Cooling Performance of Natural Circulation for a Research Reactor

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1. Introduction

The core decay heat is usually removed by natural circulation to the reactor pool water in open tank-in-pool type research reactors with the thermal power less than several megawatts. Therefore, these reactors have generally no active core cooling system against a loss of normal forced flow [1]. In reactors with the thermal power less than around one megawatt, the reactor core can be cooled down by natural circulation even during normal full power operation.

This paper deals with the core cooling performance by natural circulation during normal operation and a flow channel blockage event in an open tank-in-pool type research reactor. The cooling performance is predicted by using the RELAP5/ MOD3.3 code [2, 3].

2. RELAP5 Modeling

Fig. 1 shows the node diagram used in this study. The fuel assemblies and reflectors are modeled as several pipes and heat structures in RELAP5 code. Through P210 to P230 indicate flow channels between fuel plates and flow paths bypassing the flow channels. Of them through P210 to P212 model each single flow channel. Through HS210 to HS220 are heat structures for modelling the fuel plates. Each flow channel is surrounded with two fuel plates and two side plates which tighten 21 fuel plates. The gap and width are 2.35 mm and 66.6 mm, respectively while the thickness and heated length of fuel plates are 1.27 mm and 640 mm, respectively.

B280 and V290 are the core outlet plenum and P200 and B202 are the core inlet plenum named based on the normal flow direction for power operation. V132, B140 and V150 indicate the reactor pool while P314, B312 and P300 model the core outlet pipe. The nominal pipe size of P300 is 16 inches. FV313 is the flap valve, which opens when the primary cooling pump stops. And then natural circulation flow is established through the reactor pool, flap valve, core outlet pipe, core outlet plenum, core flow channels and core inlet plenum. The nominal size of the flap valve and its connected pipe is 6 inches. The red figures in Fig. 1 show the height from the reactor pool bottom.

The main investigated flow channel and fuel plate are P211 and HS210 during normal operation. For single channel blockage analysis, flow channel of P210 is assumed to be blocked. The surfaces of HS210 and HS212 facing P210 are modelled as insulation boundaries in this analysis.

The cooling performance of natural circulation is predicted as the core power slowly and monotonously increases as shown in Fig. 2. The core thermal power is maintained 1.0 kW for 200 seconds and then increased at 1 kW/sec. The initial pool water and core coolant temperature is assumed to be 48℃. The axial power and peaking factor are assumed similar to a chopped cosine shape and 3.0, respectively.

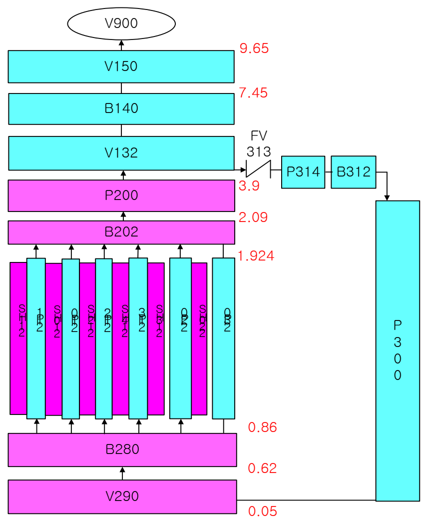

Fig. 1. Node diagram for RELAP5 simulation

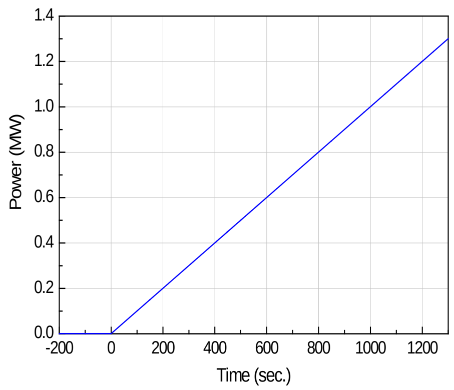

Fig. 2. Core power history

3. Results

3.1 Normal Natural Circulation

Fig. 3 through Fig. 6 show the flow rates, coolant temperatures and void fractions at the flow channels, and both surface temperatures of the fuel plate during normal natural circulation (NNC). The negative sign indicates an upward flow direction in Fig. 3.

As the core power goes up, the flow rates slowly increase and start to oscillate at around 1160 seconds after the core power begins to increase.

