

ANALYSIS OF A CORE COOLING FLOW BYPASS EVENT PRODUCED BY SPURIOUS OPENING OF A FLAP VALVE AT THE PRIMARY COOLING CIRCUIT OF THE RA-10 REACTOR

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Abstract: During 2013, within the framework of the RA-10 project, the Nuclear Safety Department at Bariloche Atomic Center has developed a plant model of the primary cooling circuit of the RA-10 to conduct the safety analysis of initiating events associated with this system. Deterministic simulations of sequences derived from initiating events were performed and also were included in the Preliminary Safety Report. In particular, sequences classified as Design Basis Events (DBE) were analysed. This paper describes the behaviour of the reactor during a "core cooling flow bypass produced by spurious opening of a flap valve in the primary cooling circuit (PCSFV)" event, which is considered as a DBE. This initiating event belongs to the "Loss of Cooling Flow" initiating event family. It is considered that the opening of one of the PCSFV may occur by a failure affecting this component. The analysis was performed using the thermal-hydraulic code RELAP5 3.3gl, which was used to develop a model of the reactor. The model includes the representation of the reactor core, the primary cooling system, its primary pipes, pumps and the reactor pool. The secondary cooling circuit was modelled as a boundary condition. In the analysed sequence, an instantaneous opening of one flap valve of the primary cooling system was postulated during reactor operating at full power. For reactor extinction, the success of the First Shutdown System (FSS) with single failure (insertion of absorbent plates with the failure of the heaviest reactivity worth control plate) was assumed. As a conservative hypotheses fuel temperature and coolant density reactivity coefficients feedback effect were not included in the analysis. It can be concluded that the design meets safety acceptance criteria (margin to redistribution of the flow and the departure from nucleate boiling), demonstrating that the reactor is properly extinguished and cooled by forced convection.

1. Introduction

The RA-10 Project has the purpose of design, construction and license a Research and Multipurpose Production Nuclear Reactor **Erreur ! Source du renvoi introuvable.**, with a high enough neutron flux to guarantee its simultaneous utilization in a wide range of medical, industrial and scientific research applications.

Within the safety analysis required for the licensing process of RA-10 Reactor, deterministic safety analyses of DBE were performed. With this objective, a thermo-hydraulic reactor model was performed and developed based on the RELAP5 plant code. This model includes the nodalization of the most important components: the reactor pool, reactor core, primary cooling system (chimney, decay tank, pumps, heat exchangers and piping sections), and the modelling of the first and second safety shutdown systems were included.

In this paper the behaviour of the reactor against a "core cooling flow bypass" event is described.

2. Identification of causes and event description

We consider that a core cooling flow bypass event is produced by the spurious opening of a PCSFV, driven by the opening of one of the flaps of Primary Cooling System (PCS) by self-failure that is by some internal component failure.

This DBE belongs to Loss of Flow Cooling family.

The aim of this analysis is to demonstrate that the reactor is properly extinguished and properly cooled by forced convection, transferring core's heat to the Reactor Pool (RP). This DBE belongs to the reactivity transient family **Erreur ! Source du renvoi introuvable.**

3. Modelling assumptions

Below it is presented the modelling assumptions which were applied to carry on this safety analysis.

- It is postulated that the spurious opening of a flap valve at the primary cooling circuit starts at time $t = 0$ s.
- Opening the bottom flap valve of the branch 400-AR-B-030 is postulated. Analysis of the individual opening of each of the four flaps is made, and the event in which the greatest decrease in flow through the core occurs is selected.
- The simulation time is 1000 s.
- The area of the aperture corresponds to the area of passage of coolant through a fully open FVPCS.
- It is postulated that the power remains constant until the performance of the First Shutdown System (FSS) not lending credence to the decrease in power for reactivity feedbacks.

4. Results

The simulation results for this BDE are presented in this section. For more simplicity, the analysis was divided in time phases marked by the most relevant phenomena in this transient.

