Reevaluation of Kori Unit 4 Natural Circulation Test

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1. Introduction

Passive cooling of reactor is inevitable in case of failures in forced cooling system such as loss of electric power for cooling pumps. Fukushima accident showed the importance of the passive core cooling. During the commissioning test of PWRs, natural circulation test is performed to demonstrate the passive core cooling by natural convection. The driving force for coolant flow is developed by the density deference along the loop multiplied by the gravitation. Using the data from "natural circulation test" and "RCS flow coast down test" [4] of Kori Unit 4, fuel behavior was reevaluated by FRAPTRAN code [1].

2. Methods

In this section an evaluation techniques were used to verify the extent to which the system is capable to remove the decay heat by natural circulation. Flow transient caused by loss of pumping power and heat transfer in the fuel rod were modeled by FRAPTRAN code.

2.1 Modeling of Mass Flow Rate

During the natural circulation test of Kori Unit 4 (2775MW thermal, core power), decay heat is simulated by operating the reactor at 3.666 % power. Three reactor coolant pumps were tripped and RCS flow started to decrease. The primary coolant system flow behavior was measured during the "RCS flow coast down test". The measured data cover only 10 seconds after the RCP trip. To extrapolate the flow rate up to the time when flow is stabilized at the natural convection flow, the following simple model (equation 1) was used. In this model, the fluid speed decreases by friction force which proportional to the square of the speed.

$$m\frac{dv}{dt} = -kv^2 \tag{1}$$

The solution of equation (1) is given in equation (2). The coefficient, 0.066, of t in equation (2) is derived from the measured data from "RCS flow coast down test".

$$F_{(t)} = \frac{F_0}{1+0.066*t} \tag{2}$$

The flow rate started to decrease from 5000 $\frac{kg}{s.m^2}$ which is the flow rate of all pump running condition. When the flow rate decreases to 194.09 $\frac{kg}{s.m^2}$ (the natural convection flow rate after 400 seconds from pumps trip), constant flow rate of this value is used until the end of flow transient. The mass flow rate applied in the FRAPTRAN model is shown in Fig. (1).

During the "natural circulation test", [3] the hot leg and the cold leg temperature were measured and the natural circulation flow rate was calculated by dividing reactor power (3.666 % F.P.) by the enthalpy difference (146.4151362 KW/kg) after the equilibrium flow is established.

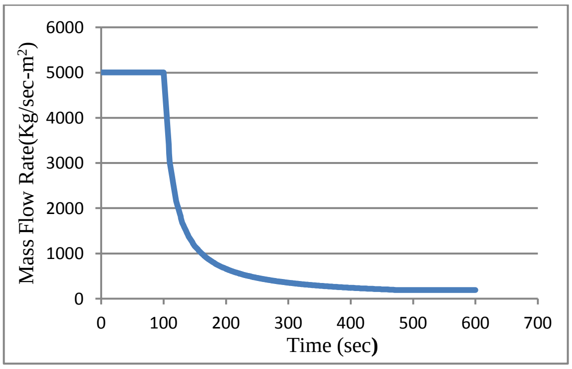

Fig.1. Mass flow rate used in the FRAPTRAN simulation.

2.2 Core Power Distribution

In the FRAPTRAN calculation, radial peaking factor of 1.59 in the Kori Unit 3, 4 FSAR [2] was used to represent the hot rod. The top skewed chopped cosine axial power profile, which was used in the calculation, is shown in Fig. (2).

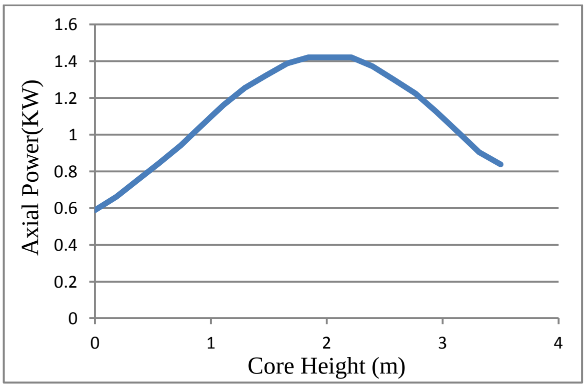

Fig.2. Axial Power Shape used in FRAPTRAN simulation.

