2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
***ISBN:* 978-85-99141-03-8**

ESTIMATIVE OF CORE DAMAGE FREQUENCY IN IPEN`S IEA-R1 RESEARCH REACTOR DUE TO THE INITIATING EVENT OF LOSS OF COOLANT CAUSED BY LARGE RUPTURE IN THE PIPE OF THE PRIMARY CIRCUIT.

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ABSTRACT

The National Commission of Nuclear Energy (CNEN), which is the Brazilian nuclear regulatory commission, imposes safety and licensing standards in order to ensure that the nuclear power plants operate in a safe way. For licensing a nuclear reactor one of the demands of CNEN is the simulation of some accidents and thermal-hydraulic transients considered as design base to verify the integrity of the plant when submitted to adverse conditions. The accidents that must be simulated are those that present large probability to occur or those that can cause more serious consequences. According to the FSAR (Final Safety Analysis Report) the initiating event that can cause the largest damage in the core, of the IEA-R1 research reactor at IPEN-CNEN/SP, is the LOCA (Loss of Coolant Accident). The objective of this paper is estimate the frequency of the IEA-R1 core damage, caused by this initiating event. In this paper we analyze the accident evolution and performance of the systems which should mitigate this event: the Emergency Coolant Core System (ECCS) and the isolated pool system. They will be analyzed by means of the event tree. In this work the reliability of these systems are also quantified using the fault tree.

1. INTRODUCTION

One of CNEN's demands for the licensing of nuclear reactors is carrying out simulations of some accidents and thermal hydraulic transients, considered as the design basis, in order to verify the integrity of the plant when submitted to adverse conditions [1]. Accidents which must be simulated are those which represent higher probability of occurrence or that can cause more serious damages. One of these accidents is the loss of the primary coolant, which consists in the total or partial loss of the reactor coolant. For the IEA-R1, the main consequences of this kind of event might be the reduction or loss of the radiological barrier provided by the pool water and the degradation in the cooling of the fuel.

From the initiating events in the loss of primary coolant category, which are identified and analyzed in [2] and listed in Table 1, the event of large LOCA is the one which causes the largest consequences due to the possibility of uncovering the core in less time than all other events in this category (approximately 6 minutes). The objective of this paper is to calculate the estimative of core damages frequency in the IEA-R1 due to the occurrence of this initiating event. The evolution of the accident and performance of the systems which should mitigate this event will be analyzed by means of the event tree: emergency coolant core system and pool isolating system. Furthermore, the reliability of these systems will be quantified using the fault tree.

Table 1. Initiating events for LOCA category

Category	Initiating Event
Loss of Coolant	Rupture of primary circuit
	Pool damage
	Loss of water pool 1. Loss of water through retreatment system; 2. Loss of water through drain.
	Failure in irradiation pipes
	Failure of the primary circuit drain
	Failure in pneumatic pipes of irradiation material
	Failure in thermal column

2. ACCIDENT ANALYSIS

The postulated event would be a complete rupture, guillotine type, of the primary coolant return pipe, next to the pool, that could lead to pool emptiness in about 6 minutes [2]. Once the primary circuit operates in low pressure and temperature, the guillotine rupture of the pipe would happen only by means of missile. However, the circuit is well protected against external events, and high magnitude earthquakes or aircraft falls occurrences are very unlikely according to the references [2].

2.1 Plant description

The IEA-R1 is a 5 MW pool type research reactor. Its core is basically composed by a set of fuel elements of the type Material Test Reactor (MTR) which stays submersed in the pool and hanged by a metallic structure. The reactor is moderated and cooled with light water and its cooling is made by the passage of the water contained in the pool through the fuel elements. The primary circuit consists of the pool with the reactor’s core, convection valve and two heat exchanger circuits in parallel. Each circuit contains a circulation pump, a heat exchanger, pipes, valves, and the instruments for its operational control. Its function is to provide the adequate cooling of the core, assuring that the fuel project criteria is not exceeded during any normal plant operation condition.

