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Inherent Safety Feature of Hybrid Low Power Research Reactor during Reactivity Induced Accident

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1. Introduction

Hybrid low power research reactor(H-LPRR) is the new design concept of low power research reactor for critical facility as well as education and training. In the case of typical low power research reactor, the purposes of utilization are the experiments for education of nuclear engineering students, Neutron Activation Analysis(NAA) and radio-isotope production for research purpose. For the case of H-LPRR, the experiments to observe neutronic characteristics of reactor or fuel can also be performed by using the central region of core provided by laterally separating the core into two regions.

H-LPRR is a light-water cooled and moderated research reactor that uses rod-type LEU UO_2 fuels same as those for commercial power plants. The maximum core thermal power is 70kW and, the core is placed in the bottom of open pool. There are 1 control rod and 2 shutdown rods in the core. It is designed to cool the core by natural convection, retain negative feedback coefficient for entire fuel periods and operate for 20 years without refueling.

Since H-LPRR is likely to be constructed near areas of high population density such as university and to be accessed by untrained personnel, high level of safety is required. Therefore it is desirable to satisfy the safety requirement by 'inherent safety'.

Inherent safety in H-LPRR is achieved by passive design features such as negative temperature feedback coefficient and core cooling by natural convection during normal and emergency conditions. In other words, the reactor can control itself even in a transient leading to core power increase. Herein, the purpose of this study is to find out that the inherent safety characteristics of H-LPRR is able to control the power and protect the reactor from the RIA(Reactivity induced accident).

2. Modeling method

RELAP5/MOD3.3Patch4 was used for the analysis of behavior of reactor during transient[1]. The modeling is described as below.

2.1. Nodalization

Fig 1 shows a nodal diagram of the modeled H-LPRR. Fuel region is modeled as a hot channel(210) and average channel(220) with corresponding heat structure. The hot channel indicates the coolant channel in a hottest fuel assembly considering peaking factor and, the average channel means the coolant channel in the rest of fuel assemblies excepting hot channel. The reactor structure assembly(RSA) model consists of inlet plenum(270), grid plate(280) and core wall(290). The Inlet plenum and core wall are connected to the pool components. Pool is divided by 4 interconnected hydrodynamic volumes(110, 120, 130, 140) in accordance with the height of each of RSA components. The pool water management system is simply modeled as boundary condition with constant flow rate and temperature. Coolant is suctioned from the top of the RSA (310) and dumped into upper pool near the surface. The volume of 190 represents pressure boundary of atmospheric condition.

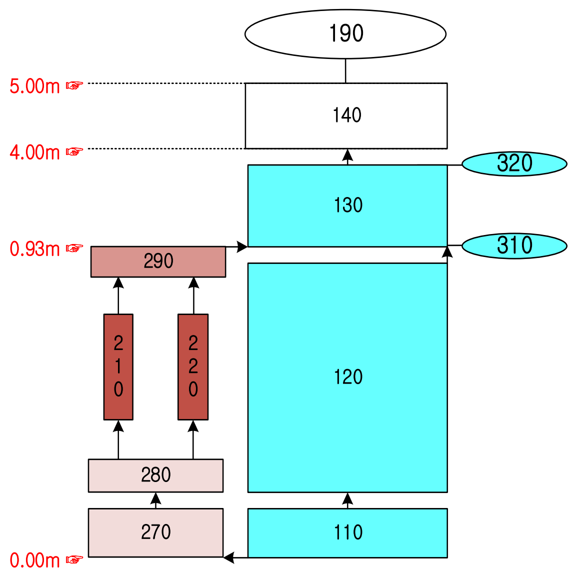

Fig 1. Nodal Diagram of Hybrid Low Power Research Reactor(H-LPRR)

2.2. Input parameter

It is assumed that the reactor is operating at its maximum power, 70kW. Temperature feedback coefficients are negative except reflector temperature coefficient. For view of conservative analysis, a less negative fuel temperature coefficient is used by adding the reflector temperature coefficient. Table 1 summarizes the key input parameters and their values.

Table 1. Input parameter

Parameter	Value
Reactor Power	70kW
Initial coolant temperature	20℃
Pool water level	4m
Peaking factor	1.87
Fuel temperature coefficient	-0.0121mk/K
Coolant temperature coefficient	-0.1744mk/K

2.3. Accident scenario

Inadvertent withdrawal of a control rod is considered an initiating event of RIA[2]. Conservatively, the maximum withdrawal speed and maximum differential worth are used to calculate the maximum reactivity insertion rate. Reactivity insertion rate is calculated as 0.264mk/s. The core excess reactivity is assumed to be 5mk which is the maximum value as well. To observe the inherent safety in the reactor design, it is assumed any trip signal from reactor protect system is ignored even though the reactor state reaches to the trip set-point subsequent to the initiating event.

