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Preliminary Thermal-Hydraulic Analysis of Beam Tube Break (BTLOCA) Accident at HANARO

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1. Introduction

HANARO is the 30MW pool-type research reactor with finned fuel rods composed of Uranium Silicide (U_3Si) and Aluminum alloy. The reactor is operated in atmospheric condition under the saturation temperature, and the fuel is cooled by natural convection when the primary cooling pumps stop. The passive core cooling during accidents prevents the fuel from damage in most of the postulated initiating events (PIEs).

The ultimate heat sink of the reactor during the accident is the pool water, which is maintained in the leak-tight pool liner supported by thick concrete walls. Even if the primary cooling pipes break outside of the pool, the pool level does not decrease lower than the top of the reactor core because the pipes and the devices such as pumps or heat exchangers locate higher than the core.

The only possible scenario which causes excessive loss of the pool water is the beam tube break. Beam tube is the penetration of pool wall for experimental apparatus, mostly for the utilizing the neutron flux from the core. The beam tube is designed to be leak-tight with multiple seals, however, the multiple failures of those seals causes the pool water loss.

In this paper, the loss of coolant accident by beam tube break (BTLOCA) was analyzed using MELCOR code, and preliminary results for the thermal-hydraulics of the reactor was presented. Although the probability of the BTLOCA is very low, the scenario provides the information required for the emergency preparation under extreme situations.

2. Modeling for Analysis

The MELCOR code is the systematic analysis code for severe accident of nuclear reactors [1]. The code contains a lot of sub-packages which can deal with the various physical phenomena during severe accident including core degradation and fission product behaviors. However, most of the models are developed for the commercial nuclear power plants with rod type UO_2 fuels. The U_3Si fuel of HANARO is therefore not suitable to be analyzed with MELCOR as is, and the fuel degradation behaviors including fission product release are under developing currently. Although the properties such as thermal conductivity and the specific heat of the fuel are correctly used for the fuel, only the thermal hydraulic behavior before the fuel degradation is analyzed for the reactor and the results are described in this article.

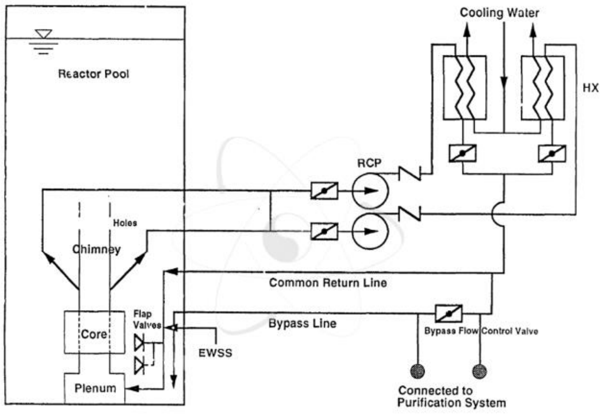

Fig. 1 System schematic of HANARO

Figure 1 shows the schematic of primary cooling system of HANARO, including the reactor structure assembly (RSA) and the pool. The reactor system is composed of two primary cooling trains, and each train has a reactor cooling pump (RCP) and a heat exchanger. The two cooling trains are then merged into a common return line before the reactor pool and connected to the lower plenum of the RSA. A bypass line is divided from the main cooling pipes for the purification of the primary coolant, and discharges the clean coolant into the pool.

The flap valves are connected to the common return line in the pool, as the paths of natural convection when the RCPs are stopped. The flap valves are passive type valves and designed to be opened when the pressure difference across the valves are lower than 100 Pa. The valves are normally closed when the PCPs are operational, and open by the pressure decrease in the common return line when the pumps stop.

