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The severe accident management of the high-power SFR with loss of the heat removal from the core

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Introduction

Studies shows

- the difficulty of predicting the place, time and energy of earthquakes, satisfying both the requirements of accuracy and reliability
- impossibility of forecasting, as evidenced by the occurred catastrophic earthquakes
- an increase in the number of earthquakes - in the twentieth century there were 2000 with a rate of magnitude more than 7, in 65 of them it was higher than magnitude 8

The Fukushima NPP (Japan) accident has shown, the design of the power unit should consider the unforeseen excess of the intensity of external influence

Earthquake in Van (Turkey), 2011

Natural safety characteristics of fast reactors

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Sodium fast reactors properties

- Low corrosiveness of sodium and insignificant mechanical stress on the reactor vessel, allowing a short-term (tens of hours) increase in the temperature of the vessel
    - safe operation limit – 600°C
    - the limit of leakage and possible release of radionuclides – 800°C

- Huge heat capacity of the integral primary circuit, allowing for a long time to provide normal radiation and other conditions for the operating personnel actions in the management of severe accident. For the BN-1200 reactor, for example, this is at least 3 hours.

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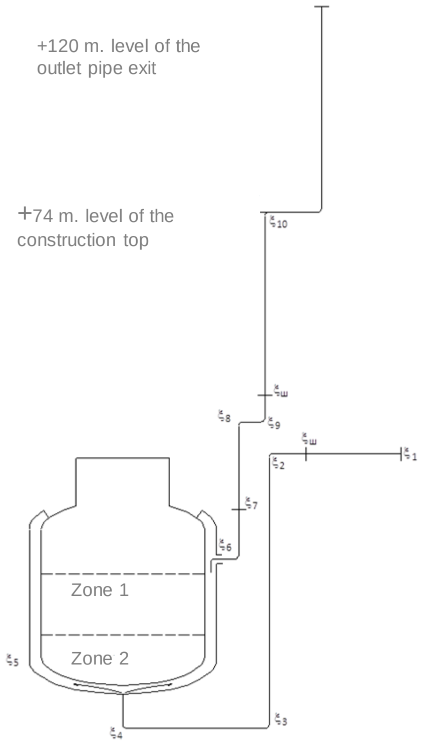
Method for managing severe accident

Heat removal from the reactor vessel due to air **doesn't ensure** that the reactor vessel operation safety limit is not exceeded

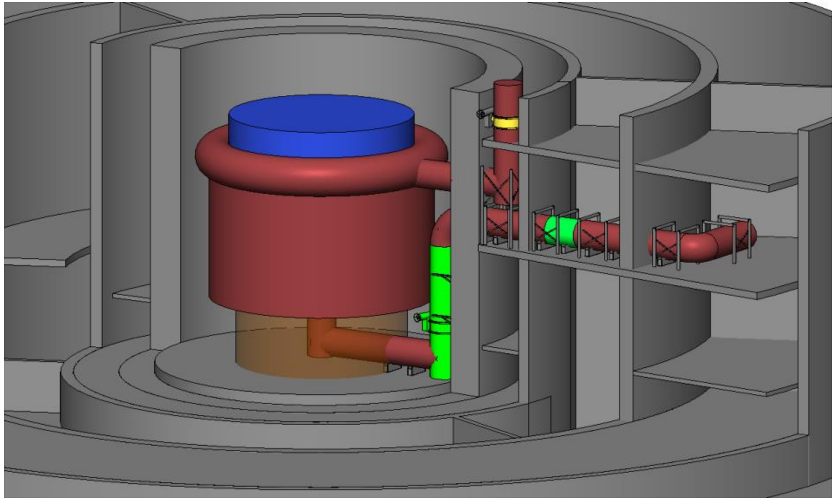
It is proposed to limit heat removal - not to exceed the vessel temperature 800 °C in the conditions of a severe accident such as the accident at the Fukushima NPP

