ANGRA 2 SMALL BREAK LOCA FLOW REGIME IDENTIFICATION THROUGH RELAP5 CODE

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Abstract. The purpose of this paper is to identify the flow regimes in the core of Angra 2 nuclear reactor with RELAP5/MOD3.2.gama code (RELAP5, 2001). The postulated accident is the loss of coolant through a small break in the primary circuit (SBLOCA), which is described in Chapter 15 of the Final Safety Analysis Report of Angra 2 – FSAR (ETN, 2006). As the primary circuit pressure decreases due to the loss of coolant, several alternating two phase flow regimes are established in the primary circuit. This paper analyses the coolant two-phase flow behavior in the nuclear reactor core during the postulated accident.

Keywords: *RELAP5, small breack LOCA, flow regimes*.

1. INTRODUCTION

The objective of this work is to identify, with RELAP5/MOD3.2 gamma code (RELAP5, 2001), the flow regimes in the core of Angra 2 nuclear reactor during a postulated loss of coolant accident in the primary circuit for small beak (SBLOCA), which is described in Chapter 15 of the Final Safety Analysis Report of Angra 2 – FSAR (ETN, 2006).

The accident consists basically of the total break (380 cm^2) of a pipe of the hot leg Emergency Core Cooling System (ECCS) of Angra 2 nuclear reactor (Andrade et. al., 2001).

The ECCS efficiency is also verified for this accident. In this simulation, failure and repair criteria are adopted for the ECCS components in order to verify the system operation in carrying out its function as expected by the project to preserve the integrity of the reactor core and to guarantee its cooling.

SBLOCA accidents are characterized by a slow blow down in the primary circuit to values that the high pressure injection system is activated. The thermal-hydraulic processes inherent to the accident phenomenon, such as hot leg of ECCS vaporization and consequently core vaporization causing an inappropriate flow distribution in the reactor core that can lead to a reduction in the core liquid level until the ECCS refills it.

It is important to point out that the results do not represent an independent calculation for the licensing process, but a calculation to give support to the qualification process of Angra 2 transient basic nodalization.

2. ANGRA 2 NODALIZATION FOR RELAP5 CODE

RELAP5 was developed by the Idaho National Laboratory (RELAP5, 2001). This code was originally developed for the analysis of thermal hydraulic transients in Pressurized Water Reactors (PWR). RELAP5 can model the primary and secondary cooling system of experimental facilities and of Nuclear Reactors with geometric details. The program uses the non-homogeneous non-equilibrium two fluid model and takes into account the mass, momentum and energy equations for the liquid and gaseous phases. RELAP5 also has two additional equations to deal with noncondensable gases and soluble boron. One-dimensional models are used to treat the fluid flow and the heat conduction at the structures, but in some special cases such as the cross flow in the reactor core and the rewetting region in flooding model, two-dimensional models are used.

The simulated accident consists basically of the total break of a pipe of the hot leg Emergency Core Cooling System (ECCS) of Angra 2, which is a 1.350 MW(e) PWR reactor with four primary loops (10/20/30/40)containing two ECCS each one. FIGURE 1 shows a schematic representation of Angra 2 and FIG. 2 shows Angra 2 RELAP5 core nodalization, although the entire plant primary circuit was modeled in the simulation with RELAP5.

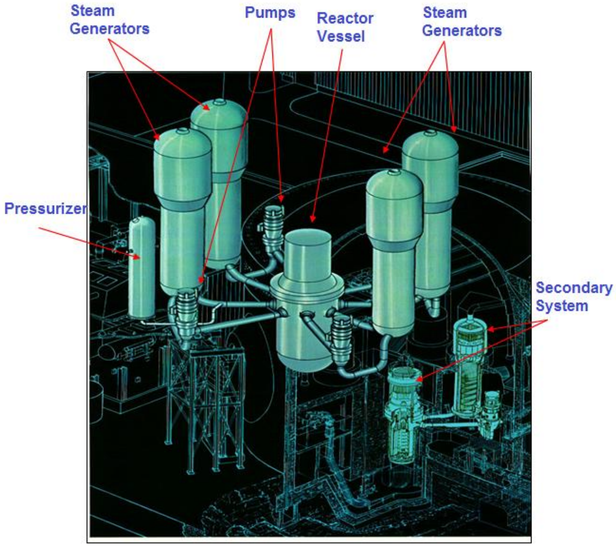

Figure 1. Angra 2 nuclear power plant components arrangement.