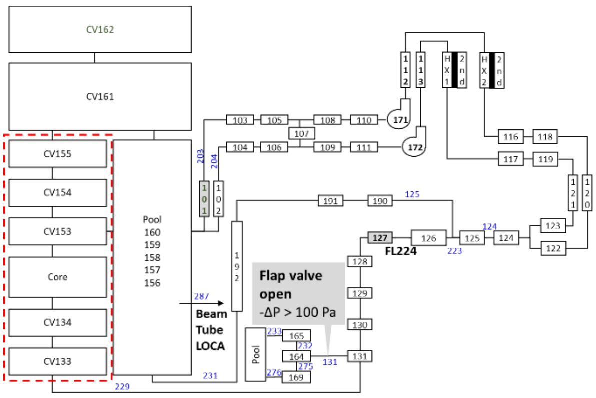

Fig. 2 Nodalization for MELCOR analysis

Figure 2 shows the nodalization of HANARO for MELCOR analyses. The information including the volumes and the connection between nodes are from the accident analyses report using RELAP/KMRR, which is the modified version of RELAP5/MOD2 developed for HANARO analyses [2].

Figure 3 shows the cross sectional view of a standard beam tube. The beam tube casing is installed in the concrete wall of the pool, and the multiple seals prevents the coolant leakage from the pool. The pool water can leak when the seal in front of the collimator and the diaphragm at the end of the beam tube break at the same time. When the both of the seal and the diaphragm break, the pool water leak through the small gap between the collimator and the first grouting, which is only 2 mm. The opening area of the gap is 1.546e-3 m^2, and the hydraulic diameter of the gap is 4 mm. The length of the gap is about 500 mm. The gap between the rear shielding plug and the grouting is also very small, however, the flow resistance of it is neglected because the opening area between the collimator and the grouting is smaller.

Table 1 shows the major initial conditions for the accident analysis. The conditions are determined conservatively considering the nominal design condition and the measurement uncertainty of the variables. Here, the pool level is the height from the fuel top, not from the pool bottom.

For accident analysis, following assumptions were used. Except for the flap valve operation, the other assumptions are given for conservative analyses.

1. Reactor is tripped by pool level low-low signal, which is 0.5 m lower than the nominal pool level.
2. The RCPs are tripped with the reactor trip. The operation of the RCPs does not affect the speed of pool level decreases.
3. Heat exchangers are stopped working when the reactor is tripped.
4. The flap valves open properly.
5. Emergency water supply system (EWSS) does not work.

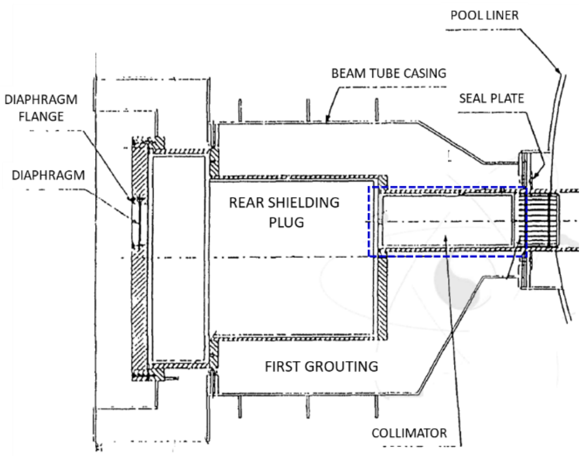

Fig. 3 Cross section of standard beam tube

Table 1 Steady-State Condition of Analyses

Variable	Design	Analysis
Core Power (MW)	30	31.5
Core flow (kg/s)	703	684.8
Pool Level (m)	10.51	10.41
Coolant Temp (^{o}C)	35	35.9

3. Analysis Results

Table 2 shows the major event sequences of BTLOCA. When the BTLOCA occurs, the pool water flows out through the beam tube, and the pool level decreases. As the pool level reaches the low-low set point, the reactor trips. The pumps were assumed to be tripped at the time of the reactor trip, and the HX secondary flow also stops. These assumptions reduce the heat removal from the core, resulting in the conservative results for the analysis. The RCPs start coast-down, and soon the flap valves open when the RCPs completely stop. Then, the core is cooled by natural convection via the flap valves.