3. Results

The result of FRAPTRAN calculation shows a good indication of the capability of the system to remove the decay heat from the fuel rod.

Because fuel rod power does not change during the "natural circulation test" to simulate decay heat, the FRAPTRAN calculation showed increasing temperature with decreasing coolant flow as expected. The time behaviors of various temperatures are shown in Fig. (3). For all temperatures except coolant temperature, the temperature differences do not change with time because rod power is maintained at constant value and so does the heat flux. But the temperature difference between coolant and cladding outer surface increases as the flow rate decreases because the heat transfer coefficient decreases along with the flow rate.

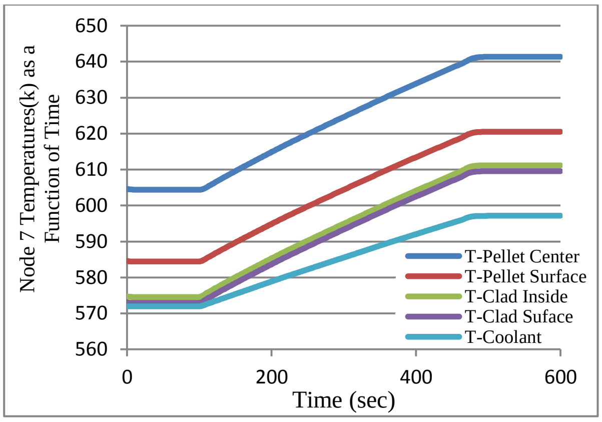

Fig.3. Temperatures of Node 7 as a Function of Time

After the RCP trip, coolant flow decreased to natural convection flow in 400 seconds and 8 seconds later pellet centerline temperature reached equilibrium value of 641 K in the 7th axial node which represents the location of the highest temperatures along the core height. Fig.(4) shows the axial variation of temperatures of the coolant, cladding and fuel pellet.

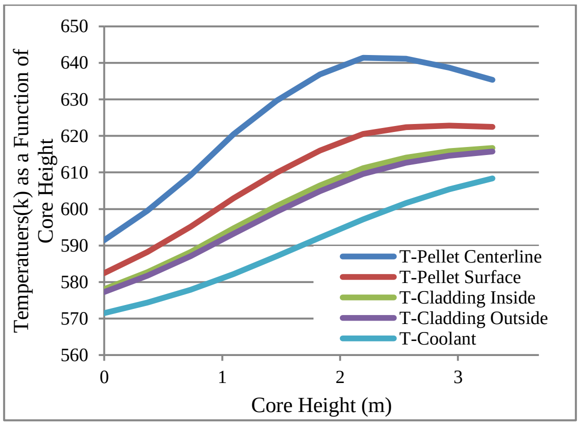

Fig.4. Axial variation of temperatures at natural circulation flow

The natural circulation flow rate is 3.88% of the flow rate for all pumps running condition. At this low flow rate, the frictional pressure drop across the fuel channel was not significant. Because the reactor power was maintained at 3.66% of full power during the test, the heat flux of the fuel rods was also close to this value. The FRAPTRAN simulation results showed that the natural circulation flow developed by density difference was capable of removing decay heat from the fuel rod. The maximum cladding temperature, maximum pellet centerline temperature at hot channel was 616.72 K, 641.37 K respectively. These temperatures were very low compared to the temperature of the normal operating condition. The maximum coolant temperature in the hot channel was 608.38 K which is well below the saturation temperature.

3. Conclusions

RCS natural circulation test of Kori Unit 4 was reevaluated by FRAPTYRAN simulation to study the fuel behavior during the flow coast down transient and at the equilibrium condition in which decay heat transport and RCS flow were stabilized. The simulation results showed that the natural circulation flow developed by density difference was capable of removing decay heat from the fuel rod. The maximum pellet centerline temperature of the hot channel showed large margin to the pellet melting temperature. The maximum coolant temperature in the hot channel was well below the saturation temperature. If steam generators provide heat sink to the primary coolant system and thus natural circulation is maintained, the integrity of the fuel in the core can be sustained with large margin.

REFERENCES

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