The coolant temperature at the top of the flow channel of P211 increases fast up to around 100 seconds, goes up gradually up to around 1160 seconds, and then begins to oscillate. The coolant temperature is not increased further. Right after the power begins to increase, the fast rise of the coolant temperature results from that the natural circulation is not sufficiently established as compared with the enhanced power. The coolant temperature at the bottom of the flow channel remains almost constant.

The oscillation of the flow rates and coolant temperature is consistent with the void fraction at the top of the flow channel as shown in Fig. 5. Steam bubbles at the middle and bottom of the flow channel do not appear in this calculation.

The behavior of fuel plate temperatures is generally similar to that of coolant temperature. Right after the core power begins to go up, the fuel plate temperatures rise fast and then gradually increase. However, the trend of temperature increase is changed at around 720 seconds. This results from that the heat transfer mode of single phase convection is replaced by subcooled nucleate boiling.

It is calculated that the maximum power without void generation at the hot channel is around 1.16 MW in normal natural circulation conditions. At this power the coolant average temperature at the core top is around 90℃ and the maximum fuel temperature is around 125℃.

3.2 Flow Channel Blockage

Fig.7 through Fig. 10 show the flow rates, coolant temperatures and void fractions at the flow channels, and both surface temperatures of the fuel plate during an event of a flow channel blockage (FCB).

As the core power increases, the flow rate at P211 slowly increases and starts to oscillate at around 820 seconds after the core power begins to increase. The flow fluctuation becomes stronger with the increase of power. There is no flow at the blocked channel.

The coolant temperature at the top of the flow channel of P211 increases fast up to around 100 seconds, goes up gradually up to around 820 seconds, and then begins to oscillate. The maximum coolant temperature equals to the saturation temperature. The coolant temperature at the bottom of the flow channel remains almost constant up to around 1000 seconds. After then, however, it also starts to oscillate. This is caused by highly oscillated flow at the channel. As shown in Fig. 9, the oscillation of the flow rates and coolant temperature is consistent with the void fraction in the flow channel. As the power increases, the void fraction becomes larger at the top, middle and bottom of the channel.

The faster increase of coolant temperature and earlier void generation in this case than in the normal natural circulation result from the flow channel blockage of P210. That is, all heat generated at the fuel plate of HS210 is transferred to the flow channel of P211.

Right after the core power begins to go up, the fuel plate temperatures increase fast and then gradually increase. However, the trend of temperature increase is changed at around 330 seconds. This change is due to the heat transfer mode transition from single phase convection to subcooled nucleate boiling. The fuel surface temperature of P210 side is greater than that of P211 side due to the flow channel blockage of P210. The temperature difference increases with the increase of power.

It is found that the maximum power without void generation at the hot channel beside the blocked channel is around 820 kW in this calculation. At this power the coolant average temperature at the core top is around 82℃ and the maximum fuel temperature is around 136℃.

4. Conclusions

The cooling performance of natural circulation in an open tank-in-pool type research reactor has been investigated during the normal natural circulation and a flow channel blockage event. It is found that the maximum powers without void generation at the hot channel are around 1.16 MW and 820 kW, respectively, for the normal natural circulation and the flow channel blockage event.

Acknowledgement

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References

[1] Park, S., et. al., Cooling Capability of Pool Water for a 5-MW Poo-type Research Reactor, Trans. Of KNS, Spring Meeting, Gwangju, Korea, May 30-31, 2013.

[2] RELAP5/Mod3.3, Code Manual Volume IV, Models and Correlations, NUREG/CR-5535/Rev1, 2001.

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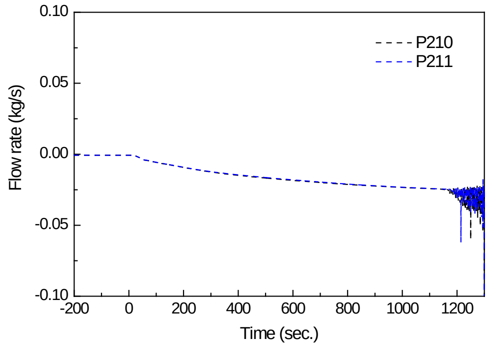

Fig. 3. Flow rates at the flow channels (NNC)