4.1 Phases identification

From the phenomenological point of view, the event of cooling flow bypass, with the FSS actuation can be divided into 3 phases:

- Phase 1, during this phase it is observed an increase of core temperatures due to reduced flow through the core (0 s - 5.5 s): from the spurious flap valve opening, to the performance of the FSS. Is characterized by an increase in temperature of the fuel and the coolant through the core. In this phase of the minimum values obtained from the safety margins (MDNB and MBO) and new stationary values for the coolant flow.
- Phase 2, shutdown of the reactor (5.5 s - 15 s) from the post-FSS period performance. It is characterized by a fast decrease in the power generated in the core, of the fuel temperature and the coolant at the outlet of the core.

- Phase 3, fronts propagating temperature (15 s - 1000 s): comprises the shutdown period of the reactor then to the end of the transient. It is characterized by the presence of fronts PCS temperature resulting from the phenomena of the phases 1 and 2, which initially cause an increase in the inlet temperature to the core and finally a monotonous decrease thereof toward longer times.

4.2 Phases Description

Phase 1 (0 s – 0.9 s): FIG. 1 shows the evolution of the mass flow in different PCS positions of interest. In this phase the appearance of flow is observed through to the flap valve. Due to pressure losses in the core, the pressure inside of the cold leg is higher than in the reactor pool (at the same level). Therefore, by opening the flap valve, the refrigerant flow occurs from the cold leg to the reactor pool, reflected as a flow with a negative sign.

Towards the end of this phase, the flow ejected by the flapper reaches a steady value equal to 64% of rated flow through the core before the opening occurs. It is important to mention the opening of this flap does not cause the opening of the other flaps for decreasing the pressure in the return branch.

Due to the bypass flow through the flap, a decrease of coolant flow occurs through the core, reaching a new steady state condition corresponding to 60% of its nominal value at full power. The mass flow in the PCS pumps due to the decrease of the pressure loss due to the spurious PCSFV opening.

FIG. 2 shows the evolution of the temperature of the fuel cladding plates –external face– on the hottest fuel channel at different heated volumes (T_{CHC}). FIG.3 shows the evolution of the temperature –external face– on the average core fuel channel at different axial heated volumes (T_{CAC}). These temperatures increase due to the mass flow decrease in the core, reaching a peak of $T_{CACmax} = 87.5$ °C and $T_{CHCmax} = 144$ °C. These temperature values cladding, it is expected that the phenomenon of ONB occurs. This phenomenon favors heat transfer plates, which this is not damage for them.