In the BTLOCA scenario, the speed of pool level decreases is one of the key variable because that determines the mission time for available mitigation measures. The pool level decrease in the previous safety analysis report is calculated based on the Bernoulli equation as [2]

$$m_{break} = \rho_{water} C_d A_{break} \sqrt{2g\Delta z},$$

where the C_d is the discharge coefficient, conservatively assumed as 1. However, the break flow rate depends not only the break area, but also the hydraulic diameter and length of the break. Since the break area through the beam tube is narrow and long annular shape, the actual discharge coefficient is expected to be much higher than 1, delaying the pool level decrease.

Figure 4 shows the break flow and the pool level during BTLOCA calculated from MELCOR and those calculated by Bernoulli equation. The initial break flow calculated by MELCOR is less than half of that by Bernoulli equation due to the narrow shape of the break. In about 9.7 hour from the beginning of the accident, the pool level reaches the top of the RSA chimney. After the pool level reaches the top of the RSA chimney, the EWSS starts operation which is not guaranteed in the analyses. The flow rate from EWSS is about 11.4kg/s when supplied passively by gravity. Since the break flow is smaller than the coolant mass flow by EWSS, The pool level does not decrease until the EWSS tank is depleted.

Table 2 Event Sequences of BTLOCA

Events	Time (s(hr))
Beam tube seals break (BTLOCA)	0
Reactor trip by low-low pool level RCPs trip, HXs trip	2004(0.56)
Flap valve open passively	2405(0.67)
Level reaches chimney top	34938(9.71)
Fuel cooled by natural circulation	~