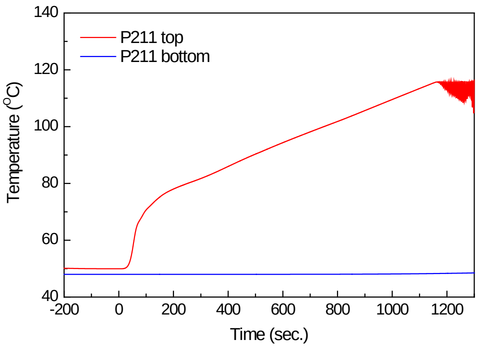

Fig. 4. Coolant temperatures at the flow channel (NNC)

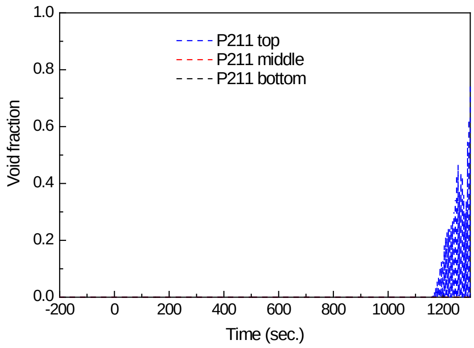

Fig. 5. Void fractions at the flow channel (NNC)

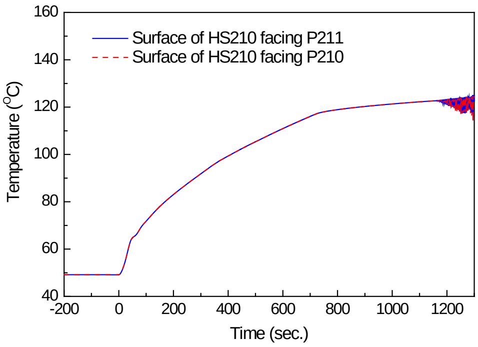

Fig. 6. Fuel surface temperatures at the fuel plate (NNC)

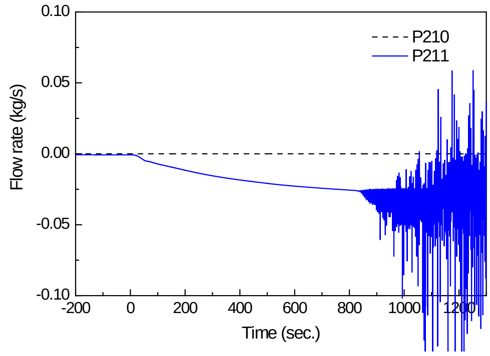

Fig. 7. Flow rates at the flow channels (FCB)

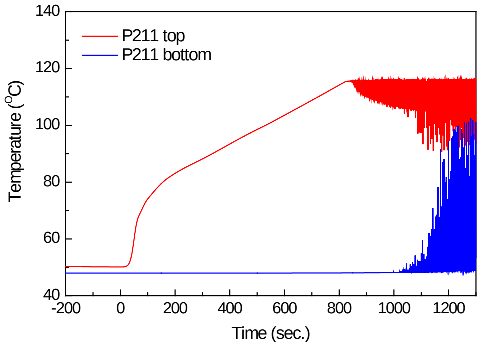

Fig. 8. Coolant temperatures at the flow channel (FCB)

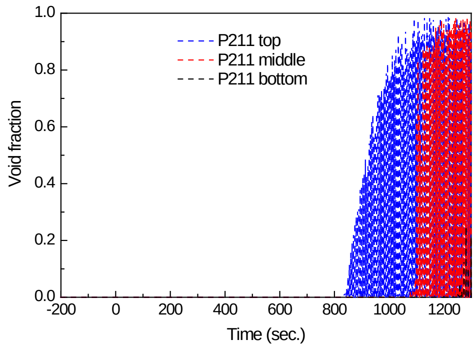

Fig. 9. Void fractions at the flow channel (FCB)

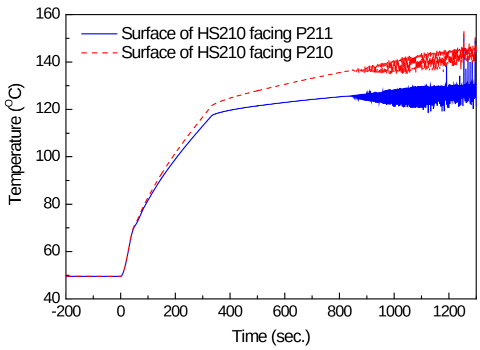

Fig. 10. Fuel surface temperatures at the fuel plate (FCB)