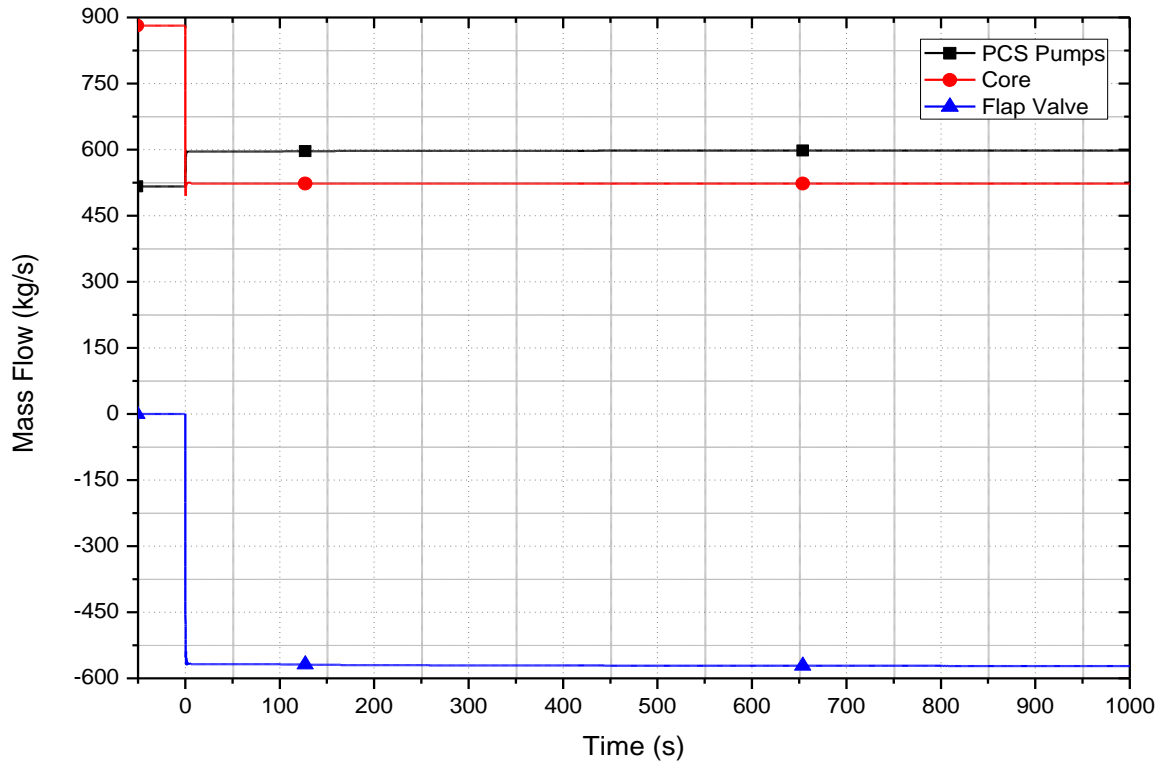


Fig. 1 Coolant mass flow through different positions of PCS.

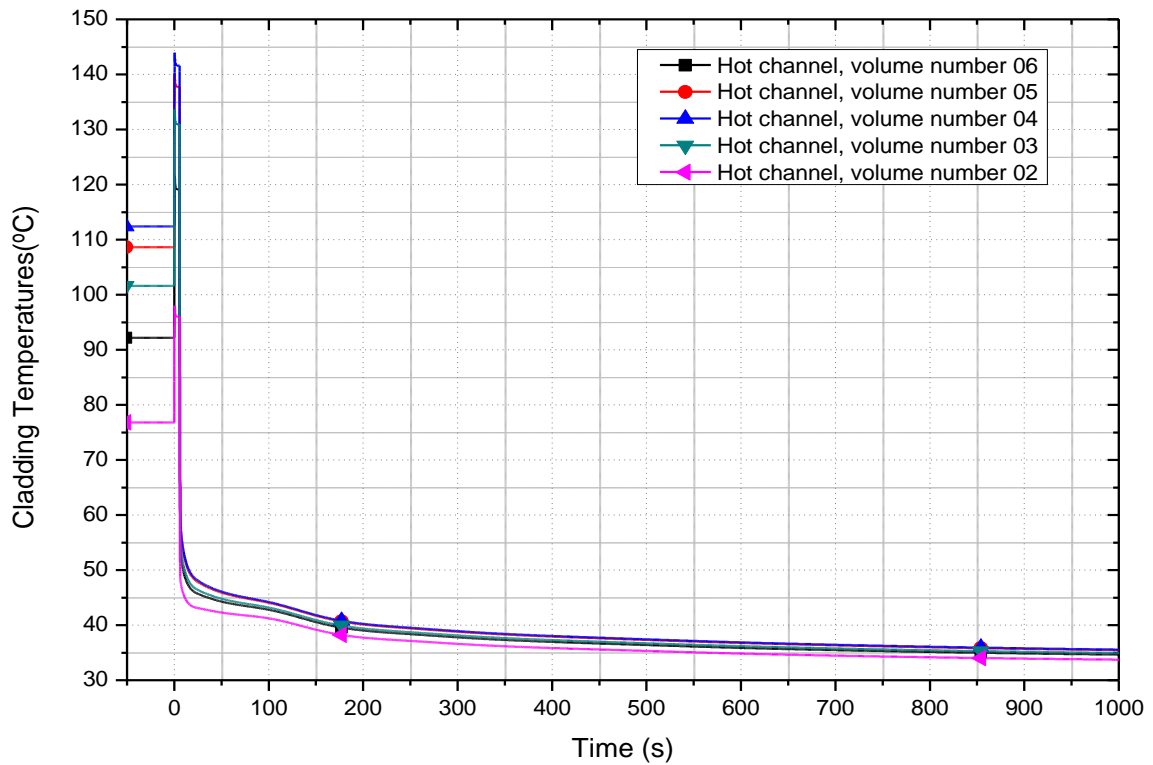


FIG 2: Cladding temperature in different hot channel positions.

