SAFETY RE-EVALUATION OF KYOTO UNIVERSITY RESEARCH REACTOR BY REFLECTING THE ACCIDENT OF FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

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ABSTRACT

Kyoto University Research Reactor (KUR) is a light-water moderated tank-type reactor operated at rated thermal power of 5MW. After the accident of Fukushima Daiichi nuclear power plant, we have settled a 40-ton water tank near the reactor room, and prepared a mobile fire pump and a mobile power generator as additional safety measures for beyond design basis accidents (BDBAs). We also have conducted the safety re-evaluation of KUR, and confirmed that the integrity of KUR fuels could be kept against the BDBA with the use of the additional safety measures when the several restrictions were imposed on the reactor operation.

1. Introduction

After the accident of Fukushima Daiichi nuclear power plant, the newly established regulatory body, the Nuclear Regulation Authority (NRA)[1], required the preparedness for the severe accident to the nuclear power plants (NPPs), and has formulated the new regulation codes that executed in last July. At present, the safety review of the NPPs that applied for the new license has been implemented by the NRA.

For the research reactors, the new regulation code is under formulated by the NRA and it will be executed in coming December. Although the hazards of research reactors are quite smaller than those of NPPs, the countermeasures for the beyond design basis accidents (BDBAs) will be required by reflecting the accident of Fukushima Daiichi nuclear power plant. In this paper, the additional safety measures installed to Kyoto University Research Reactor (KUR) for the BDBA and the safety re-evaluation to confirm the integrity of KUR fuel against the BDBA are presented.

2. Outline of KUR

KUR is a light-water moderated/cooled thermal reactor using low-enriched uranium as fuel with the rated power of 5MW[2]. The core consists of plate-type fuel elements using about 20% enriched uranium reflector elements, control rod elements, plugs, which are inserted into the grid plate made of an aluminum alloy having a row of holes 9 column 6 rows. The core configuration will be changed to control the excess reactivity and control rod worth. The example of core configuration is shown in Fig. 1.

KUR is operated by using four shim rods (designated as A, B, C and D in Fig.1) and a regulating rod (as R in Fig.1); those are made of the stainless steel containing boron. The core is constructed at the bottom of the aluminum core tank with the size of 2m-diameter and 8m depth, which is filled with light-water as shown in Fig.2. During the operation, the

core is cooled by the forced coolant flow driven by the primary coolant circulation pumps. The primary coolant flows downward in the core with the flow rate of about 900 m^3/h and the outlet coolant temperature is restricted to be lower than 55^oC at the maximum thermal power of 5 MW. When the operation is shutdown, the primary circulation pumps are stopped manually, and the shut-off valves at the inlet an outlet lines of primary coolant are automatically closed. Then, the decay heat of the core is cooled by the natural convection of the primary coolant in the core tank.
As the experimental facilities, there are 8 neutron beam tubes, 6 irradiation facilities and 2 thermal columns.
Presently, about 55 hours operation (1MW for 48 hours and 5MW for 7 hours) per week is conducted as a standard operation pattern.

[Graphite column]

G	R	F	F	F	F	SSS	G	G
G	G	F	A	F	B	F	G	G
G	G	F	F	Hyd	F	F	G	G
G	G	F	C	F	D	F	G	Pn
G	G	F	F	F	F	F	G	Pn
G	G	G	G	G	G	G	G	Pn

[Heavy water tank]

F: Fuel element, G: Graphite reflector
A~D: Shim rods, R: Regulating rod
In-Core Experimental Facilities
Hyd: Hydraulic conveyer
Pn: Pneumatic tubes
SSS: Material controlled irradiation facility

