DETERMINISTIC ANALYSIS OF A BEYOND DESIGN BASIS ACCIDENT IN A LOW POWER, PIN-TYPE FUEL RESEARCH REACTOR

H. ABDOU *[1], D. DELBIANCO [1,2], J GONZÁLEZ [1,2,3], V. GAREA [1]

1 Department of Safety and Environmental Impact, Nuclear Projects Division – INVAP, R8403CPV, S. C. de Bariloche, Argentina,
2 Instituto Balseiro, Centro Atómico Bariloche, San Carlos de Bariloche, R8402AGP, Argentina,

3 Consejo Nacional de Investigaciones Científicas y Tecnológicas, Av. Rivadavia 1917, CABA, C1033AAJ, Argentina

*Corresponding author: habdou@invap.com.ar

ABSTRACT

During a loss of coolant accident leading to total emptying of the reactor pool, the decay heat can be removed through air natural convection (depending on the decay heat value). However, under partial pool emptying the core is partially submerged and the pathways for natural circulation of air in the vertical direction are modified. In order to predict fuel rod temperature evolution under such conditions a 2 dimensional model of the hydrodynamic components in the vertical and cross flow directions is performed. RELAP5/MOD3.2 code has been used to assess the thermal behavior under loss of coolant accident in the neutron beam tube. It is shown that in the case of a partially submerged core the highest cladding temperature remains below the safety limit (1000 °C).

1. Introduction

Pool type research reactors with neutron beams are susceptible to Loss of Coolant Accidents (LOCA) through the beam tubes. Handling of heavy objects inside the pool, e.g. shielded casks for transport of irradiated material or fuel, increases the probability of a catastrophic failure of the beam tube with uncover of the core. A numerical analysis has been carried out to analyze the capability of the fuel rods to withstand the Loss of Coolant Accident (LOCA) event in the Neutron Beam Tube (NBT). The break locations are at the two ends of the NBT. The centre line of the NBT is the centre line of the core, thus the reactor core is submerged in 10 cm of water (the effective core length is 50 cm and the NBT diameter is 30 cm). This event is classified as a Beyond Design Basis Accident (BDBA) due to its low probability ensured by design provisions in the reactor hall crane and hoisting system. Figure 1 shows the schematic diagram of the core a of pool type reactor with Zry clad pin type fuel and the NBT in the reactor pool.

2. Safety criterion

The deterministic acceptance criterion to demonstrate no damage to the core for the transient is the maximum cladding midpoint temperature of the hot channel ≤ 1000 °C (start of breakaway oxidation of Zircaloy-4 cladding, Ref. 1).

3. BDBA Sequence

1. A double-ended break occurs instantaneously at the NBT.
2. The reactor pool water level starts to decrease.
3. The reactor shuts down (when the reactor pool water level is 1 m below its top level) on a "low pool water level signal".
4. The reactor pool water level reaches 0.1 m over the core bottom position.

4. Computational Model

1. Calculations were performed with RELAP5/MOD3.2 code (Ref. 2). The code is based on a non-homogeneous and non-equilibrium model that is solved by a fast, partially implicit numerical scheme. RELAP5 is a highly generic code that, in addition to calculating the behaviour of a reactor coolant system during a transient, can be used for simulation of a wide variety of hydraulic and thermal transients in both nuclear and non-nuclear systems.
2. Figure 2 shows the RELAP nodalization of the control volumes in the reactor pool.
3. There are two types of channels representing the 900 fuel rods core. One channel represents the hottest fuel rod and the second represents the remaining channels, averaged. The hot and average channels are subdivided into 5 axial control volumes (205-209 and 105-109 respectively).
4. Another channel represents the cold leg and it is subdivided into 5 axial control volumes (905-909) and two components represent the lower and upper reactor pool parts (150 and 904 respectively). Two other components represent the lower and upper plenums for core (100 and 200 respectively) and cold leg (101 and 201 respectively).
5. For the 900 fuel rods, the power distribution is a cosine shape with a conservative total peaking factor of 3.0 for the hot channel.
6. Table 1 summarizes the main core configuration data.
7. The thermal conductivity and the volumetric heat capacity for meat and cladding are taken from (Refs. 3, 4 and 5).
8. The decay heat was calculated by the RELAP code taking into account not only fission products but also actinides decay.

