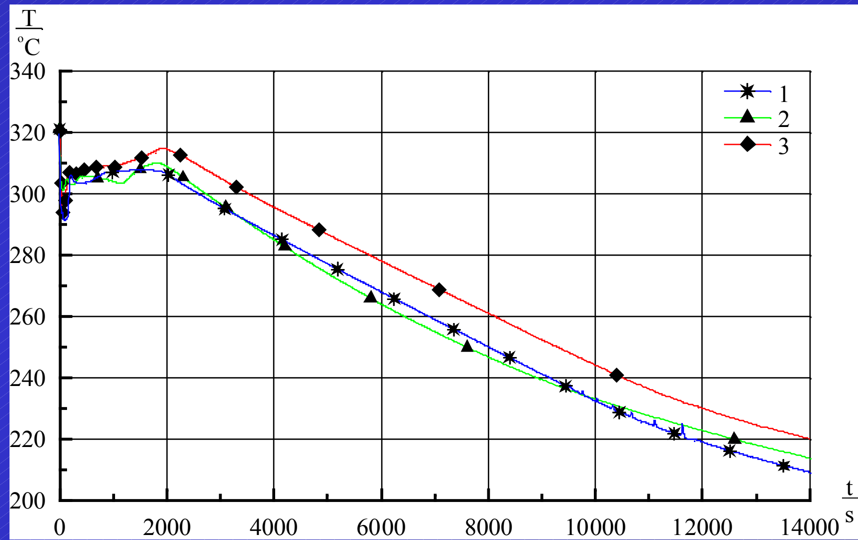
SPOT during the first period works in the control mode, and after 1800 s is switched over by operator to cooldown mode.

The optimized (taking into account the pre-determined containment pressure change) dependence of the water flowrate from HA-2 was used in calculation.

Station blackout (1/2)



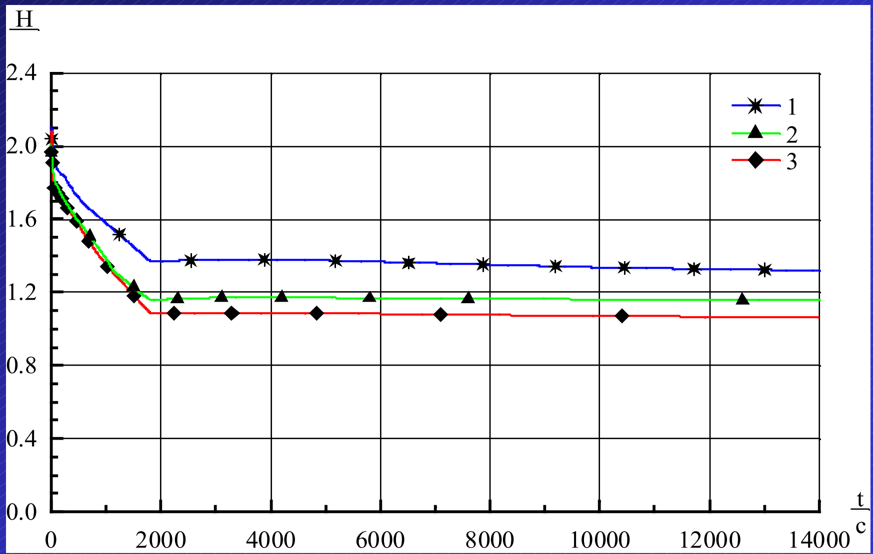
Pressure at the core outlet



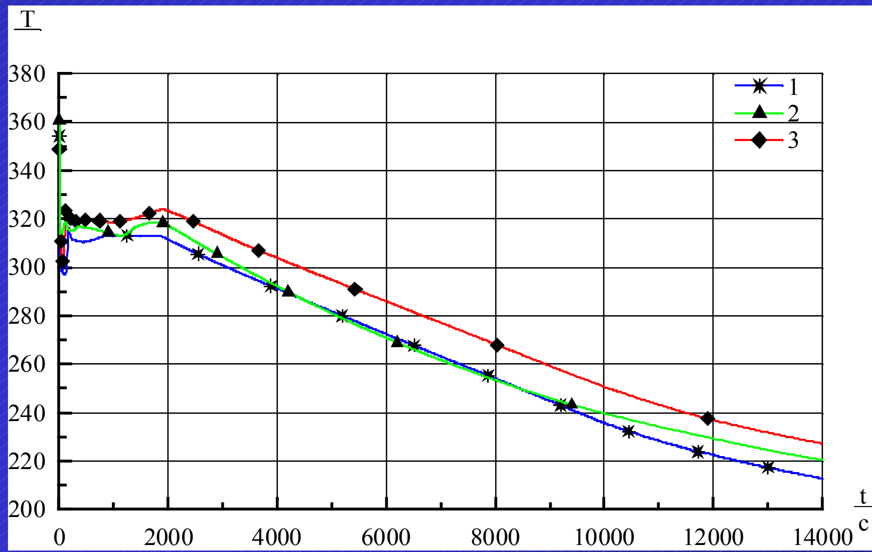
Coolant temperature at the reactor outlet