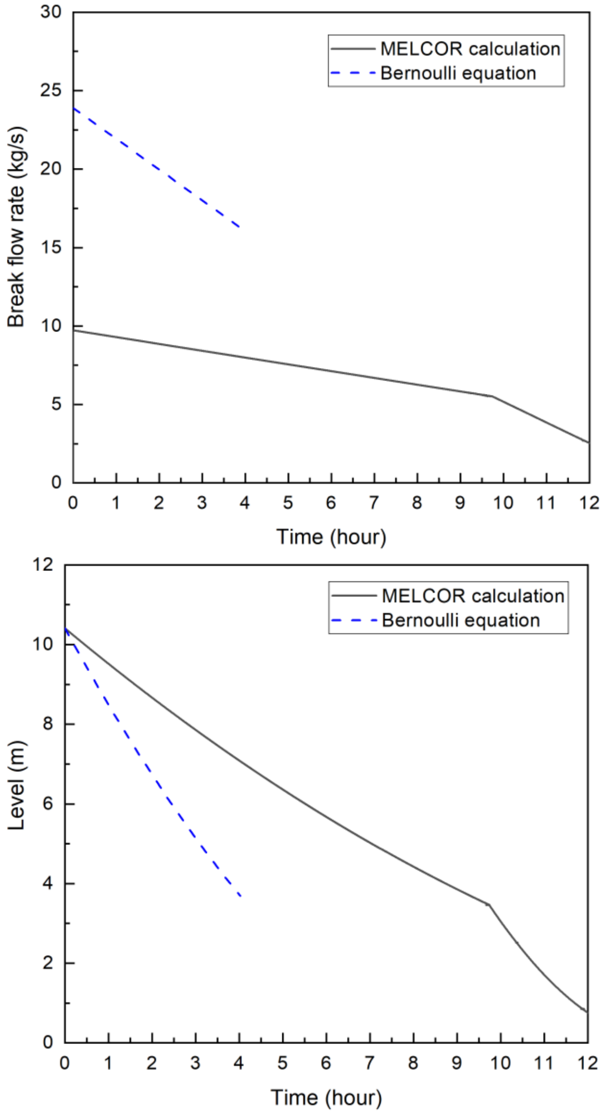

Fig. 4 Break flow and pool level during BTLOCA

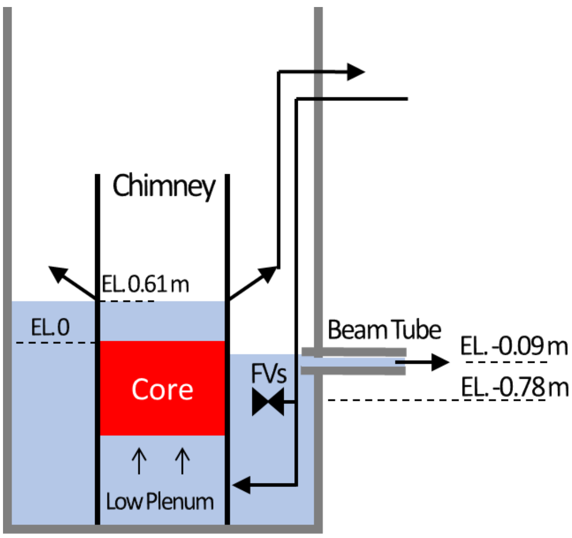

Fig. 5 Long term water levels by BTLOCA

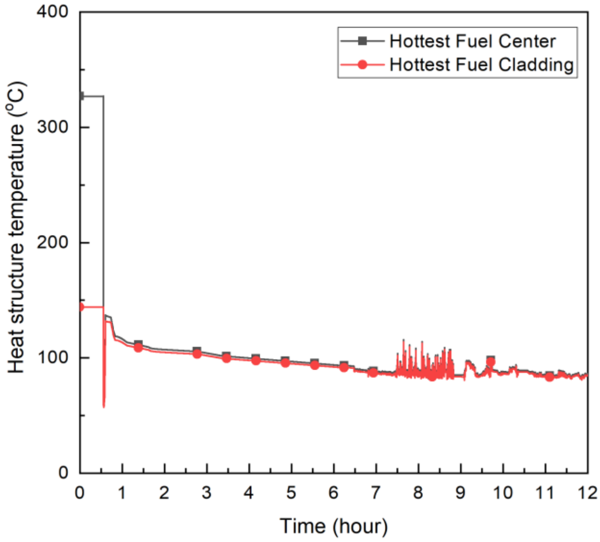

Fig. 6 Temperatures of hottest fuel

Figure 5 shows the long term pool level by BTLOCA. When the pool level decreases lower than the chimney, the path for natural convection via the flap valves is blocked. Then, the another path of the natural convection opens, which is the primary cooling loop. And from this point, the level outside of the RSA decreases further by the break flow through the beam tube, however, the level inside the chimney does not follow the level, because the flap valve is highly probable to be closed by the flow of EWSS. Once the water levels inside and outside of the RSA become different, the flap valve stay closed due to the water head by the level difference. The outer water level finally reaches the elevation of the beam tube, and the level inside the RSA stops at the core outlet nozzle, which is higher than the fuel top. Therefore, the fuel is maintained submerged in the water inside the RSA.

Figure 6 shows the temperature of the hottest fuel during the accident. The temperature of the fuel is the highest during the normal operation, and the temperature never get hotter after the reactor trip. Even the level reaches the core outlet nozzle, the fuel is not overheated, because the decay heat at this time is sufficiently low, enough to be cooled by submerging in water.

Without any additional action of safety system or by operator, the water inside the chimney is going to evaporates by the decay heat of the core, then finally the fuel will be exposed out of the coolant. Although those scenario is not probable due to the sufficient time for mitigation measures, the scenario is planned to be analyzed with proper modification of model suitable for the U_3Si fuel for extending the knowledge about accident beyond the extreme condition.

5. Summary

The thermal hydraulic behavior during BTLOCA in HANARO was analyzed using MELCOR code. The beam tube break was assumed by the simultaneous break of seals, and the pool level decrease and the corresponding core cooling behavior was reported.

The water level decreases much slower than that expected by Bernoulli equation in the previous safety analysis, therefore the fuel integrity is ensured more than 12 hours without any aids of safety systems or operator actions. Even the BTLOCA occurs, the fuel is expected to be submerged in the water until the water evaporates by the decay heat.

Based on the thermal hydraulic analysis results, the authors are preparing a complete MELCOR modeling of HANARO including the U_3Si fuel degradation and the fission product behavior.

Acknowledgement

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REFERENCES

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