Fuel type	UO_2
Cladding	Zircalloy-4 tube
Enrichment	2.1%
Number of Fuel Rods (minimum)	900
Reactor Power (maximum)	100 kW
Pitch	1.4 cm
Active fuel rod length	50.0 cm
Active meat diameter	8.19 mm
Cladding inner diameter	8.36 mm
Cladding outer diameter	9.5 mm
Core cooling	By natural convection
Prompt neutron lifetime (Λ)	47 µs
Effective delayed neutron fraction ($ß_{eff}$)	0.00785
RPS scram signal	Low pool water level
Delay time to actuate the RSS	2 s
RSS Reactivity Margin with single failure	-8.05 $
RSS effective insertion time	1.0 s

Table 1: Main core configuration data

5. Steady State

1. A steady state was calculated to verify the RELAP model and to establish the initial condition for the transient simulation.
2. Table 2 summarises the most important steady state variables and their values for fuel rods.

Description	Value
Inlet core coolant temperature (conservative assumption)	38 °C
Average heat flux of the core	0.745 W/cm^2
Maximum heat flux of the average/hot channel respectively	0.95/2.23 W/cm^2
Outlet coolant temperature of the average/hot channel respectively	42.4/44.6 °C
Outlet (minimum) coolant saturation temperature	113.5 °C
Cladding temperature at the middle of the fuel rod of the average/hot channel respectively	45.1/50.5 °C
Meat temperature at the middle of the fuel rod of the average/hot channel respectively	52.2/67.2 °C
ONB temperature at the middle of the fuel rod of the average/hot channel respectively	115.5/116.3 °C
CHFR at the middle of the fuel rod of the average/hot channel respectively	45.6/29.8
Coolant mass flow rate of the average/hot channel respectively	4.9/0.009 kg/s