In order to assure the core integrity, even in the occurrence of an initiating event of this type, the reactor has two systems as described below:

- **Pool isolation:** this system interrupts the loss of primary coolant. The primary circuit has two sets of three isolation valves. Each isolation set is composed of a manual valve and two motor valves (one redundant) remotely operated. The four motorized valves are located in four strategic positions, very close to the concrete walls of the pool, being two at the beginning (out of the pool) and two at the end of the pipe of the primary circuit (entrance of the pool). They are physically protected in this way against possible impacts. These valves are automatically activated when the water level in the pool reaches 400 mm below the normal level. The closing of just one motorized valve of each set is enough to isolate the pool from the primary circuit, i.e., one valve of each set is redundant. **Emergency Coolant Core System:** this system cools the reactor's core in case it is uncovered. The ECCS is a passive system composed by a storage tank which injects water directly over the core by gravity, through the opening of two valves which are automatically activated when the pool level reaches 4,500 mm below the normal level.

2.2. Hypothesis

For the analysis of this accident the following hypothesis are assumed:

- reactor in normal operation at full power;
- after the rupture, the reactor protection system shutdowns the reactor.
- it is not considered the possibility of isolation of the pool minutes after the pipe rupture through manual valves, due to the fact that they need the intervention of the operator at the local of the valves, located in the basement and inaccessible during the reactor operation;
- before the occurrence of the rupture both water storage tanks from the ECCS are full;
- before the occurrence of the rupture all support systems are available;
- the rupture of the pipe occurs in one of operating periods of the reactor. Each operating period has duration of 63 hours.

2.3 Accident description

The expected sequence of events for the case of rupture of the primary circuit would be as follows [2]:

- rupture of the 10" pipe of the primary circuit (next to the return to the pool);
- alarm signal of low water level in 200 mm below normal level;
- automatic reactor shutdown when water level reaches 350 mm below normal level;
- automatic shutdown of the primary pump and closing of the isolation valves of primary circuit when water level reaches 400 mm below normal level.
- the time of closure of isolation valves is expected to be around 30 to 60 seconds, ensuring a minimum final level of water in the pool between 6.0 and 7.5 meters above the bottom;
- with the pool isolated and core covered, there will be decoupling of the convection valve, starting the cooling by natural circulation, which is sufficient to remove the decay heat and maintain the core at low temperatures;
- in case of no decoupling of the convection valve, the natural circulation will not be established and can cause local damage in the fuel plates [3];

- in case of failure in closing the isolation valves after the rupture of the pipe, the total emptying of the pool will occur in about 6 minutes. When the water level in the pool reaches 4,500 mm below the normal level, the Emergency Core Coolant System (ECCS), of passive action, is activated; which will ensure the cooling of the core.

2.4. Analysis of the accidental sequences

The development of the accident after the initiating event is show in the event tree of the Figure 1. The four resulting accidental sequences are:

- **SEQ1**: rupture of the pipe and isolation system of the pool operating successfully, decoupling of the convection valve and consequent establishment of natural circulation. This sequence leads to a final state without core damage;
- **SEQ2**: rupture of the pipe and isolation system of the pool operating successfully and failure in the decoupling of the convection valve without the establishment of natural circulation. This sequence may lead to a final state with local damage in the fuel [3];
- **SEQ3**: rupture of the pipe with failure in the isolation system of the pool and emergency coolant core system successfully working. This sequence leads to a final state without core damage, because the ECCS was designed to cool the core and remove the decay heat in this situation. It should be emphasized that this sequence leads to loss of radiation shielding provided by the pool water, resulting in direct exposure of the reactor core and, consequently, in high doses in the pool lobby and possibly inside the reactor building;
- **SEQ4**: rupture of the pipe with failure in the isolation system of the pool and failure in the performance of the emergency coolant core system. This sequence leads to a final state with core damage, because the core is uncovered. This scenario is the most severe with melting of fuel, and there may be release of radioactivity. It must be emphasized that the reactor has a ventilation system that should act to control potential releases of radioactivity in this accidental condition.

2.5 Estimation of frequencies

The frequency of occurrence of the four accidental sequences described above depends on the following values:

- frequency of rupture of the pipe of the primary;
- probability of failure in isolating the pool;
- probability of failure in the performance of the natural circulation;
- probability of failure of the ECCS.

