Present Status of Kyoto University Research Reactor, KUR

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Abstract. By reflecting the lessons learned from the accident of TEPCO's Fukushima-Daiichi Nuclear Power Plant which occurred on 11th March, 2011, the Nuclear Regulation Authority (NRA), Japan has formulated the new law regulating the nuclear facilities including the research reactors. Then, all the research reactors in Japan had to temporary shutdown, and they must have the safety review by NRA under the new law.
For the Kyoto University Research Reactor, KUR, we also shut it down in May, 2014 and then had the safety review by NRA. In September, 2016, we got the new license for KUR. After that, we have made refurbishment of the facility to comply with the safety requirement under the new regulation. Then, in the end of August, 2017, we finished the refurbishment works and the inspections by NRA, and we have started KUR operation.
In this report, we will describe the NRA's new regulation for research reactors and our response to it for the case of KUR.

1. Introduction

The Nuclear Regulation Authority (NRA)[1], a newly established regulatory body, formulated the regulation rules for research reactors[2] in the end of 2013, and all the research reactors in Japan have to renew the license under the new regulation rules, in order to continue the operation. The new regulation rules require the strict evaluation of natural hazards, enhancement of safety measures and establishment of countermeasures for severe accidents.
The Kyoto University Research Reactor, KUR[3], had the safety review by the NRA from the mid of 2013, and obtained the certificate on 21 September, 2016. Then, the refurbishment of the facility and the inspections by the NRA were conducted, and finally obtained the new license for operation on 25 August, 2017. Then, KUR started its operation for joint-research works on 29 August, 2017.
We have summarized the new regulation for research reactors and the safety re-evaluation of KUR under the new regulation [4,5].

2. New Regulation for Research Reactors after Fukushima-Daiichi NPP Accident

On 18th December, 2013, the new regulation rules for research reactors became effective in Japan. They were formulated by the NRA, based on the regulation rules for nuclear power plants (NPPs) which became effective on 8th July, 2013. Those new rules require the licensees to enhance the safety against the various hazards. The main requirements are as follows [6,7]:

- Emphasis on defense-in-depth concept.
  - Prepare multi-layered protective measures and, for each layer, achieve the objective only in that layer regardless of the measures in the other layers
- Assessment and enhanced measures against extreme natural hazards.
  - Introduce accurate approaches in assessment of earthquake and tsunami and measures against tsunami inundation.
  - Introduce assessment of volcano, tornado, & forest fire.

- Prevention of common cause failures.
  - Enhance measures against fire, internal flooding, & loss of power.
  - Make much account of “diversity” and “independence”.
- Protective measures against severe accidents and terrorism.
  - For research reactors, those measures are not legally required; however, the NRA requests some measures even for research reactors.
- Back-fitting to the existing plants.

3. Outline of KUR

KUR is a light-water moderated/cooled thermal reactor using low-enriched uranium as fuel with the rated power of 5MW. 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 aluminium 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. Figure 1 shows the KUR core configuration. As shown in the figure, there are 8 neutron beam tubes, 6 irradiation facilities and 2 thermal columns.