Table 2: Summary of the steady state parameters

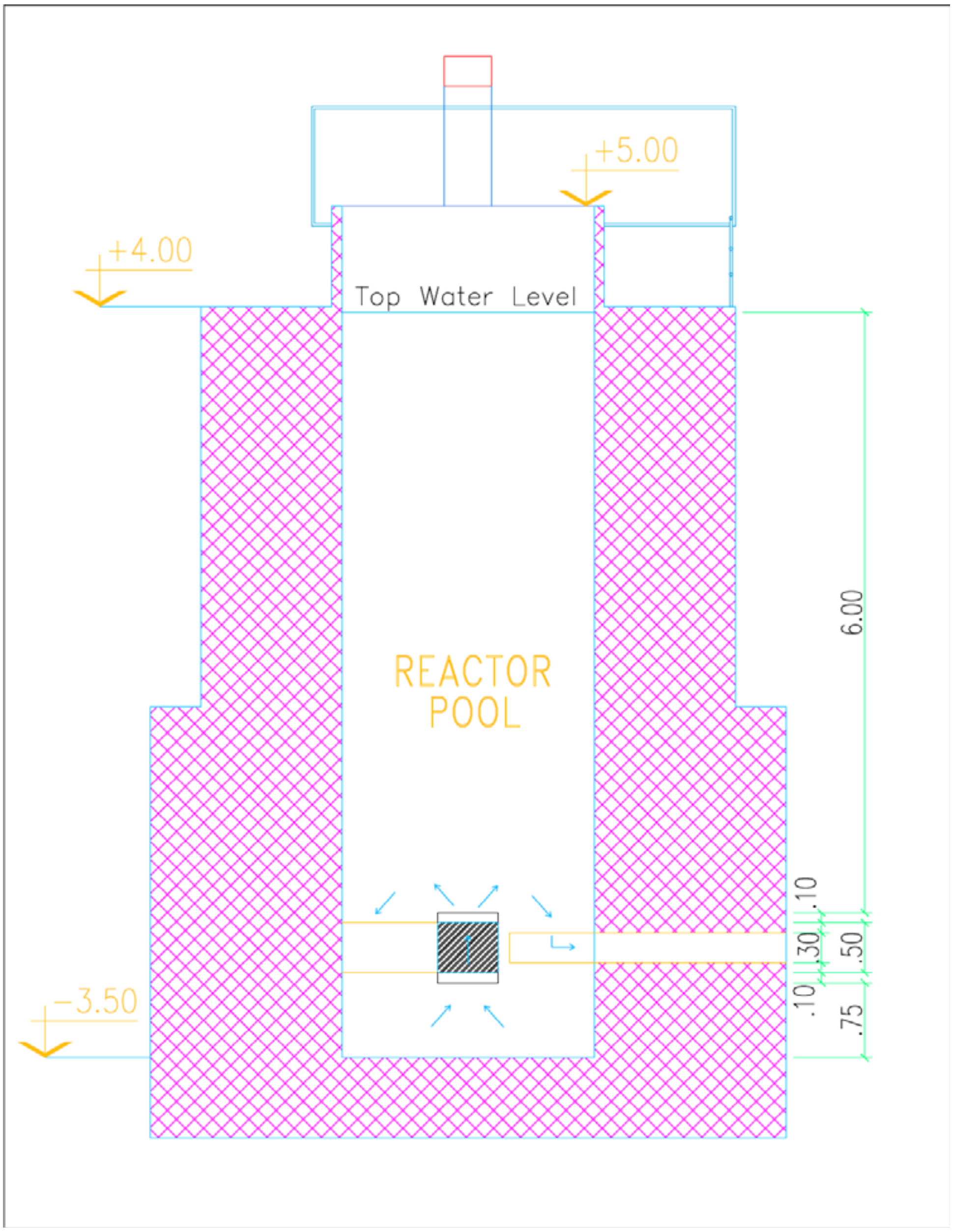

Figure 1: The schematic diagram of the LPRR core and the NBT in the reactor pool

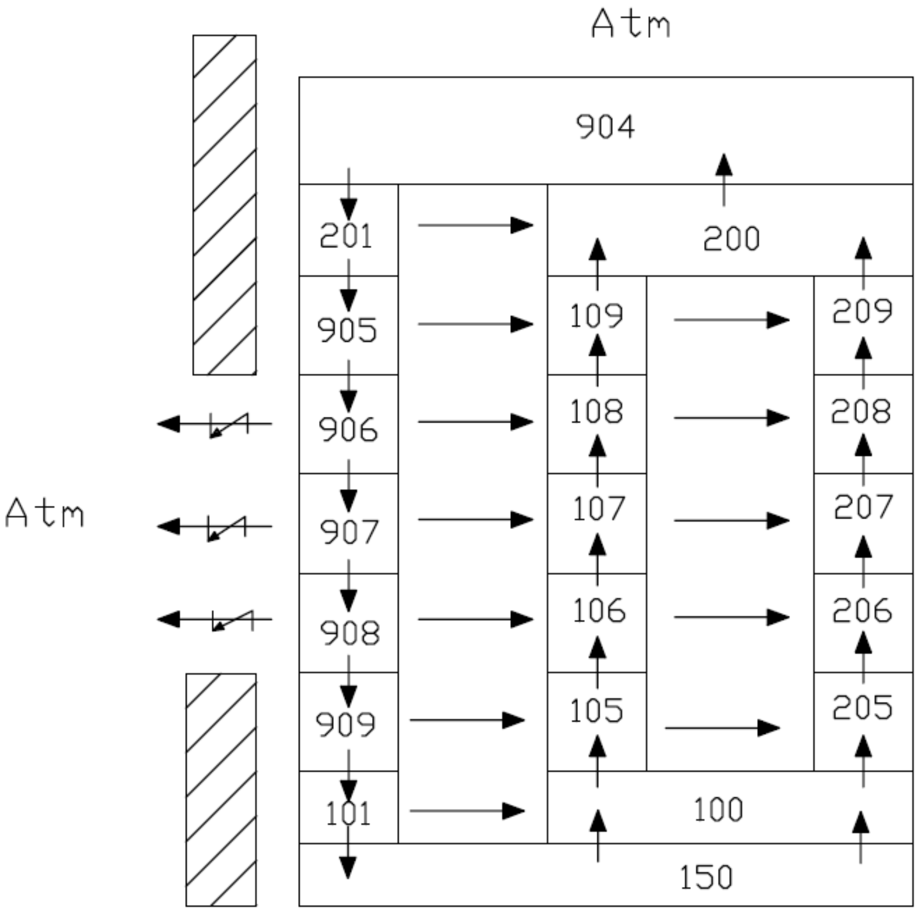

Figure 2: RELAP nodalization of the control volumes in the reactor pool

6 Transient State

1. The transient has been analysed by means of a numerical simulation with RELAP5/MOD3.2.

2. When the reactor pool water level reaches the lower part of the NBT, only Control volumes 909, 105, 205, 101, 100 and 150 are filled with water and the other control volumes of the reactor pool are filled with air.

3. Figures 3 to 6 show the coolant mass flow rate through the NBT, reactor pool water level, core power and cladding midpoint temperatures.

4. Table 3 summarizes the most important transient state variables and their values for fuel rods.