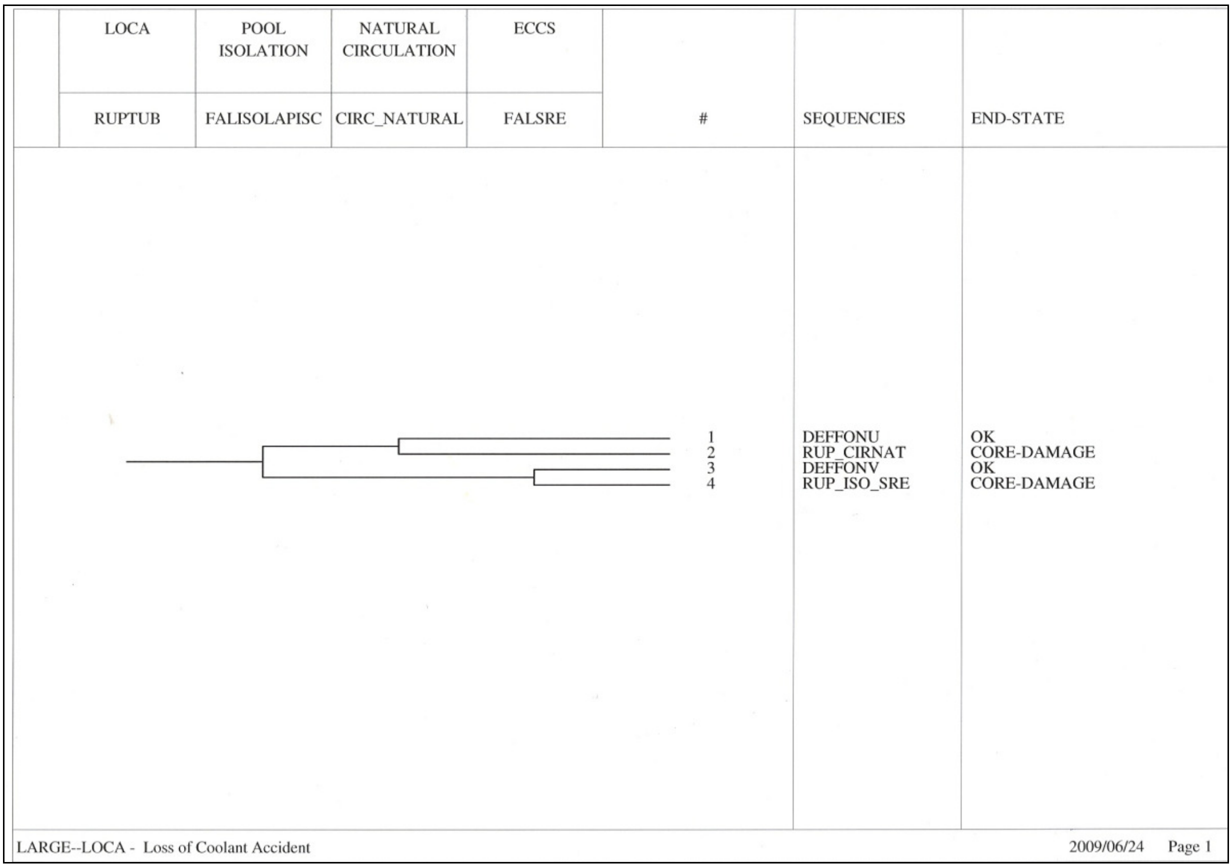

Figure 1. Event tree for the initiating event LOCA

In order to obtain the probability of failure of both the isolation system of the pool and the emergency cooling system was necessary to obtain the probability of failure in the supply of electric energy in the following electric panels:

- motor control center of 440 V– vital bus;
- motor control center of 440 V– essential bus;
- electric distribution panel of 220 V – vital.

The probabilities of failure were obtained using the fault tree with program SAPHIRE [4] and data of failures shown in Table 2. These data were obtained from generic databases [5, 6], data from similar plant [3] and specific data from IEA-R1 [7].