The system of emergency heat removal from the reactor vessel by air consists of:
Inlet cold air pipe
cladding of lower part of reactor vessel
cladding of upper part of reactor vessel
outlet hot air pipe
one valve on cold and hot pipes



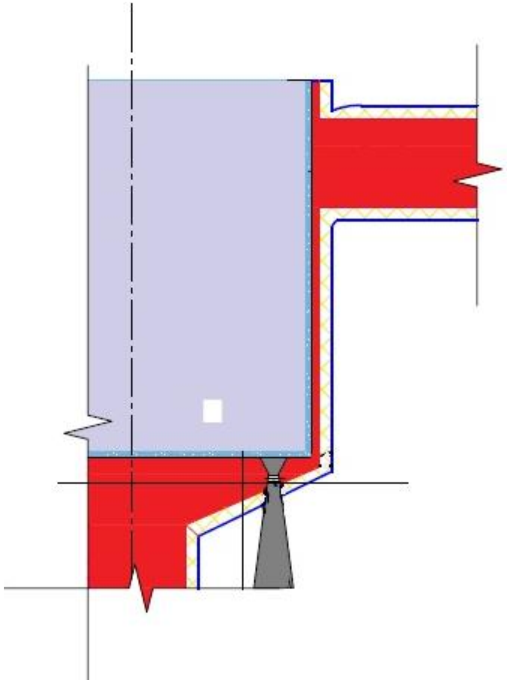
System layout

- The arrangement of the cold air inlet pipe can be made based on the convenience of general arrangement solutions
- A heat-insulated hot air chimney is installed along the wall inside the main building before entering the annex
- Valves on cold and hot pipes should be located as close as possible to the vessel



Air circulation path

- The air path around the safety vessel is created by the lining with a 100 mm gap
- On the length of the cylindrical part of the safety vessel ~ 12 m high, the cladding itself consists of a aluminum alloy with vertical ribs every 100 mm around the circumference
- On the pit side, the cladding is provided with thermal insulation
- The cladding elements are fixed in the load-bearing cells section in such a way that they can be removed for access to the safety vessel
- The removable cladding elements are not provided with ribs in the lower part of the safety vessel
- The internal cladding surface is coated by a heat-resistant black paint to improve radiation heat transfer



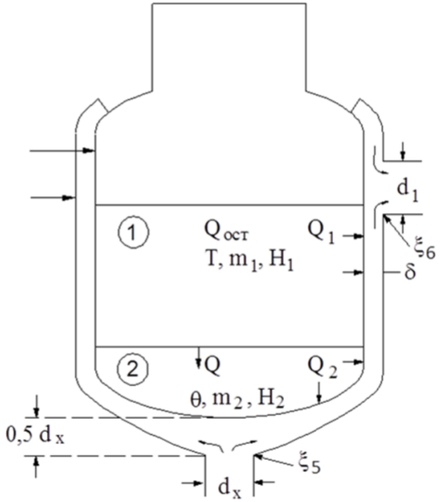
Physical model of the process and basic prerequisites

Heat transfer to air is carried by:

- Due to the transfer of heat by radiation to the safety vessel and cladding
- Due to heat removal from the safety vessel shell and the cladding to the air
- Heat transfer due the contact of the ribs and the safety case is not taken into account

The sodium thermal regime and the vessel temperature in zone 1 are determined by intense circulating flows of sodium, which are initiated by the core decay heat, the heat outflow to the air, and to zone 2.
In zone 2, circulation flows is neglected and thermal regime is determined by the heat flux from zone 1 to zone 2 by the sodium layer thermal conductivity and heat removal to air

It is considered that there is no lag of the structural elements temperature from the sodium temperature



Mathematical description of the process and initial parameters.