Description	Value
Maximum cladding temperature at the middle of the fuel rod of the average/hot channel	73.8 °C, (7850 s) / 117.5 °C, (8300 s)
Maximum coolant mass flow rate through the break of the NBT	477.9 kg/s (2s)

Table 3: Summary of the transient state parameters

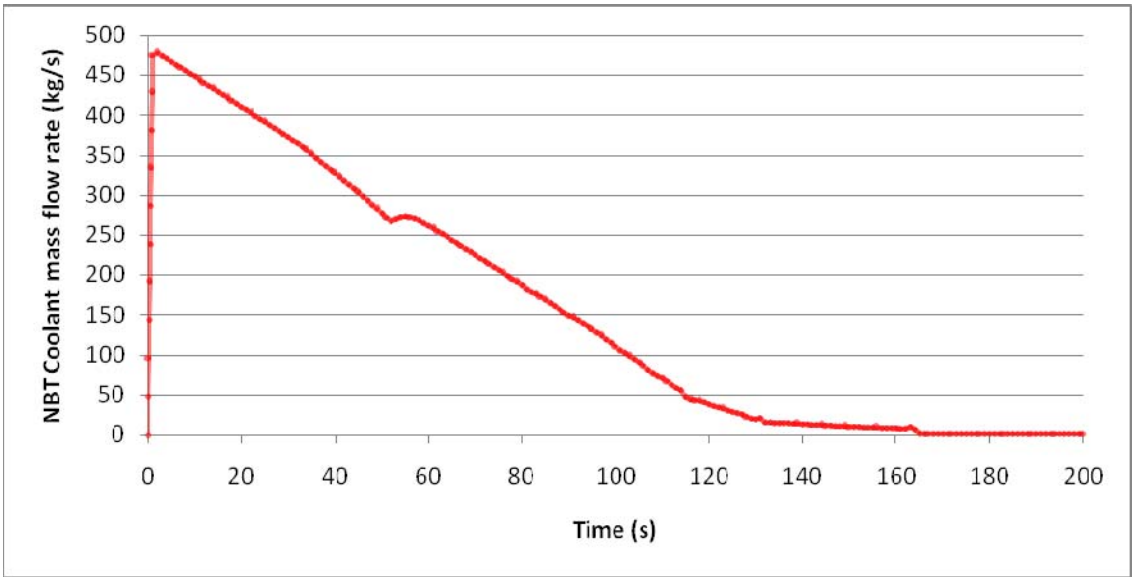

Figure 3: The coolant mass flow rate through the break of the NBT evolution

1. Figure 3 shows the evolution of the coolant mass flow rate through the NBT.Following the BDBA LOCA event, the coolant mass flow rate through the NBT break increases sharply from 0 to 477.9 kg/s. With the decrease in the reactor pool water level there is a decrease in the flow rate through the NBT break. The coolant flow rate through the NBT break reaches zero at 166 seconds when the reactor pool water level reaches the bottom level of the NBT.