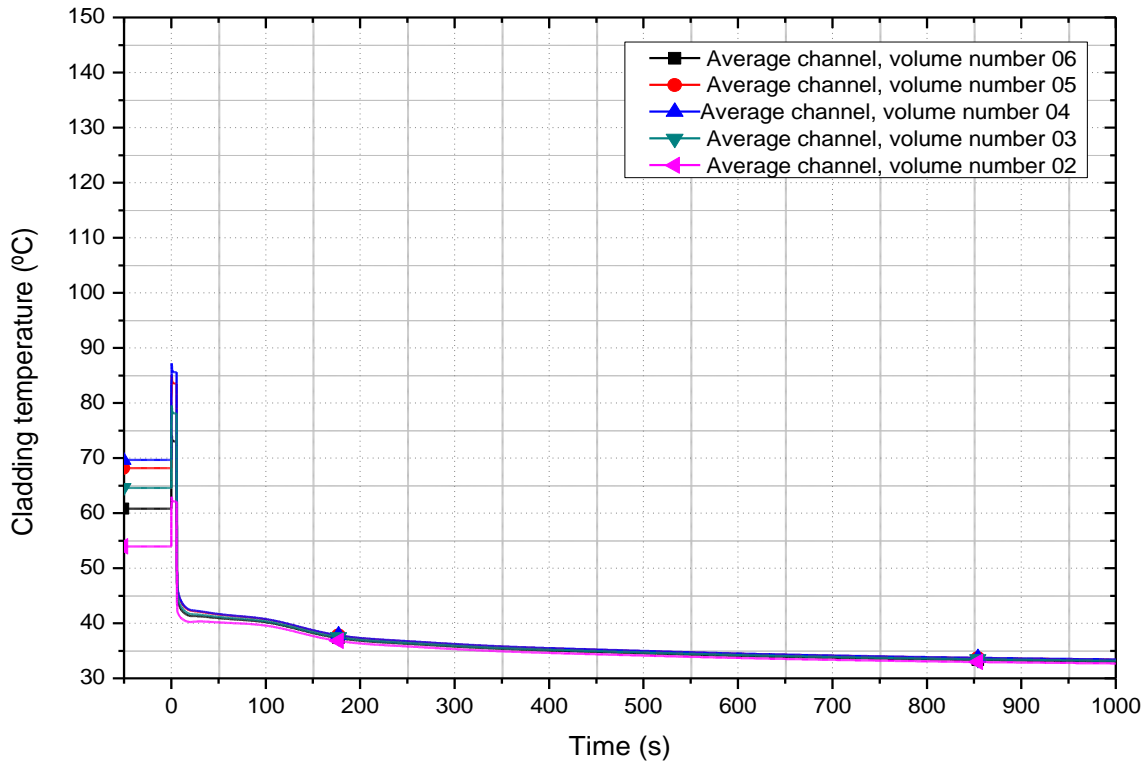


FIG. 3: Cladding temperature in different average channel positions.

In FIG. 4 the inlet and outlet temperatures of the reactor core channels are shown. In the same figure the outlet of the primary heat exchanger coolant temperature is shown. Due to the increased residence time of the coolant in the active region of the core, an increase to 53°C is observed in the core exit temperature. As a result, the temperature at the outlet of the primary heat exchanger increases with the arrival of the temperature front from the core. The inlet temperature of the core is not altered given the short time of this phase.

FIG.5 and FIG.6 (zoom) show the core power. It is observed that it is constant in the first few seconds until the performance of the FSS. The pressure drop in the core overcomes the threshold set point value. The failure of the trip by pressure drop in the core is assumed, and the successful of the trip by delta temperature in the core. So that the demands the FSS actuation with a delay of 5.0 s due to the electronic and measurement instrumentation. The reactor extinction starts at 5.5 s.

In FIG. 7 the reactivity feedback is shown. As shown, for this simulation does not give credit to the reactivity feedbacks fuel density and temperature would tend to decrease the power of the core by heating. Negative reactivity observed in the figure, corresponds to the reactivity inserted by the PSP.

FIG. 8 shows the safety margins of the hot fuel channel. As is seen in the same figure, the RDR and DNBR margins tend to decrease due to heating of the fuel, due to the reduced flow through the core, reaching their minimum values are RDR= 1.63 and DNBR = 1.86.