The main assumptions are as follows

- The temperature in zones 1 and 2 of sodium and vessel is average
- The safety vessel heat capacity is not taken into account
- The surfaces of the vessel and the safety vessel in the zones are equal
- The surface of the cladding in zone 1 increases by 3 times due to the ribs

initial parameters for the air circulation path

- Hot pipe height – 105 m.
- Diameters of inlet and outlet pipes – 2 m.
- Surface of vessel and safety vessel of zone 1 – 600 m^2
- Surface of cladding with ribs of zone 1 – 1800 m^2
- Surface of vessel, safety vessel and cladding of zone 2 – 400 m^2
- Gap between vessel and safety vessel – 0,14 m.
- Height and length of zone 1 channel – 12 m.
- Height of zone 2 channel – 3 m.
- Inlet air temperature– 20^{o}C

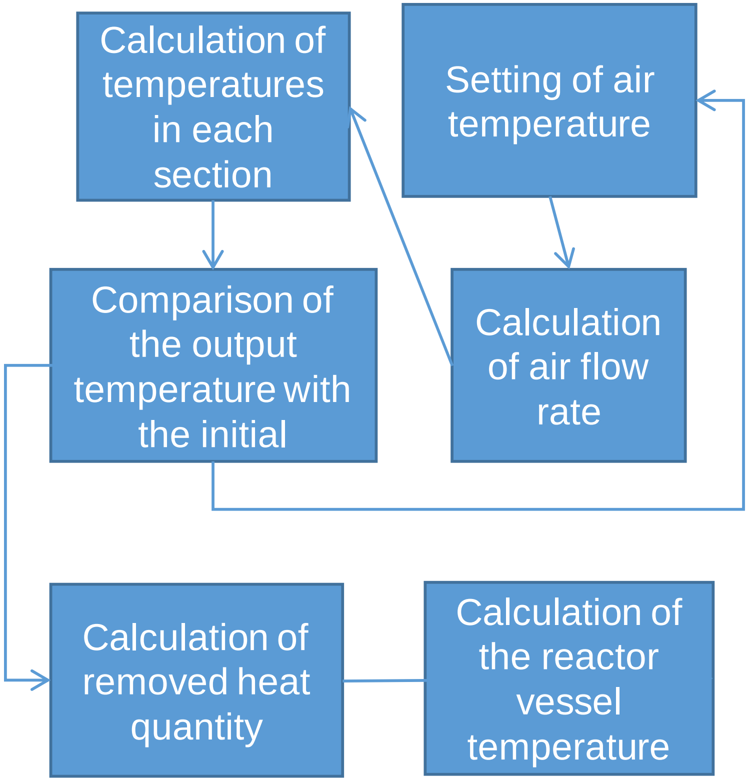
Calculation procedure

•Between the vessels only the heat transfer by radiation is taken into account

•Average sodium temperature in zone 1 – 515°C
•Average sodium temperature in zone 2 – 410°C

Forced circulation
The forced air flow powered by compressor with rate 70 kg/s
•Required pressure is 200 kg/m^2

The matching of the obtained parameters is achieved by several iterations at each time step



The gap between the vessel and the safety vessel

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This option changes the established canons regarding the tasks of the safety vessel

The gap between the vessel and the safety vessel inclusion in the air cooling system presupposes the elimination of the superposition of two severe accidents: significant vessel failure and external influence leading to common failures of all systems, except those located in the reactor building

The physical and mathematical models differ from those stated only in designations and in the number of equations and initial data

Calculation results

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Parameter	Option					
	1	2	3	4	5	6
Hot pipe height, m	105	60	-	105	105	30
Time to reach maximum temperature zone 1, h	36	42	27	48,3	20	28,3
The vessel zone 1 maximum temperature , ^{o}C	748	775	700	796	651	698
Air flow circulation channel	cladding	cladding	cladding	v-sv gap*	v-sv gap* /cladding	v-sv gap* /cladding
Intensifier in zone 1 (ribs)	no	yes	no	no	no/yes	no/yes