3. Results

Using the model described above, a transient analyses are carried out for 10,000sec. Fig 2 shows the reactor power responses during transient. Reactor power increases rapidly after the control rod starts to withdraw at 0sec, and reaches to the maximum value of 994kW at 212sec. Then, the power level decreases gradually and converges to a constant power.

The reactivity behavior is presented in Fig 3, showing core reactivity, insertion reactivity and reactivity feedback (fuel temperature feedback, coolant temperature feedback). To observe the temperature behavior, the response of the average fuel centerline temperature and coolant temperature in the hottest fuel assembly are presented in Fig 4. Reactivity is inserted by control rod withdrawal and, core reactivity increases leading to rapid power increase. According to the power increase, fuel and coolant temperatures are raised quickly and, negative feedback reactivity is inserted.

Since fuel temperature has decreased by core reactivity drop and continuous natural convection cooling, fuel temperature feedback has diminished. But coolant temperature feedback increases with time and retain a constant value. This is from the fact that coolant temperature increases due to reactor power and reaches a constant when reactor power is equivalent to the cooling capacity of pool water management system. Finally the core reactivity becomes the almost zero keeping constant power.

Maximum coolant temperature is 65.9℃, quite below the saturation temperature. Maximum fuel centerline temperature and maximum cladding temperature during transient are 537.1℃ and 131.3℃ respectively, which are much smaller than melting temperature.

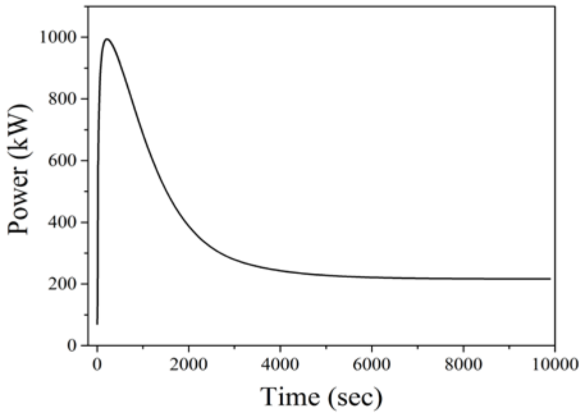

Fig 2. Reactor power responses in RIA.

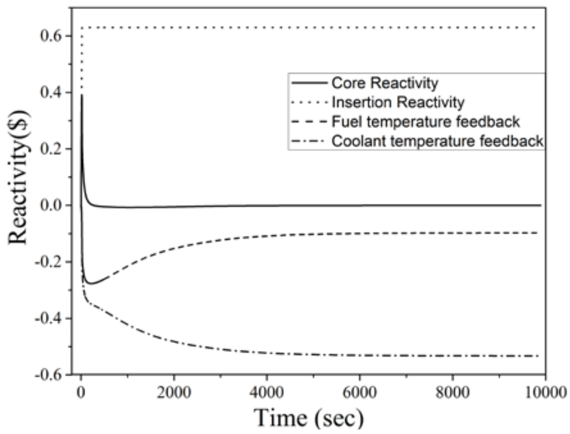

Fig 3. Reactivity responses in RIA.

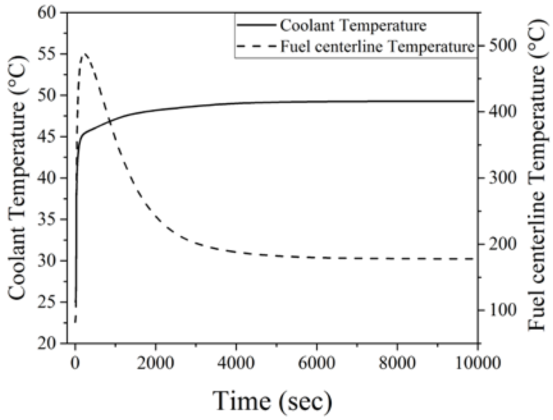

Fig 4. The average fuel centerline temperature and coolant temperature responses in the hottest fuel assembly.

4. Conclusion

RIA analysis was performed to investigate the inherent safety feature of H-LPRR. As a result, it was found that the reactor controls its power without fuel damage in the event and that the reactor remains safe states inherently. Therefore, it is believed that high degree of safety inheres in H-LPRR.

Acknowledgement

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REFERENCES

[1] RELAP5/Mod3.3, Code Manual Volume V, User's Guideline, NUREG/CR-5535/Rev1, 2001
[2] IAEA Safety Standards, Safety requirement No. NS-R-4, 2005