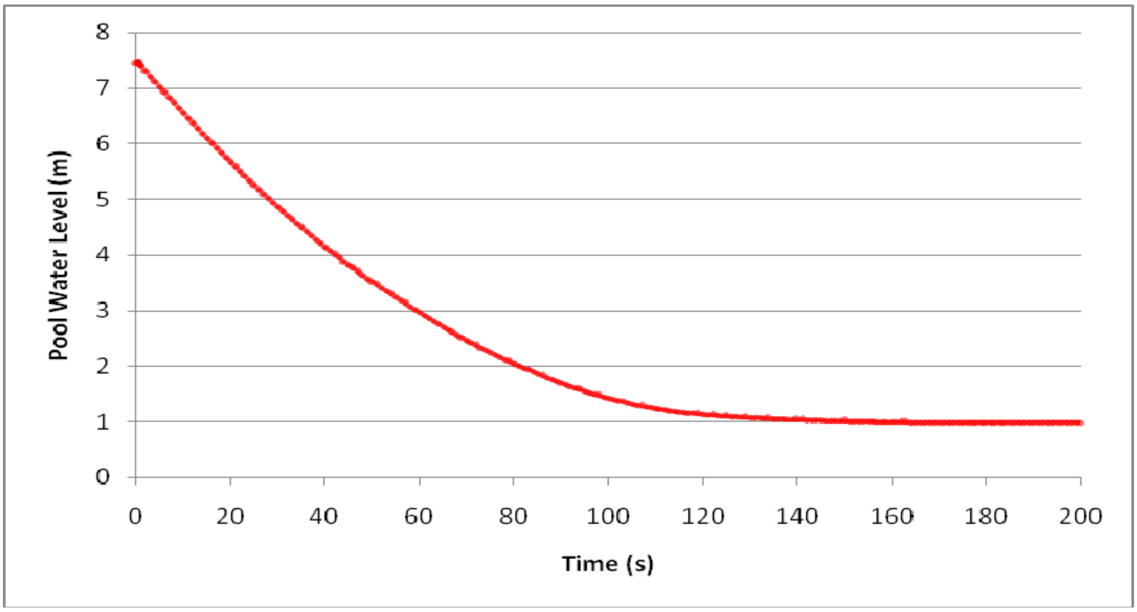

Figure 4: Reactor pool water level evolution

1. Figure 4 shows the evolution of the reactor pool water level. Following the BDBA LOCA event, the reactor pool water level decreases rapidly due to the rupture of the NBT. The decrease in the water column level in the reactor pool stops at the bottom level of the NBT.