Fig. 1 KUR core configuration

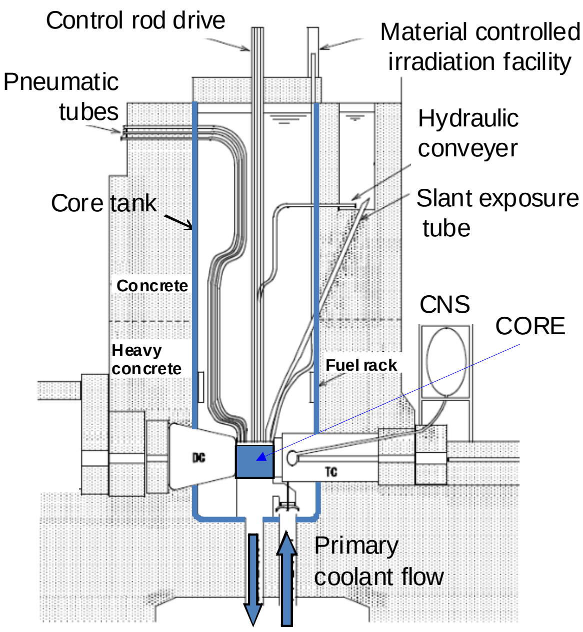

Fig.2 Sectional view of KUR
TC: Graphite column
DC: Heavy water tank
CNS: Cold neutron source

3. Safety measures for LOCA at KUR

For the loss of coolant accident (LOCA) at KUR, the following safety measures are prepared.
When the coolant leaks from the primary coolant lines, the check valve in the inlet line will automatically close due to the decrease of coolant flow rate and the hydraulic driven valve in the outlet line, which is kept open by the hydraulic pressure of coolant, will also automatically close. If those valves do not close, the operator will close the mail shutoff valves manually those located at the bottom of core tank. Therefore, the water level in the core tank is kept at a certain level. While the natural circulation valve, which is lifted by the inlet flow of coolant, will drop and it closes the inlet line and opens the natural circulation loop. Finally, the core is cooled by the natural circulation of coolant in the core tank as shown in Fig.3.
When the leakage occurs at the core tank or the lines between the tank and one of the main shutoff valves, the feed of water to the core tank should be conducted to cool the core. In addition to the regular feed system, there are the following water feed systems for the emergency cases (see Fig. 4).

1) Feed water from the water tower. The water is fed from the 100m^3 water tower by gravity. No pump is necessary for this system.
2) Feed water from the spent fuel pool using feed pump with the feed rate of about 5m^3/h.
3) Feed the leaked water from the sub-pile room. The sub-pile room is located beneath the

core tank and the leaked water will be accumulated there. When the accumulated water level reaches to the high-level sensor, two pimps will be activated automatically and fee the water to the core tank until the level decreases to the low-level sensor. The feed rate is about 15m^3/h for each pump.

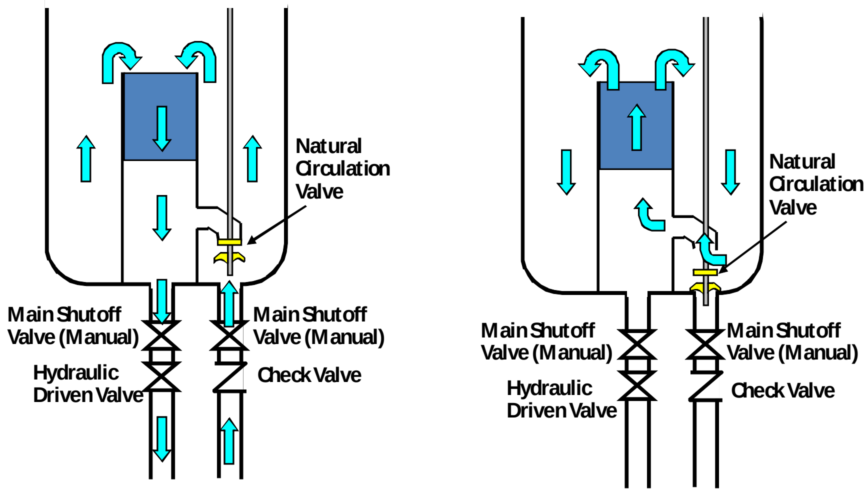

Fig. 3 Coolant flow with forced circulation (left) and natural circulation (right)