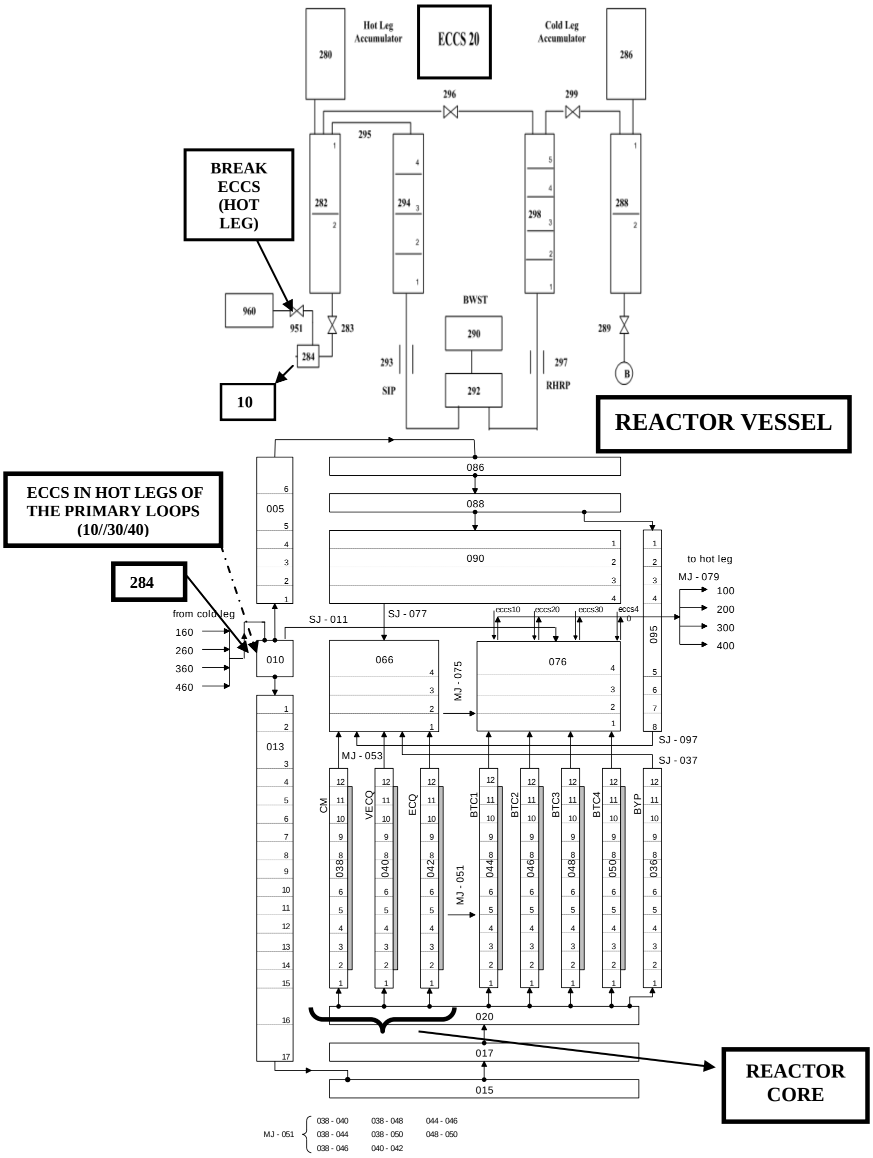

Figure 2. RELAP5 Angra 2 nuclear reactor core nodalization.