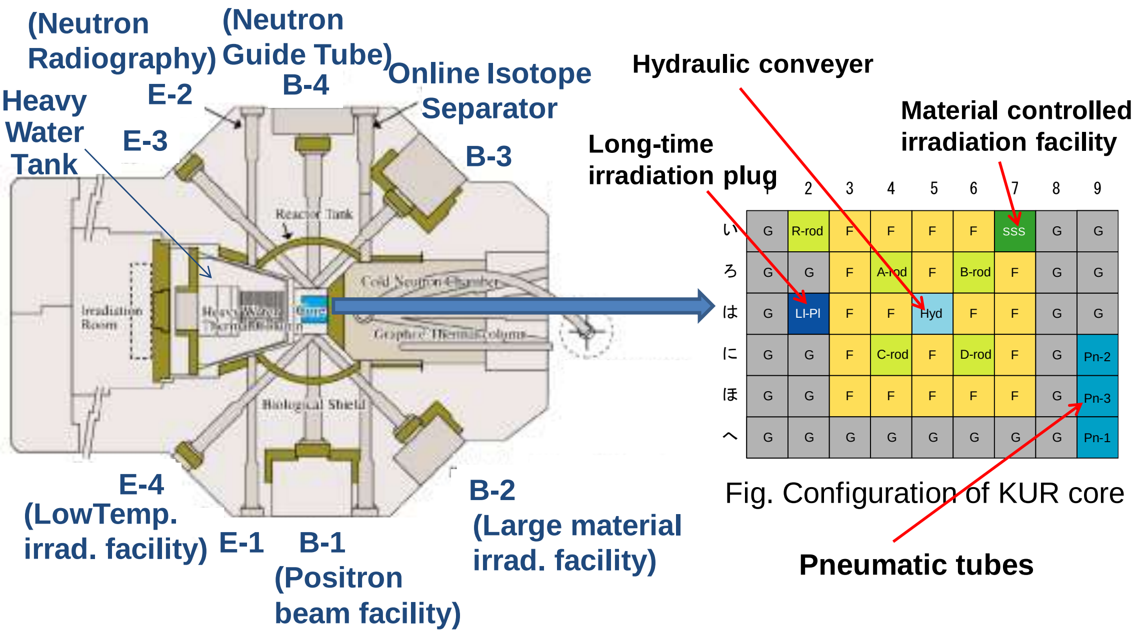

Fig. 1 KUR core and experimental facilities configuration

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 aluminium 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 900m^3/h and the outlet coolant temperature is restricted to be lower than 55°C at the maximum thermal power of 5MW. 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.
Presently, about 55 hours' operation (1MW for 48 hours and 5MW for 7 hours) per week is conducted as a standard operation pattern.

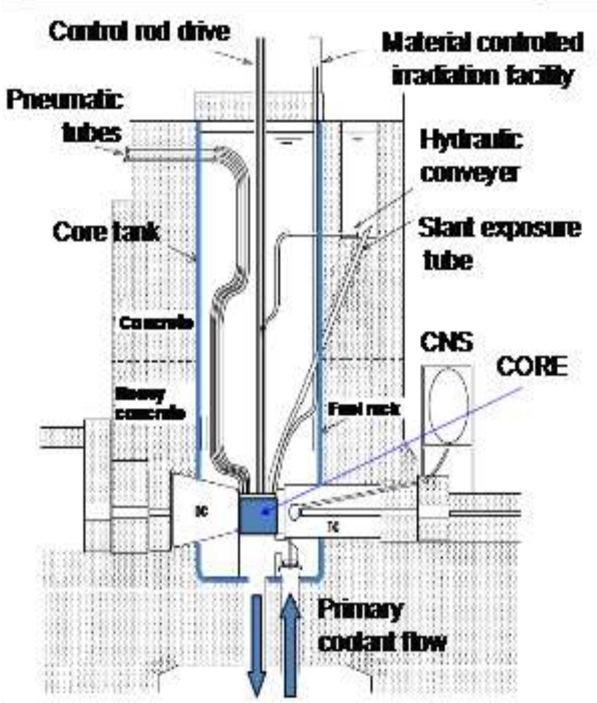

Fig.2 Sectional View of KUR

TC: Graphite column, DC: Heavy water tank, CNS: Cold neutron source

4. Safety Re-evaluation of KUR under New Rules

4.1 Natural Hazards

1) Earthquake and Tsunami

In the earthquake evaluation, the core of KUR is classified as "S-class" facility because that it has a potential to give public radiation exposure over than 5mSv when all safety systems failed. Thus, the basis ground motions for S-class facility were determined based on the investigations of geological structure, past earthquakes (see Fig.3). Then, the seismic evaluation was performed using the basis ground motions, and it was confirmed by numerical simulation that the core of KUR, including a core tank, control rods, and shut-off valves for primary coolant system, was not damaged by the basis ground motions.
For Tsunami, it was concluded that there was no attack by Tsunami because KUR is located at over than 45m high.