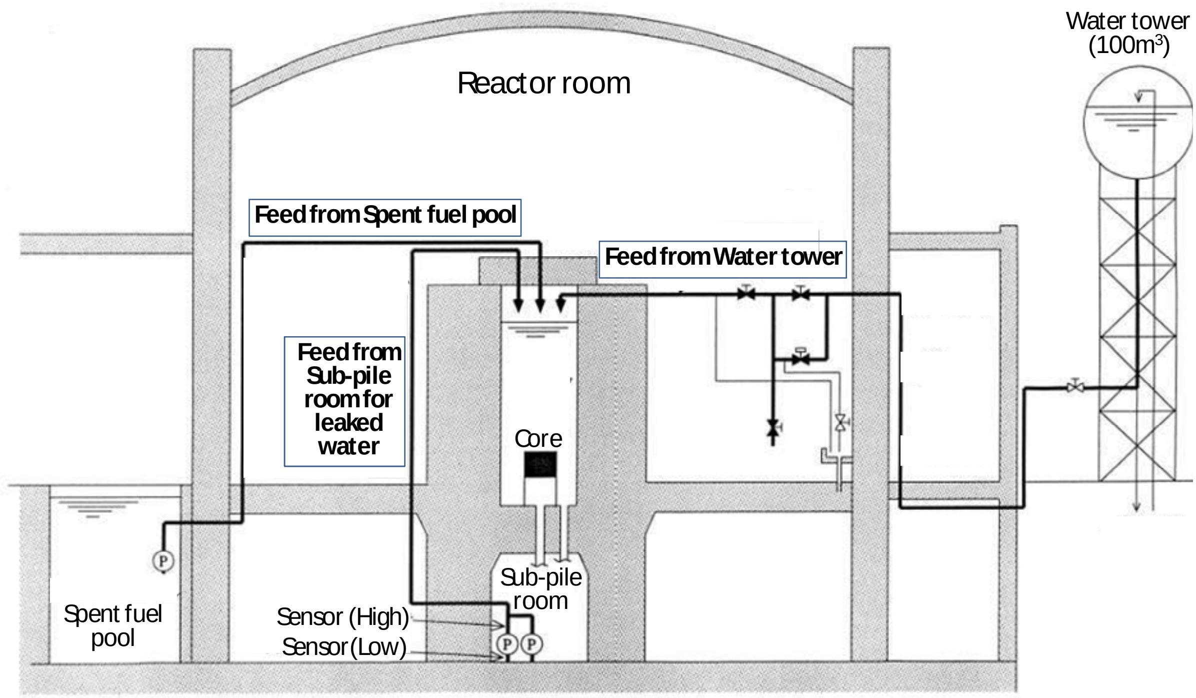

Fig. 4 Safety measures of KUR for LOCA

4. Additional safety measures by reflecting the accident of Fukushima-Daiichi nuclear Power plant

At the accident of Fukushima Daiichi nuclear power plant (hereafter, the Fukushima accident) on 11th March 2011, the station blackout (SBO) including the battery power supplies was occurred due to the large earthquake following the huge tsunami. In our analysis of KUR for the assumed earthquake, the core tank and the lines to the shutoff valves will not be damaged and the decay heat removal will be successfully conducted by the natural circulation of coolant in the core tank. However, to avoid the unexpected circumstances, we have introduced a portable fire pump, a portable power supply and a 40-ton water tank as additional safety measures for the beyond design basis accident as shown in Fig. 5. The portable power supply is just used for the instrumentation to observe the water level in the core tank, temperature and power of the core, etc. The water feed line to the core tank from the 40-ton water tank and the external cable to the reactor instrumentation from the outside of the reactor room were also installed. We also have performed the emergency exercise using those additional safety measures.

Fig. 5 Additional safety measures

5. Safety re-evaluation of KUR for the beyond design basis accident

As the beyond design basis accident (BDBA) by reflecting the Fukushima accident, we have employed the simultaneous events of SBO and LOCA at KUR. Since there is no power supply including batteries, the water feed pumps in Fig. 4 are not available. The water tower will be damaged if the earthquake is the initiating event. Then, the portable fire pump is the first available safety measure in this case.
The conditions of LOCA are as follows that are the same as those used in the safety evaluation as DBA of KUR[3].