The postulated rupture area is 380 cm², which represents 100% of the ECCS pipe flow area (Andrade et al., 2001) and the boundary conditions used in the simulation are from Angra 2 FSAR (ETN, 2006). The most important of them are:

- reactor power - 106% nominal power;
- reactor trip from Reactor Coolant System (RCS) pressure < 132 bar;
- 100 K/h secondary-side cool down (from P_{RCS} < 132 bar and containment pressure > 1.03 bar);
- ECC criteria (P_{RCS} < 110 bar and containment pressure > 1.03 bar).

In this simulation, failure and repair criteria are adopted for the ECCS components in order to verify the system operation in carrying out its function as expected by the project to preserve the integrity of the reactor core and to guarantee its cooling, as presented in the TABLE 1. The accident started at 100 seconds of the simulation time, after the steady state condition establishment.

TABLE 1. Failure and repair criteria adopted for the ECCS injection.

ECCS Components	**Injection**							
	Loop 10		**Loop 20**		**Loop 30**		**Loop 40**	
	hot	cold	hot	cold	hot	cold	hot	cold
Safety Injection Pumps	1	–	Break	–	SF	–	RC	–
Accumulators	1	1	Break	1	1	1	1	1
Residual Heat Removal Pumps	1		Break		SF		RC	

Break: Injected coolant lost via the break SF: Single failure of diesel engine RC: Diesel engine down for repairs

RELAP5 code is capable to identify, each one of the regimes associated to an integer number, fifteen different flow patterns, which are presented in Tab. 2, and eleven different heat transfer modes presented in Tab. 3. Those numbers are stored in RELAP5 code output file for each control volume and heat structure, respectively.

TABLE 2. Flow regime number (RELAP5 output).

Flow regime	**Number**
High mixing bubbly	1
High mixing bubbly/mist transition	2
High mixing mist	3
Bubbly	4
Slug	5
Annular mist	6
Mist pre-CHF	7
Inverted annular	8
Inverted slug	9
Mist	10
Mist post-CHF	11
Horizontal stratified	12
Vertical stratified	13
Level tracking	14
Jet junction	15

TABLE 3. Heat transfer mode numbers and correlations used by RELAP5.

Number	Heat Transfer Mode	Correlation
0	Convection to noncondensable-water mixture	Kays, 1955; Dittus-Boelter, 1930; ESDU*; Shah, 1992; Churchill-Chu, 1975; McAdams, 1954
1	Single-phase liquid convection at supercritical pressure	Same as mode 0
2	Single-phase liquid convection, subcooled wall, low void fractions	Same as mode 0
3	Subcooled nucleate boiling	Chen, 1966 **For horizontal bundle**: Polley-Ralston-Grant, 1981; ESDU*; Forster-Zuber, 1955
4	Saturated nucleate boiling	Same as mode 3
5	Subcooled transition boiling	Chen-Sundaram-Ozkaynak, 1977
6	Saturated transition boiling	Same as mode 5
7	Saturated film boiling	Bromley, 1950; Sun-Gonzales-Tien, 1976; and mode 0 Correlations
8	Saturated film boiling	Same as mode 7
9	Single-phase vapor convection or supercritical pressure with the void fraction greater than zero	Same as mode 0
10	Condensation when the void is less than one	Nusselt, 1916; Shah, 1979; Colburn-Hougen, 1934
11	Condensation when the void equals one	Same as mode 10

* ESDU (Engineering Science Data Unit, 73031, Nov 1973; ESDU International Plc, 27, Corsham Street, London, N1 6UA)

3. RESULTS

FIGURES 3 to 10 summarize the results of Angra 2 SBLOCA. Some of them area compared to the calculations of Angra 2 FSAR. FIGURE 3 compares RELAP5 and Angra2 FSAR break mass flow calculation. They are very similar until 480 s, when the FSAR predicted the actuation of ECCS broken leg Accumulator. This actuation was indicated by RELAP5 to occur 100 s later with a smaller flow rate. A similar behavior can be seen in FIG. 6 for the ECCS intact loop actuation.