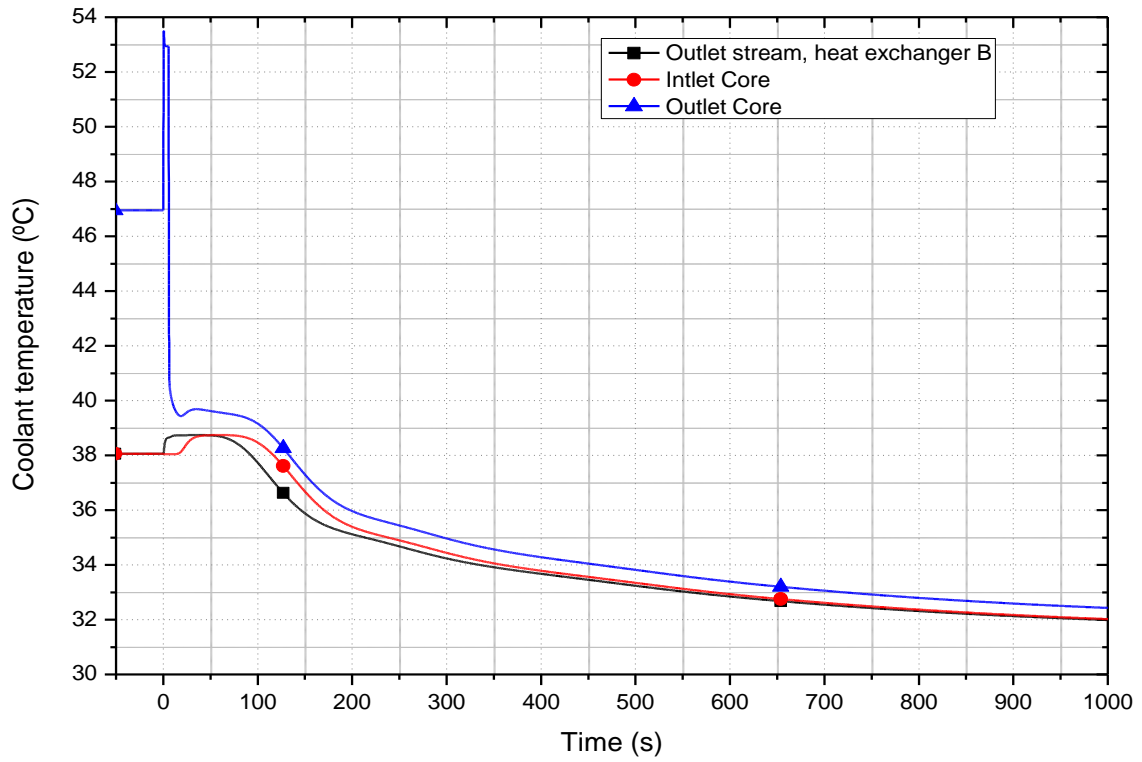


FIG. 4: Coolant Temperatures in different position of the PCS.