(a) The leakage occurs at the primary coolant line (one of the inlet or outlet lines, diameter 35cm, thickness 7mm) between the core and the main shutoff valve (about 2m below the bottom of core tank).
(b) The leakage area S is calculated as (Diameter/2) times (Thickness/2) and the leak rate W is calculated as follows.

$$W = C \cdot S\,(2gH)^{0.5},$$

where C is a coefficient of contraction, g is the acceleration of gravity, H is the height of water.

Assume that the initial water level is 800cm from the bottom of the core and the top of active fuel (TAF) is 220cm, the time required for that the water level reaches to the TAF is calculated as about 1.5 hours. Through the exercise, it was confirmed that 30 minutes are enough to setup the portable fire pump and feed the water to the core tank from the 40-ton water tank. When the water is fed in the feed rate to keep the water level at TAF, the 40-ton water will be consumed in about 3 hours. Then the water in the spent fuel pool (SFP) can be used by changing the root of feed line. Although the SFP has over than 100 tons of water, we restrict the amount of water to less than 20 tons because the air-tightness of reactor room is kept by the SFP water level. Thus, the duration of the feed from SFP is evaluated about 1.6 hours. Finally, the total time from the initiate of LOCA to the end of water feed is evaluated as about 6 hours.
During 6 hours, it will be possible to prepare other water resources and/or to recover the power supply to the pumps. However, as the worst case study, we have evaluated the fuel integrity after 6 hours from shutdown for the standard pattern of KUR operations. In this evaluation, the decay heat was calculated using the Borst-Wheeler’s equation shown below.

$$Q = 6.9\times10^{-3}\, P[(T_c^{-0.2} - (T_0+T_c)^{-0.2}]$$

where Q is the decay heat (W), P is the power of reactor (W), T_0 is the time of reactor operation (d) and T_c is the cooling time (d).

The heat loss from the uncovered core after LOCA was evaluated by the following equation and the maximum temperature of the fuel surface was calculated.

$$Q_{loss} = H(T_w - T_{amb})$$

where Q_{loss} is the heat loss (W), T_w is the temperature of fuel surface (ºC), T_{amb} is the ambient temperature (ºC) and H is the heat removal capacity (W/ºC). We have used the conservative value of 30(W/ºC) as the heat removal capacity from the experimental results at ORNL[4].

The standard pattern of KUR operation is 1MW for 48 hours followed by 5MW for 7 hours. In the evaluation, the duration of 5MW operation was varied and the maximum duration was surveyed to keep the maximum temperature less than 640ºC, after the succeeding 41 weeks operation. The result showed that the maximum duration of 5MW was 7.7 hours, that is, there need no restriction for the operation of the standard patterns. Then the change of the maximum temperature was calculated by changing the number of succeeding operation weeks. The results are summarized in Tab 1.

No.of succeeding weeks	41	20	15	10
Max. temperature(ºC)	640	634	632	628

Tab 1: Maximum temperature as a function of operation week

The maximum temperature only slightly depends on the number operation weeks; this indicates that the duration of 5MW operation is dominating the maximum temperature.

6. Conclusion

The additional safety measures, a 40-ton water tank, a portable fire pump and a portable power supply, were installed to KUR for the beyond design bases accidents. We have made the safety re-evaluation of KUR for the simultaneously events of the site blackout (SBO) and the loss of coolant accident (LOCA) as a BDBA. The results showed that the fuel is covered by water in the core tank for over than 6 hours and its integrity is kept for the BDBA by using the additional safety measures, when the present standard operation pattern (1MW for 48hours + 5MW for 7 hours) is conducted.

7. References

[1] Nuclear Regulation Authority, Japan. http://www.nsr.go.jp/english/

[2] Kyoto University Research Reactor, KUR. http://www.rri.kyoto-u.ac.jp/en/facilities/kur

[3] “Application of the reactor alteration permit,” Research Reactor Institute, Kyoto University, 2009 (in Japanese).

[4] J. A. Cox and C. C. Webster, “Water-loss Test at the Low-intensity Resting Reactor,” ORNL-TM-632 (1964).