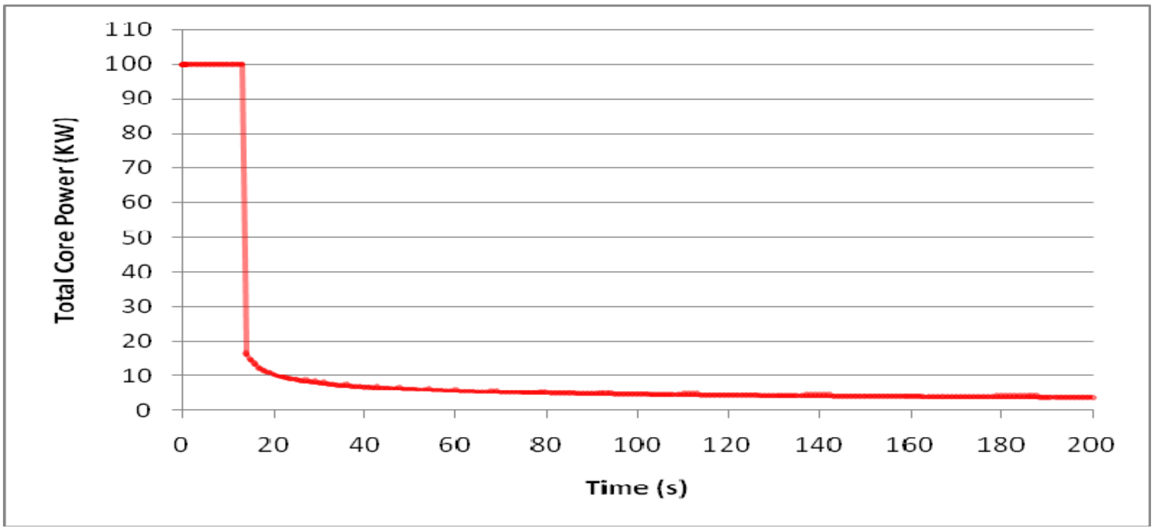

Figure 5: Total core power evolution – Actuation of the RSS

1. Figure 5 shows the total core power evolution with the actuation of the RSS. After the LOCA event the core power is 100 kW for 13 seconds till the reactor pool water level decreases 1 m below its top level. The RPS triggers the RSS due to the low water level signal and the RSS control rods will be inserted into the core to shut down the reactor. Following reactor shut down the decay heat from the fission products and actinides is the only source of heat generation in the core.

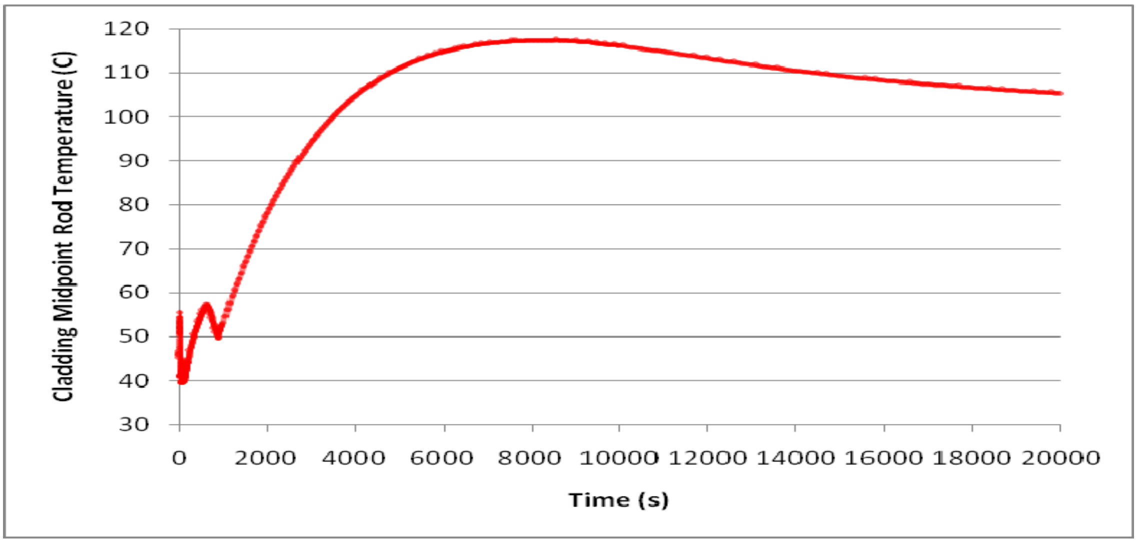

Figure 6: Evolution of the cladding midpoint rod temperature of the hot channel.

1. Figure 6 shows the evolution of the cladding midpoint rod temperature of the hot channel.

2. After the LOCA event, only 10 cm at the bottom level of the core is covered by water and the rest of the core is uncovered.

3. This 10 cm of water interferes with the natural air circulation in the vertical direction. But because the hot and average channels in the core are open channels and also are open to the reactor pool cold leg and to the volume of air connected to the pool via the NBT break, there will be cross flow among the cold leg and the average and hot channels. This is a significant difference with MTR type cores where the fuel is enclosed inside the fuel elements and there is no possibility of cross flow of air inside the core. The presence of the side plates, effectively forming a box that houses the MTR type fuel plates, inhibits the cross circulation of air.

4. The maximum cladding midpoint temperature is 117.5 °C at 8300 seconds.

7. Conclusions

1. The thermal conditions for the fuel rods following a BDBA scenario that results in LOCA in the NBT have been analysed.

2. The analyses performed, of the core composed by (900 fuel rods); demonstrate that the maximum cladding midpoint temperature reaches 117.5°C at 8300 seconds.

3. This complies with the acceptance criterion to demonstrate no damage to the core.

8. References

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