FIGURE 4 shows the comparison between both calculated, RELAP5 and Angra2 FSAR, primary system pressure. Despite the faster initial depressurization presented by the RELAP5 calculation, after the actuation of the High Pressure Injection System (HPIS) the depressurization calculated by RELAP5 was slower than that reported by Angra2 FSAR. This slower depressurization not only delayed the accumulator in about 100 s, but also decreased its effectiveness and prevented the actuation of the Low Pressure Injection System (LPIS) since its pressure set point was not achieved.

FIGURES 4 and 5 show the pressure and the water temperature in the core cooling channels obtained with RELAP5 code. It can be seen that as the pressure decreases, the temperatures go to values near the saturation temperature.

ECCS actuation guaranteed the integrity of the reactor core as seen in FIGURES 6 (ECCS actuation) and 7 (cladding temperature). FIGURE 7 shows the temperature of the cladding heat structure which is below the cladding melting temperature (~ 1200°C). Calculations present a reasonable agreement with the FSAR results.

SBLOCA accident two-phase flow is presented in FIGURES 8 and 9. FIGURE 8 shows the reactor core void fraction. These results are according to the ones presented in FIG. 9 where the flow regimes are shown. FIGURE 9 illustrates the flow regimes identified by RELAP5 calculation. For this simulation, RELAP5 output captured three alternately flow regimes during the oscillatory phase, namely: Bubbly, Slug and Annular Mist corresponding to number 4, 5 and 6 from TAB. 2, respectively. Results are as expected, since the SBLOCA blow down was very slow.

FIGURE 10 illustrates the wall convection heat transfer mode numbers, related to TAB. 3, identified by RELAP5 calculation.

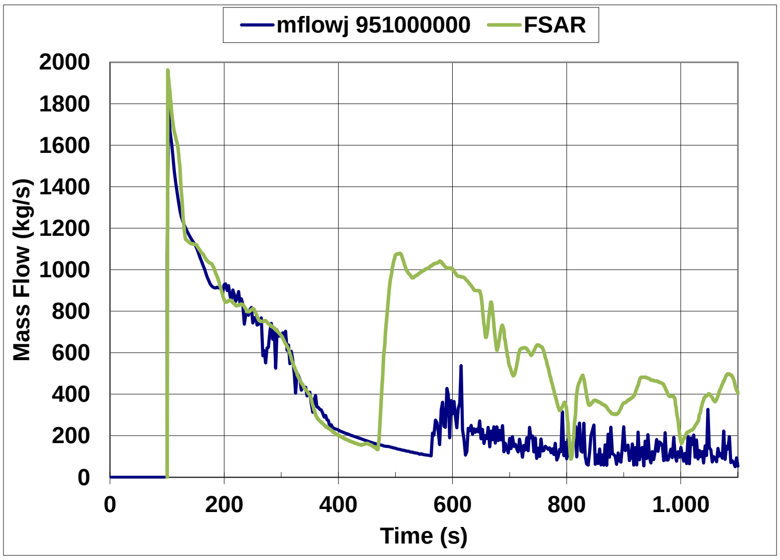

Figure 3. Break mass flow (RELAP5 and FSAR).

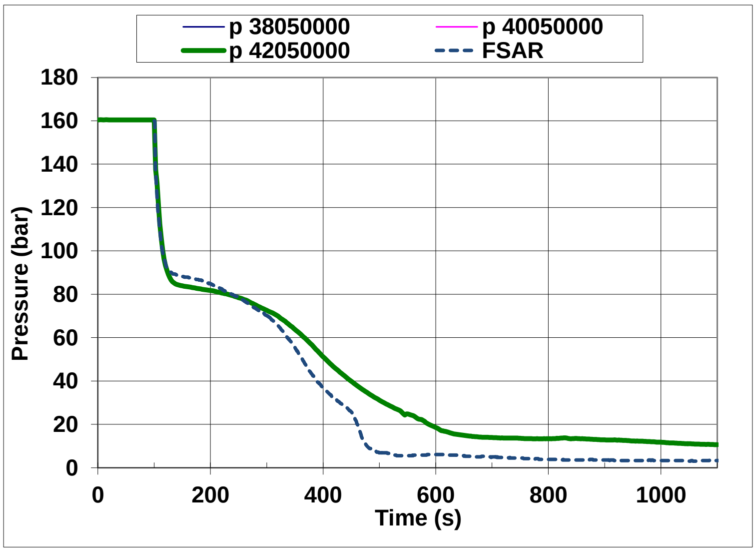

Figure 4. Angra 2 primary circuit pressure (RELAP5 and FSAR).