1 – ATHLET 1.2A; 2 – RELAP5/MOD3.2; 3 – DINAMIKA-97

Station blackout (2/2)



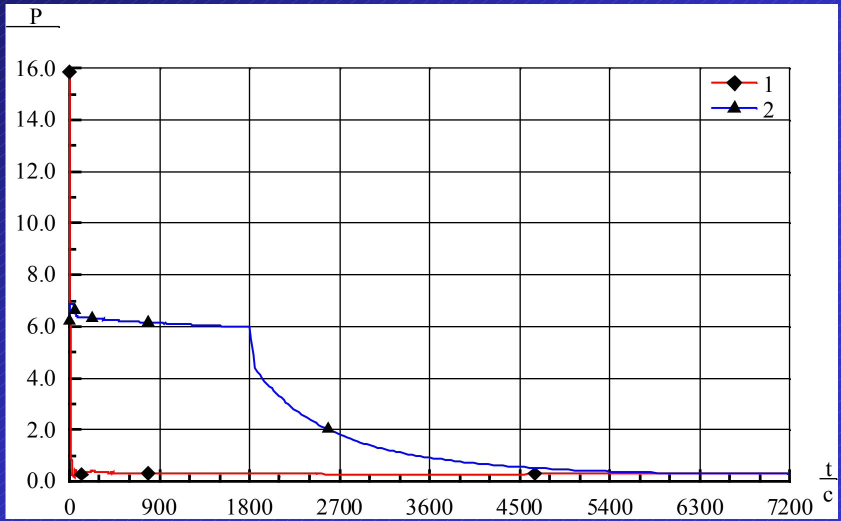
Collapsed level in SG

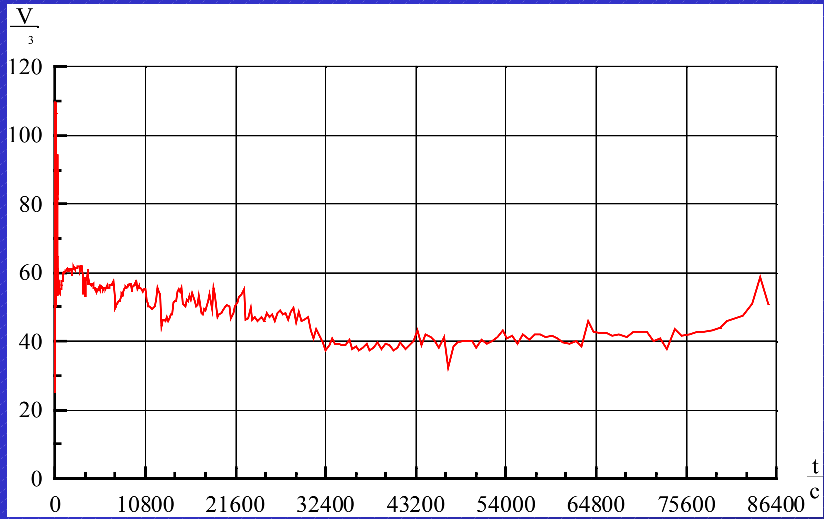


Maximum temperature of fuel rod claddings

1 – ATHLET 1.2A; 2 – RELAP5/MOD3.2; 3 – ДИНАМИКА-97

Main coolant pipeline break at reactor inlet (2x100% CL LOCA) with station blackout *(1/3)*