Table 2. Failure data

COMPONENT	DESCRIPTION	FAILURE RATE / HOUR	FAILURE PROBABILITY	REFERENCE
ALARM	ALARM FAILURE	7.50E-05		[5]
BATERY	BATERYFAILURE (ALL MODES)	4.60E-06		[5]
CABLES AND CONECTIONS	CABLES AND CONECTIONS FAILURE	9.00E-07 6 ou 4 x 9E-07 6 ou 4 =NR connections		[5]
CIRCUIT BREAKER	CIRCUIT BREAK FAILURE	2.0E-06		[5]
CONTACTOR	CONTACTOR FAILURE (ALL MODES)	6.0E-5		[6]
DIESEL GENERATOR	FAILURE TO RUN		4.23E-02	[7]
DIESEL GENERATOR	FAILURE IN OPERATION	2.82E-02		[7]
DIESEL MOTOR (MOTO GENERATOR)	FAILURE TO RUN		7.00 E-03	[5]
DIESEL MOTOR (MOTO GENERATOR)	FAILURE IN OPERATION	2.30E-05		[3]
DISTRIBUTION POWER BUS (13.2 KV)	BUS FAILURE (ALL MODES)	2.30E-06		[5]
ECCS PIPING	ECCS PIPING FAILURE (RUPTURE OR BLOCKAGE)	1.40E-06		[5]
ELETRIC MOTOR (CNB)	ELETRIC MOTOR FAILURE	2.30E-06		[5]
ELETRIC PANEL	ELETRIC PANEL FAILURE (ALL MODES)	4.86E-04	-	[7]
FUSE	FUSE FAILURE	5.00E-06		[5]
HAND VALVE	HAND VALVE FAILURE (DOES NOT OPEN)	3.00E-07		[3]
HUMAN ERROR	OPERATOR FAILURE TO ACT		1.00E-02	[3]
INTERRUPTER	INTERRUPTER FAILURE (SPURIOUS OPEN)	1.0E-06		[6]
INVERTER	INVERTER FAILURE (ALL MODES)	1.60E-05		[5]
LEVEL SENSOR	POOL LEVEL SENSOR FAILURE	2.82E-05		[5]
MAGNETIC CULTCH	MAGNETIC CULTCH FAIL TO ENGAGE	3.0E-04		[6]
MONOPHASE BUS (120-220 V)	BUS FAILURE (ALL MODES)	7.20E-05		[5]
MOTO GENERATOR (220 V)	MOTO GENERATOR FAILURE (ALL MODES)	7.70E-06		[5]
MOTO GENERATOR (440 V)	MOTO GENERATOR FAILURE (ALL MODES)	7.70E-06		[5]
POOL ISOLATED VALVE	POOL ISOLATED VALVE FAILURE (DOES NOT CLOSE)	7.29E-05		[7]
RELAY	RELAY FAILURE	8.30E-06		[5]
RETIFIER	RETIFIER FAILURE (ALL MODES)	1.14E-05		[5]
SOLENOID VALVE	SOLENOID VALVE FAILURE (DOES NOT OPEN)	4.50E-06		[5]
SPRAY	SPRAYFAILURE	1.4E-08		[5]
THREE PHASE BUS (220-440 V)	BUS FAILURE (ALL MODES)	3.10E-06		[5]
TRANSFORMER (13.2 KV/440V-220V)	TRANSFORMER FAILURE (ALL MODES)	1.38E-05		[5]
TWO WAY VALVE	TWO WAY VALVE FAILURE (BLOCKAGE)	1.4E-07		[5]

The results obtained are:

- probability of failure in the pool isolation = 1.53 E-03;
- probability of failure of the ECCS = 1.97E-04.

The probability of failure in natural circulation was obtained from reference [3] = 1.008E-02.

The rupture frequency of the primary circuit from reference [3] = 1.2E-04/year.

Using the program SAPHIRE and values from above, it was obtained the frequencies of occurrence of the sequences that lead to core damage (SEQ2 and SEQ4), which are equal to 1.21E-06 and 1.35E-10 per year, respectively.

3. CONCLUSIONS

In this work it was calculated the estimation of core damage frequency of the IEA-R1 reactor, due to the event of rupture of the pipe of the primary circuit. It was analyzed the evolution of the accident and the performance of systems that should mitigate this event: emergency coolant core system and isolation system of the pool of the reactor. Furthermore, it was assessed the reliability of these systems and electric power supply system.

Of the four accidental sequences (Figure 2), two sequences lead to scenarios with core damage (SEQ2 and SEQ4). The values obtained for the occurrence frequencies of these sequences are:

- occurrence frequency SEQ2 = 1.21E-06;
- occurrence frequency SEQ4 = 1.35E-10.

As expected, the value is low, the same order of magnitude as obtained in the reactor Greek (SEQ2 = 1.19E-06 e SEQ4= 1.26E-10), which is a similar plant to reactor IEA-R1. These values indicate the low frequency of occurrence of the postulated initiating event (large LOCA) and high reliability of the systems that should mitigate the occurrence of this initiating event.

Although the SEQ3 doesn't lead to core damage, this is not a totally safe scenario, because it leads to loss of radioactive shielding provided by the water of the pool, resulting in direct exposure of the reactor core and, consequently, in high doses in the pool lobby and possibly within the reactor building.

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