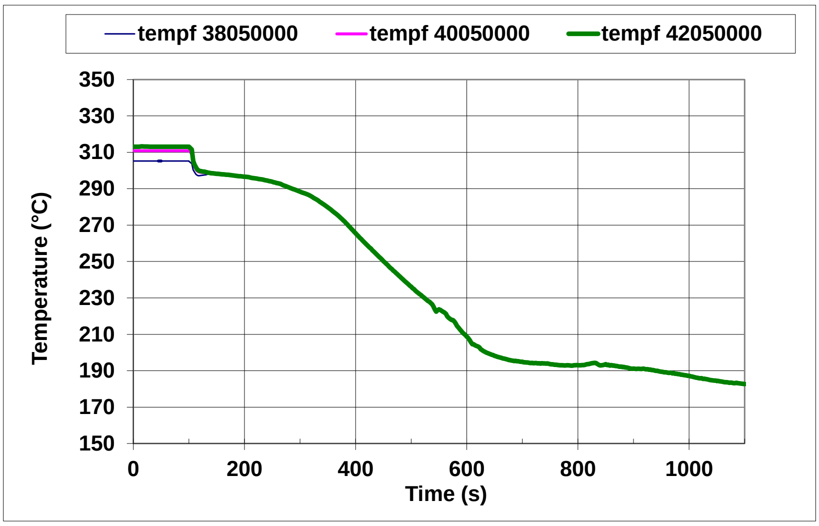

Figure 5. Reactor core water temperature.

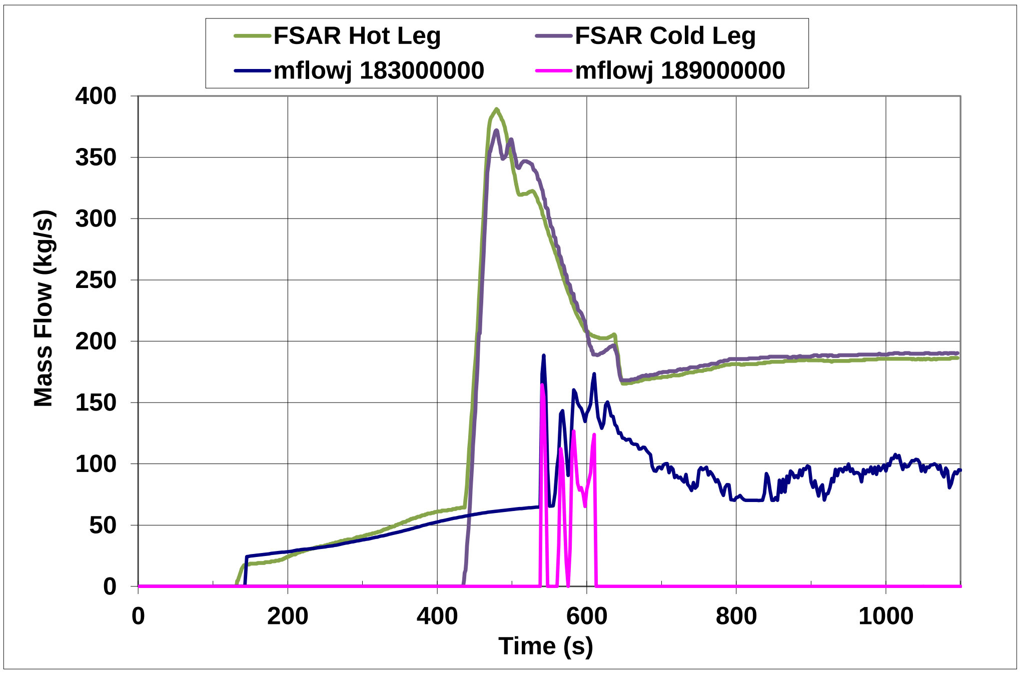

Figure 6. ECCS mass flow – Loop 10 (RELAP5 and FSAR).

