INIS-FR--1141

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# Physical and Technical Aspects of Lead Cooled Fast Reactors Safety

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The safety analysis of lead-cooled fast reactors has been performed for the well-developed concept of BREST-OD-300 reactor. The most severe accidents have been considered. An ultimate design-basis accident has been defined as an event resulting from an external impact and involving a loss of leaktightness of the lead circuit, loss of forced circulation of lead and loss of heat sink to the secondary circuit, failure of controls and of reactor scram with resultant insertion of total reactivity margin, etc. A direct consequence of such an accident will be direct contact between hot coolant and air and radioactivity release into the atmosphere.

The features meant to ensure natural safety of BREST reactor are indicated. To exclude the possibility of reactor runaway at prompt neutrons, loss of cooling and damage to fuel in abnormal conditions, the reactor core and cooling circuits have been designed as follows:

- mixed mononitride uranium-plutonium fuel (UN + PuN) characterized by high density $\gamma \geq$ **13 g/cm$^3$**, heat conductivity $\lambda \approx$ **18 W/(m·K)**, melting temperature $\mathbf{T_{melt}}$ = **2800 °C** and phase transition temperature $\mathbf{T_{phase}}$ **= 1600 ° C**;
- coolant is liquid lead which does not come into exothermic reaction with water, air and structural materials, does not catch fire, resistant to radiation, is only slightly activated, allows heat removal at low pressure and has a large subcooling margin ($\mathbf{T_{boil}} \approx$ **2000 ° C** at **P ≈1 MPa**);
- lead sublayer between fuel and fuel cladding excludes their thermal mechanical interaction and provides high heat conductivity of the fuel element, low operating temperature of fuel ($\mathbf{T_{av}}$ **≈620° C** and $\mathbf{T_{max}}$**<900 ° C**), low release of gaseous FP and low pressure of FP to cladding, low fuel element constant ~ 1s;
- fuel composition and fuel element design ensure required breeding ratio (**BR≈ 1**), low reactivity effect due to fuel burnup ($\Delta\rho_{burnup} << \beta_{eff}$), low power and total reactivity effects ($\Delta\rho_{tot} \sim \beta_{eff}$);
- wide square lattice for fuel elements and shroudless FAs help to avoid loss of heat removal because of local blocking of flow area at FA inlet, increase coolant flow area and enhance of its natural circulation;
- three-zone profiling of power and coolant flow rate owing to the use of fuel elements with various diameters but with the same fuel composition and with the same pitch in FA, provides for the equalization of lead heatup and fuel cladding temperatures in all FAs, stabilization of these parameters during a microcampaign as well as margins to ultimate temperatures;
- lead reflector excludes production of weapons-grade Pu and provides high negative reactivity effect in case of low level of lead in the reactor as well as negative component of density reactivity coefficient;
- passive reactivity feedback on coolant flow rate is implemented by means of the special channels with lead columns, level in the channels being determined by head at the core inlet;
- passive reactivity threshold feedback on flow rate and coolant temperature is implemented by means of hydraulic controls which are designed for passive shutdown of the reactor in case of loss of forced circulation or high coolant temperature at the core outlet;

- lead circuit is designed to provide high heat accumulating capability and allow flow rate momentum in case of pump trip; besides, a by-pass flow path is provided to ensure natural circulation of lead;
- passive removal of decay heat by means of the system with natural circulation of air;
- steam-water circuit arrangement and parameters are designed so as to minimize the risk of steam generator freezing;
- steam discharge from the gas space to safety condensers will prevent overpressurization of the circuit in case of SG tube rupture.

The safety analysis of BREST-300 includes the following types of severe accidents without actuation of active protection features (without scram – WS):

- TOPWS – insertion of positive reactivity (unauthorized withdrawal of CPS rods, the effects of shock waves, ingress of gas or steam into the core in case of fuel element failures or SG damage, loading of non-standard FAs in the core, formation of the secondary critical mass in case of fuel element damage);
- LOFWS – loss of forced circulation of lead (pump trip, damage of the barrel separating the riser and downcomer parts of the circuit);
- LOHSWS – loss of heat sink to the secondary circuit (trip of feed pumps, rupture of secondary pressure pipelines, blocking of flow area in water or steam pipelines);
- OVCWS – coolant overcooling at the core inlet (rupture of steam header, rupture of SG tubes, mismatch between the primary and secondary circuits operation);
- coincident occurrence of the above-mentioned initiating events.

It was assumed in accident analysis that the protective feature available for accident mitigation was only reactivity feedback on the changes in the temperatures of the reactor core elements and coolant flow rate, and in some cases also actuation of passive protections of threshold action in response to low flow rate and high coolant temperature at the core outlet. It should be noted that the majority of the analyzed accidents could be overcame even without initiation of the above protections. It has been demonstrated that a combination of inherent properties of lead coolant, nitride fuel, physical and design features of fast reactors will ensure natural safety of BREST and are instrumental for avoiding deterministically the accidents associated with a significant release of radioactivity and requiring evacuation of people in any credible initiating event and a combination of events.

## References

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