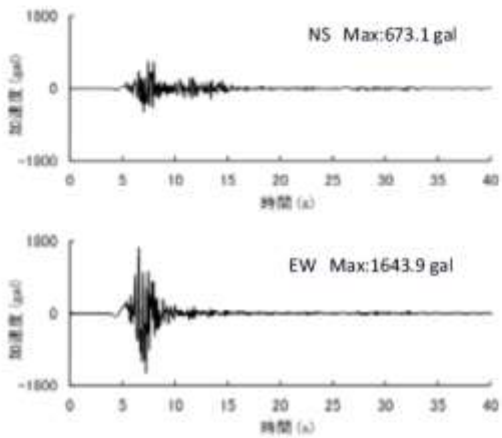

Fig.3 Horizontal Accelerations of the Basis Ground Motion for KUR Seismic Evaluation

Fig.4 Safety Net for Cooling Tower of Diesel Generator against Tornedo

2) Tornado

The maximum wind speed of Tornado was determined as 92m/s according to the Guide of Tornado evaluation for NPPs. To protect the facility against the tornado, several facilities were modified to withstand the flying objects (see Fig.4), and some emergency actions will be taken when the tornado alert was activated, such as the reactor shutdown, evacuation of cars parked at the designated areas close to the KUR facilities.

3) Volcano

It was no hazard due to the volcanos located within the area of 160km from KUR. However, there is a possibility of volcanic ash falling from the volcanos out of the area. It was evaluated that the maximum deposit thickness of the ash was 2cm, and it did not affect the safety of KUR.

4) Forest Fire

Inside the site, there is a small forest on the south of KUR. To protect the KUR facilities from the forest fire, we have constructed a fire-protection area between the forest and the facilities (see Fig. 5), in which water is sprinkled for the prevention of fire spreading by the persons on duty when the fire is detected.

Before construction Present

Fig.5 Construction of Fire-Protection Area

4.2 Internal Hazards

1) Internal Fire

To prevent the internal fire, the amounts and locations of ignition sources and combustible materials are strictly controlled, i.e. all the ignition sources and combustible materials inside the KUR reactor room should be reported and checked regularly. In addition, non-flammable cables are used for the KUR instrumentation in general.

To protect the facilities from the fire, the detection systems and the extinguishing equipment are installed properly.

To reduce the influence of the fire, the facility is designed as the fire-proof structure and the safety systems are properly isolated so that the loss of safety function by a common cause is avoided.

2) Internal Flooding

In the internal flooding evaluation, we assumed that all the water inside the KUR rector room would leak into the basement of the room and accumulated there. As a result, the power panels to supply power for safety facilities would be damaged, thus we have added another power distribution system with automatic switching circuit to protect the safety function from the internal flood.

3) Loss of Power

For the loss of external power, an emergency diesel generator (EG) was installed for KUR. In addition, there was another EG for KUCA, a critical assembly with the maximum power of 100W. In the safety review for KUCA, it was concluded that it was not necessary to facilitate the EG for KUCA because KUCA required no cooling system due to its low power. Then, we have modified the power distribution system from the EGs so that the both EGs can supply the power to KUR in emergency cases. Moreover, the battery power supply system, which would be used for the instrumentation, has been change to the larger capacity one.

4.3 Severe Accident

The new rules require preparing for the severe accident in which the significant amount of radioactive materials would be released as a result of damage of fuels in the core or in the spent fuel pool. For KUR, the decay heat of spent fuels in the pool would be very small and there is no possibility to occur the severe accident. Then, we focused on the severe accident at the core fuels, and the accident will be initiated by the loss of coolant accident (LOCA).

1) Safety Measures for LOCA

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 did not close, the operator would close the main 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.

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 (see Fig. 6).

- 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.
- Feed water from the spent fuel pool using feed pump with the feed rate of about $5m^3/h$.
- 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 pumps will be activated automatically and feed 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.

In addition, 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. 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 cables 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.