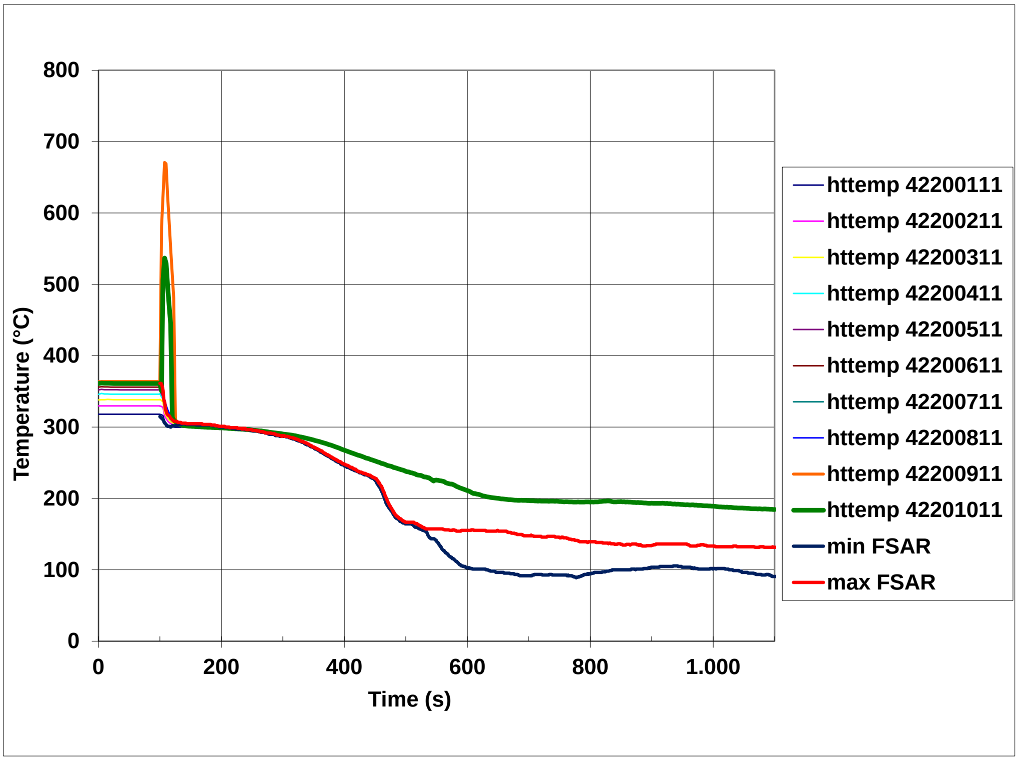

Figure 7. Hot fuel rod maximum temperature (RELAP5 and FSAR).