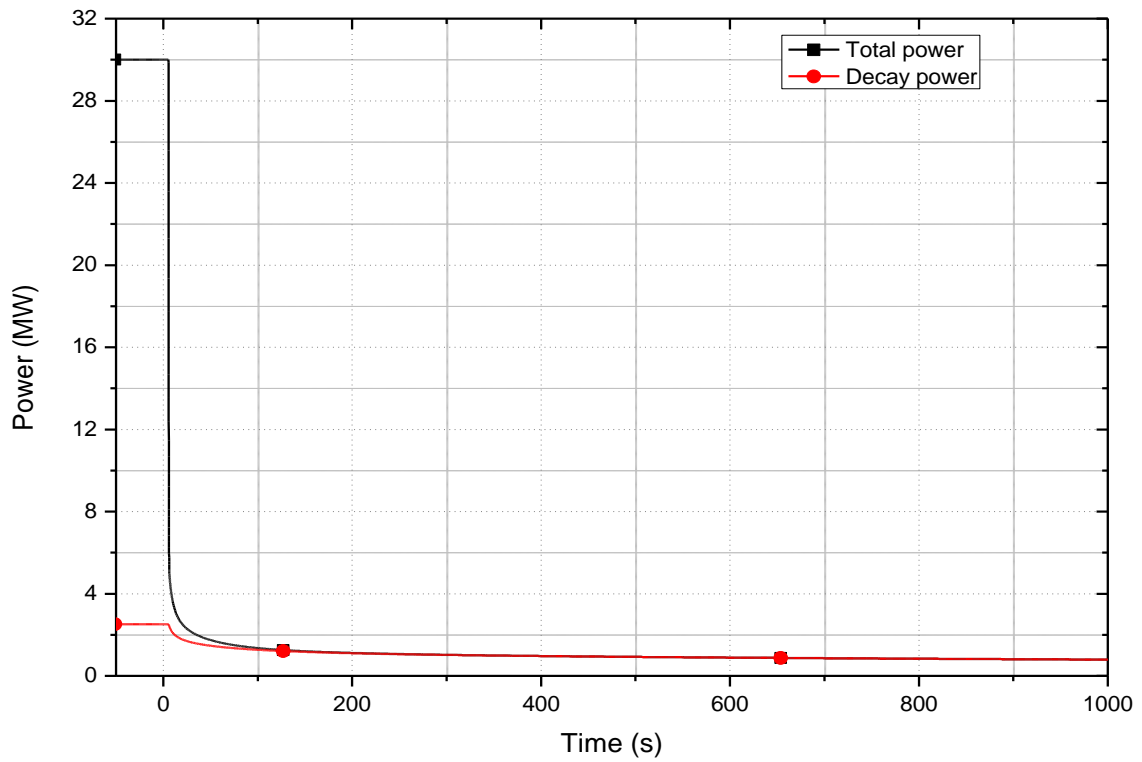


FIG. 5: Core Power.

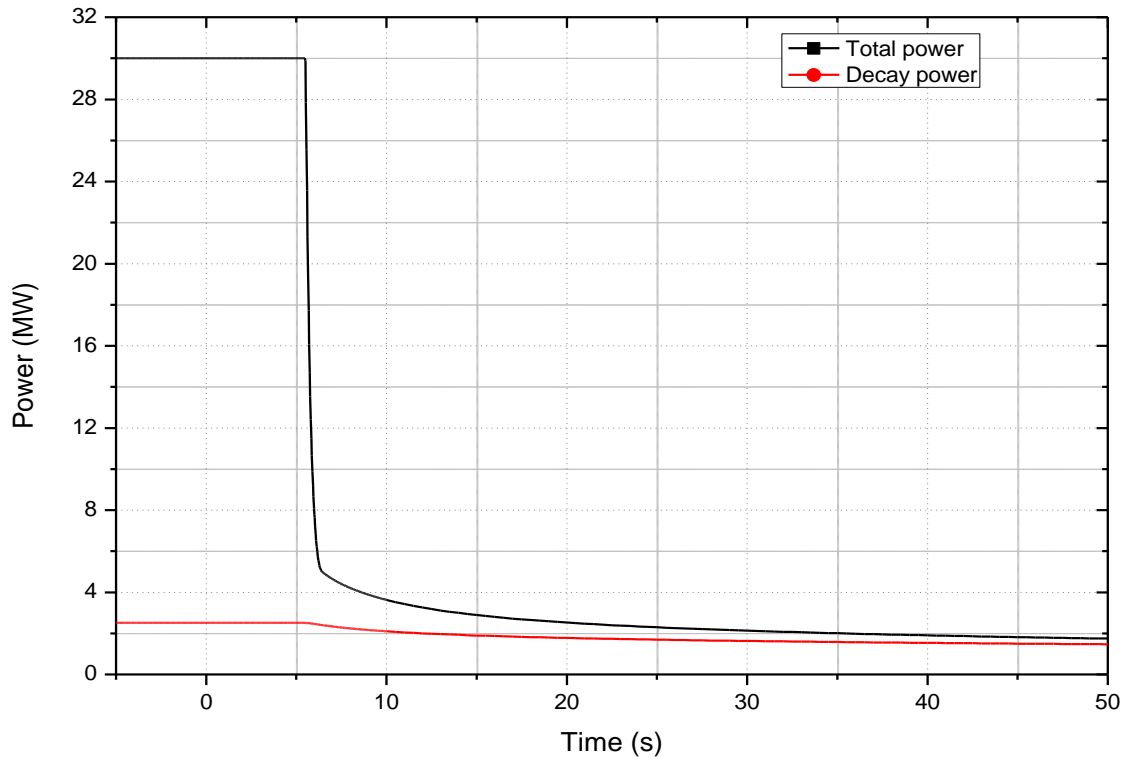


FIG. 6: Core Power (zoom).