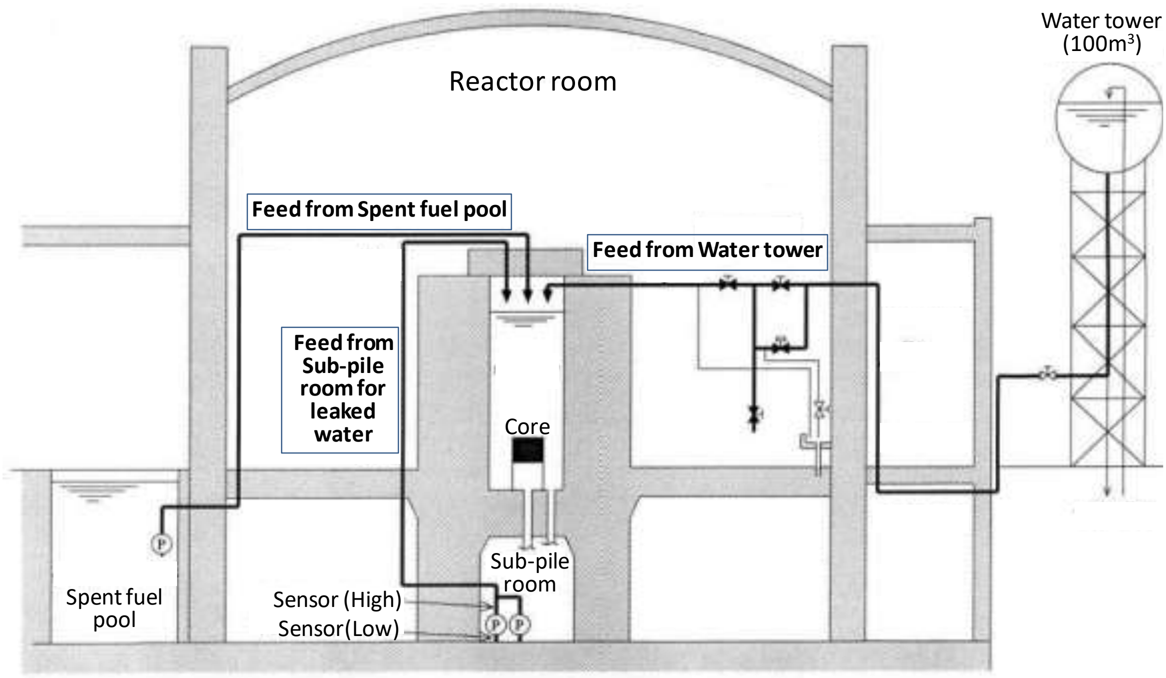

Fig.6 Safety Measures of KUR for LOCA

2) Safety Measures against the Release of Radioactive Materials

When all the safety measures for LOCA are failed, the core fuels will melt and gaseous and volatile radioactive materials will be released to the atmosphere. To reduce or mitigate the amount of radioactive materials released and the impact to the environment, the following procedures should be executed.

- Feed water to the core tank using any available method described above.
- Stop the air ventilation system and close the ventilation lines, if available.
- Cover the core top area with sheets to prevent the diffusion of gaseous and volatile materials.
- Monitor the radiation level at inside and outside of the site, and convey the information to public.

5. Conclusion

The new regulation rules have been formulated by the NRA for research reactors, reflecting the lessons learned from the accident of Fukushima-Daiichi NPP. They require the strict evaluation of natural hazards, enhancement of safety measures and establishment of countermeasures for severe accidents, and all the research reactors in Japan have to renew the license to continue operation.

KUR had the safety review by the NRA from the mid of 2013, and obtained the certificate in 2016. Then, the refurbishment of the facility and the inspections by the NRA were conducted and finally obtained the new license for operation, and KUR started its operation for joint-research works on 29 August, 2017. Through those process, KUR enhanced the safety capability, especially for the natural hazards and severe accidents, although they took a long time, 3 years, and much costs. The NRA has applied the back-fit rule for existing facilities and requires the quality assurance for the safety issues, then the continually efforts toward enhancing the safety should be conducted.

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