*v-sv gap - gap between vessel and safety vessel

Calculation results

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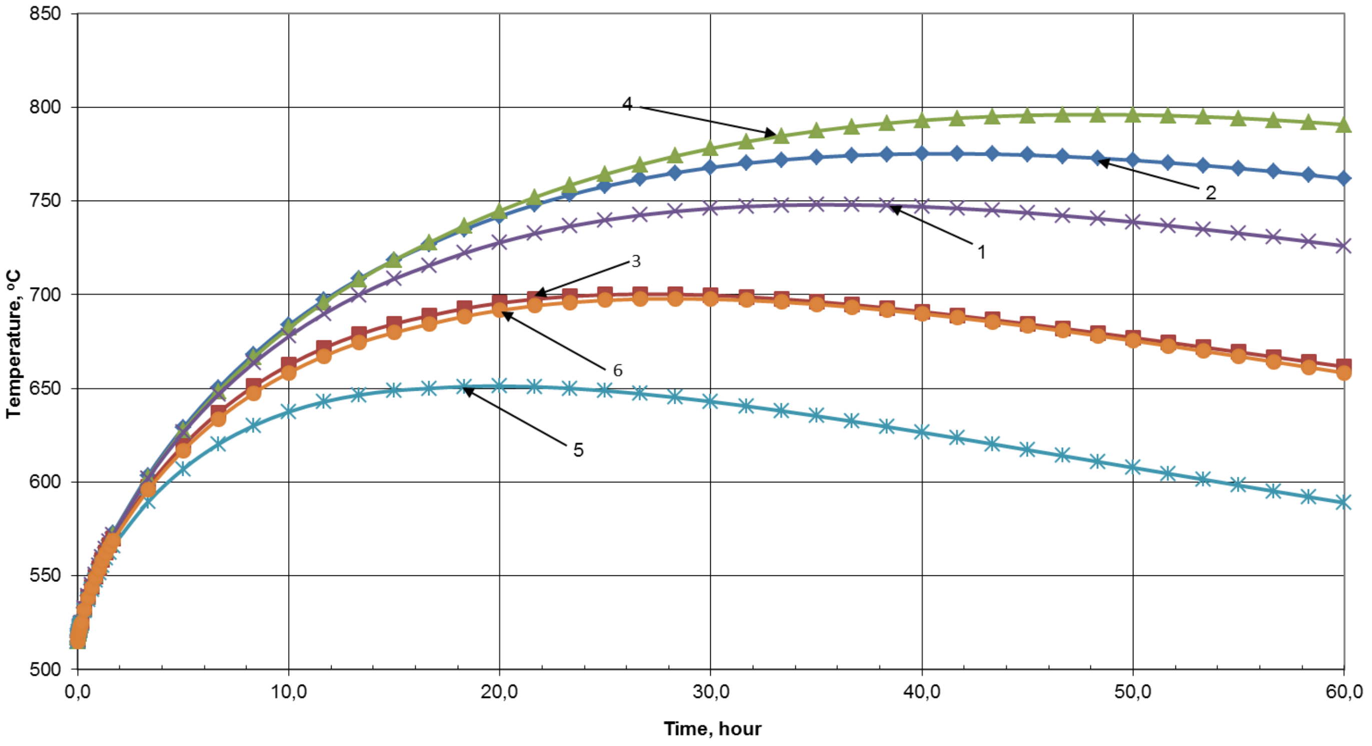

Conclusion

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1. Thus, taking into account heat exchange by radiation provides a regime for managing a severe accident for fast reactors with sodium coolant by removing heat from the reactor vessel through natural air circulation channels around the reactor

2. Even with heat removal through only one channel, the safety vessel – cladding, only a short-term increase in the temperature of the vessel to 750^{o}C

3. Optimization of hydraulic resistance and heat transfer intensifiers in air channels can significantly reduce the limiting temperature of the main vessel

Thank you for your attention

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