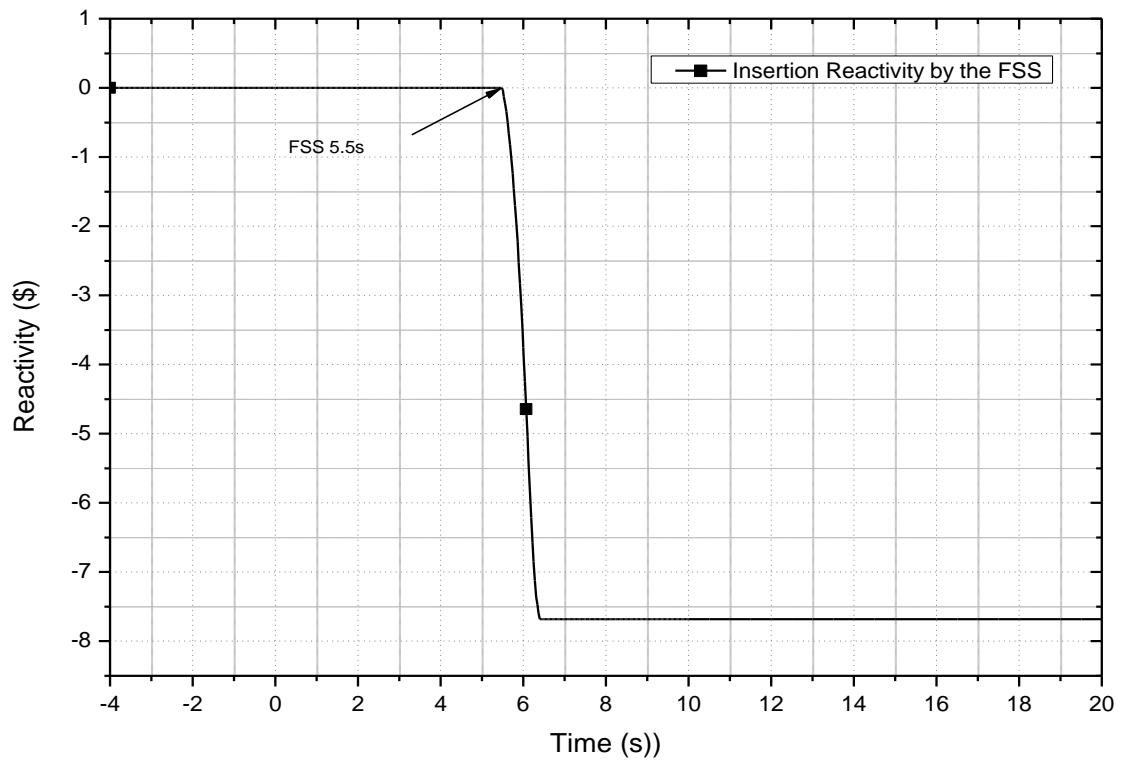


FIG. 7: Reactivity

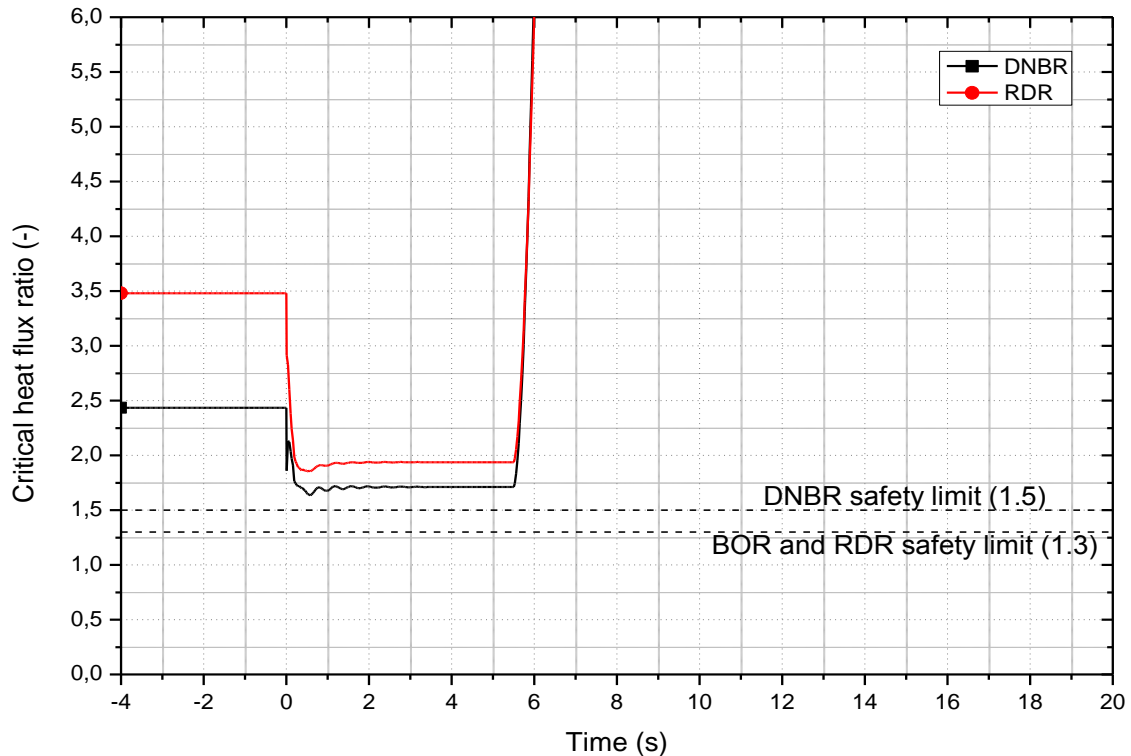


FIG.8: Safety Margins

Phase 2 (5.5 s - 15 s): At 5.5 s after the start of the event, acting the PSP signal demanded by high temperature difference in the core, assuming failure in the signal from the first low pressure drop in the core (2 s). As shown in Figure 5 and Figure 6 negative reactivity insertion produces a rapid reduction in the power generated in the core, corresponding to reaching values of decay and maintained in this state until the end of simulation. That is, it is observed that the PSP (with single fault) successfully extinguished the reactor.

Due to the decrease in the power generated by the reactor shutdown in this phase decreases and fuel temperatures of coolant in the core, without seeing modified the core inlet temperature.

Phase 3 (15 s - 1000 s): At 15 s of cooling the hot-face originated in the core, due to the FVPCS opening, reenter the same by raising the inlet temperature to 38.7 °C, and then gradually decreases due to the opposite lower temperature caused by the reactor shutdown . Because during the whole simulation, heat exchangers functioning normally, after the reactor shutdown core inlet temperature drops below 38 °C (nominal core inlet temperature), tending to a value close to the temperature of secondary side input of the heat exchanger (31 °C). Finally, in Table I is shown a summary of the acceptance criteria, namely: RDR and DNBR. Table 1 also shows the critical temperature margin and cladding.

Table I: Acceptance criteria and cladding temperature.

Parameters	Safety limits	Simulation results
DNBR	> 1.5	1.63
RDR	> 1.3	1.86
BOR	> 1.3	144 °C
Cladding maximum temperature, hot channel	-	87.5 °C
Cladding maximum temperature, average channel	-	1.63 °C

5. Conclusions

Facing a core cooling flow bypass produced by spurious opening of a flap valve in the primary cooling circuit event, the shutdown of the reactor was studied with the instant action of FSS (applying the single failure criteria). The reactivity feedback coefficients for fuel temperature and coolant density changes were not considered.

Proper cooling of the core and transition from normal operation mode (with forced circulation cooling) to natural circulation cooling was studied.

It was observed from the simulation that the reactivity inserted by the FSS, was sufficient to extinguish the reactor in the short term and keep it in this state all the analysed period.

Finally, the acceptance criteria adopted for the deterministic safety analysis for this DBE were satisfied.