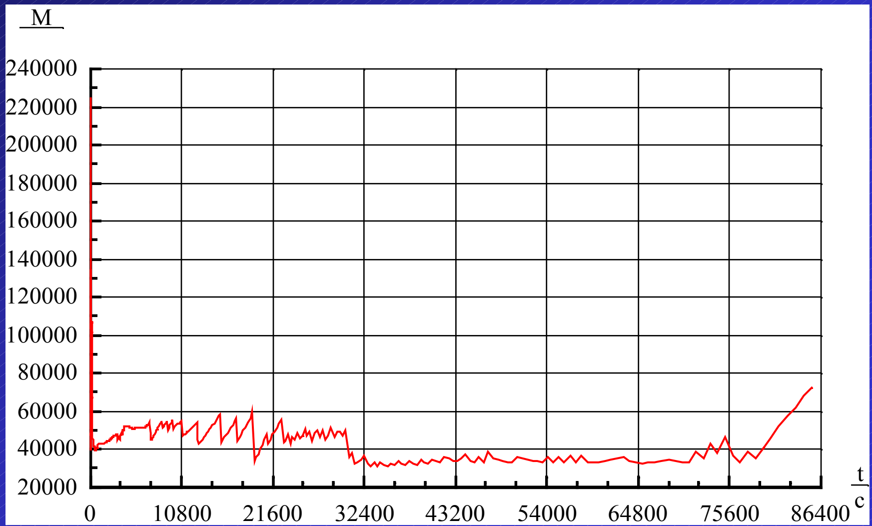


1 – pressure at the core outlet
2 – pressure in SG

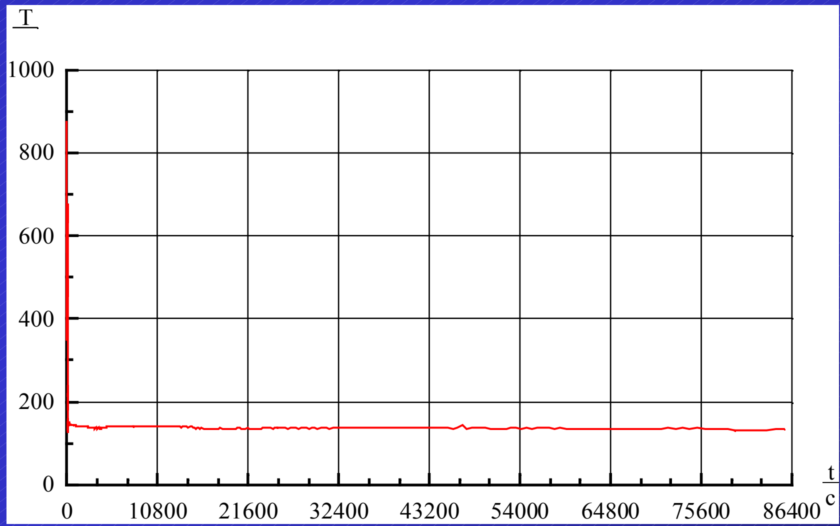
Water inventory in the reactor

TECH-M-97 code (with HA-2 and SPOT)

Main coolant pipeline break at reactor inlet (2x100% CL LOCA) with station blackout *(2/3)*



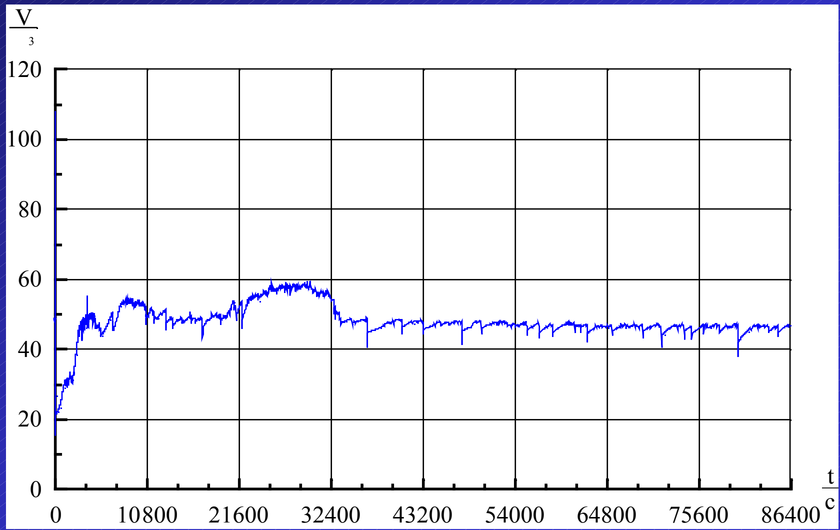
Mass of the primary coolant



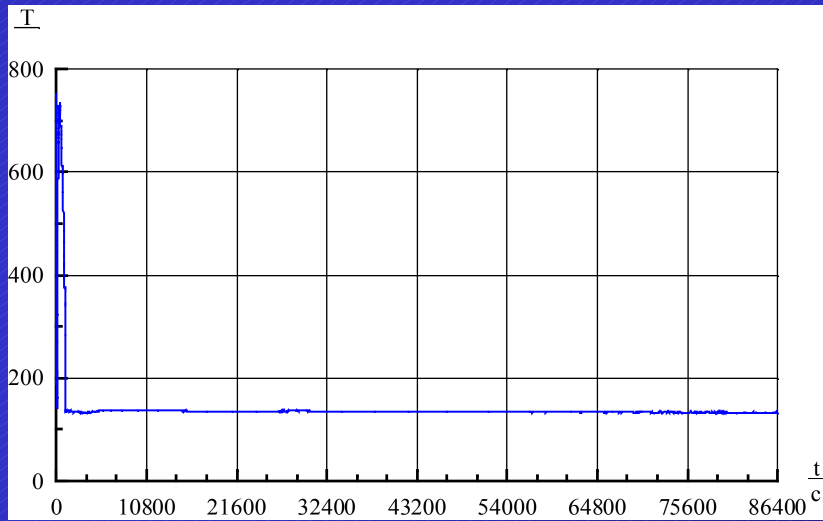
Maximum temperature of fuel rod claddings

TECH-M-97 code (with HA-2 and SPOT)

Main coolant pipeline break at reactor inlet (2x100% CL LOCA) with station blackout *(3/3)*



Water inventory in the reactor



Maximum temperature of fuel rod claddings

RELAP5/MOD3.2 code (with HA-2 and SPOT)

Conclusion

Operation of the new passive systems (SPOT and HA-2) in considered beyond-design accidents provides a possibility of effective cooling of the core during required 24 hours of accident. This ensures the essentially decreased probability of severe core degradation.