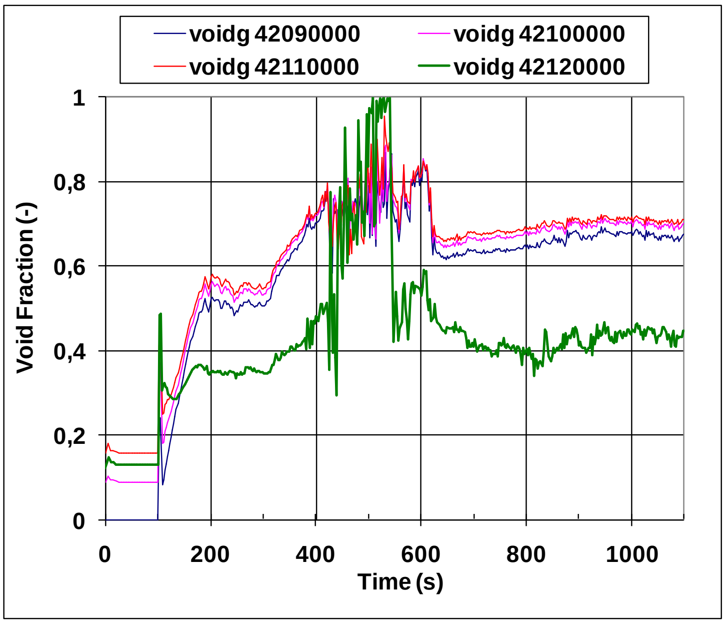

Figure 8. Core void fraction (RELAP5).

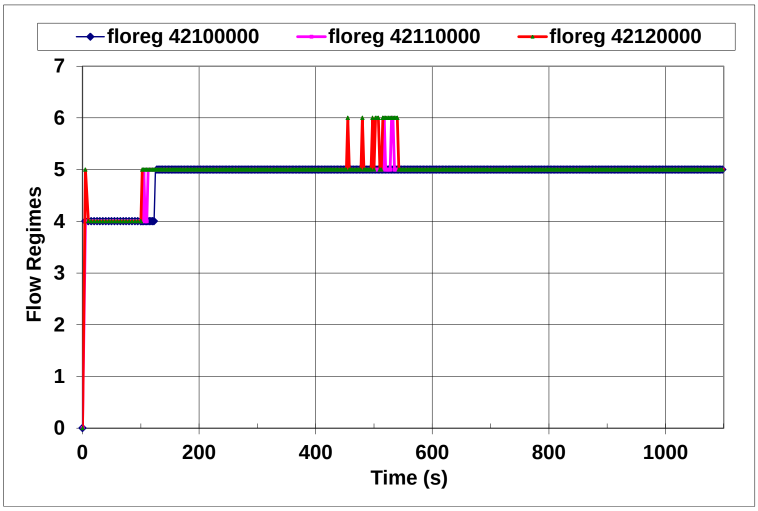

Figure 9. Core flow regimes (RELAP5)

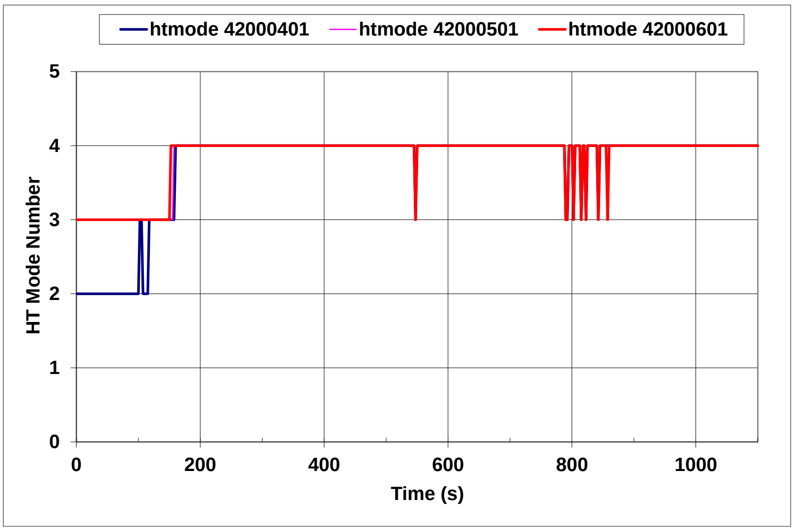

Figure 10. Cladding heat transfer mode numbers (RELAP5)

5. CONCLUSION

The actuation of ECCS accumulators occurred 100 s later with a smaller flow rate compared to FSAR results.

Although all the ECCS's have not effectively actuated, results presented in this paper showed that they guaranteed the integrity of the reactor core. The HPIS injection was enough to keep the cladding temperature within limits. Despite the differences, RELAP5 preliminary simulations were satisfactory.

Further work will be developed to better understand the FSAR differences, specially the primary system depressurization, and guide us to improve the RELAP5 model.

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