Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Development of Procedure for Stage C Commissioning: Reactor Performance Test (LOEP) for a Research Reactor

Hyeonil Kim [a*], Youn-Gyu Jung [b], In Sub Jun [b], Su-Ki Park [b]

[a]*Research Reactor Technical Management, Korea Atomic Energy Research Institute, 111, 989 beon Daedeok-daero, Yuseong, Daejeon, 34057, Rep. of Korea*
[b]*Research Reactor Safety Analysis, Korea Atomic Energy Research Institute, 111, 989 beon-gil Daedeok-daero, Yuseong, Daejeon 34057, Rep. of Korea*
[*]*Corresponding author: hyeonilkim@kaeri.re.kr*

1. Introduction

The commissioning programme is established to demonstrate that the requirements and intent of the design as stated in the Safety Analysis Report (SAR) have been met. "Procedures shall be prepared, reviewed and approved for each commissioning stage prior to the commencement of tests for that stage". The procedures may also be used as an aid for assessing and documenting the results of tests. The commissioning procedures should include information that specifies several items. Those are mainly (1) all the activities and performance parameters that are to be measured under specified steady state and transient conditions, (2) the requirements on performance, together with clearly stated acceptance criteria [1].

The final phase of stage C commissioning is reactor performance test, which is to prove the integrated performance (neutron power calibration, Control Absorber Rod drop time, I&C functioning, Rod worth, Core heat removal with natural mechanism) and the safety of the research reactor at full power with fuel loaded [1][2].

The last test will be to assure the result of the safety analysis is sufficiently marginal enough to be sure about the nuclear safety by showing that the reactor satisfies the acceptance criteria of the safety functions (Fig. 1) such as for reactivity control, maintenance of auxiliaries, reactor pool water inventory control, core heat removal, and confinement isolation. After all, the fuel integrity will be ensured by verifying there is no meaningful change in the radiation levels.

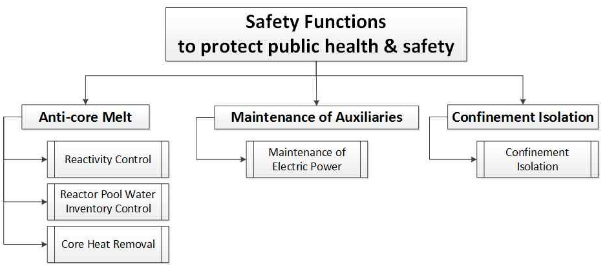

FIG. 1 Safety Functions Classification

To confirm the performance of safety equipment, loss of normal electric power (LOEP), possibly categorized as Anticipated Operational Occurrence (AOO), is selected as a key test to figure out how safe the research reactor is before taking over the research reactor to the owner.

This paper provides a development of procedure for Stage C commissioning: reactor performance test (RPT), loss of normal electric power (LOEP) for a research reactor, and the acceptance criteria for the test.

2. Description of LOEP

Loss of normal electric power can occur due to either electric load conditions such as overload in the system buses or natural & environmental conditions such as flood, storms, earthquake, and tsunami. Terror of sabotage can also be the possibility.

For any reason, if a loss of normal electric power, also called as a loss of offsite power (LOOP), a possibly anticipated operational occurrence (AOO), occurs, incoming switchgear, intermediate switchgear, load center, and motor control center are tripped all at once. Therefore, the primary cooling system pumps, secondary cooling pumps and cooling tower blowers come to stop. And as soon as the electrical power to the reactor shutdown system is cut off, the reactor power decreases rapidly by the immediate insertion of control rods and second shutdown rods.

At the beginning, the reactor core is cooled by slowing down coolant through the PCS pipe by the inertial force of pump, flywheel and coolant itself. Due to the decay power after reactor trip, the flow at the core changes its direction from downward to upward as the natural convection is developed.

As the flow through the PCS decrease, the flap valves open, and pool water inflow to the pipe which connects to the core and a natural circulation through the flap valve is established using the pool as an ultimate heat sink. The siphon valves connected to the reactor outlet PCS pipe also open when the flow through the PCS decreases to a preset value.

3. Commissioning Procedure

3.1 Summary of the test

This test is to verify and confirm that the following safety functions have been accomplished as designed after the intentional LOEP at the full power and thereby the nuclear safety will be ensured:

1) Reactivity control

The safety function for reactivity control will be verified by checking the power trend, and the positions of both the CARs and SSRs.

When LOEP occurs at the full power, the CARs and SSRs shall drop automatically into the core. The reactor power shall decrease promptly to the corresponding level and monotonically to the level of decay power with respect to the time.

2) Maintenance of auxiliaries

There is no safety function by auxiliary systems in the JRTR. The availability of the facility will be enhanced by controlling the maintenance of the auxiliaries such as electric power supply system in the JRTR.

The status of the electric systems such as Class I, II, III and IV including the status of the diesel generator will be verified.

3) Reactor pool water inventory control

It will be verified that there is no change in the pool water level.

4) Core Heat Removal

The safety function for the core heat removal will be ensured by checking that the flow through the core is well established during this test: a) first, the measured PCS coastdown flow shall meet the input requirement for the safety analysis described in the FSAR, b) second, the flap valves and the siphon break valves shall be open as designed.

5) Confinement Isolation

If the radiation level reaches the predetermined level due to the fuel failure, the reactor confinement shall be isolated. During and after this test, the confinement isolation dampers (CIDs) are not expected to be closed.

The fuel integrity can be ensured by verifying that there is no meaningful change in the radiation levels on the same reactor conditions before and after the test.

3.2 Procedure of the test: LOEP

<u>Check and records</u>
check and record at the full power (before LOEP)

<u>Initiation of LOEP</u>
Cut off offsite power.

<u>Check and Record of Reactor Response</u>

Check and record the parameters related to the safety functions such as power, PCS flow.

Check if the required safety functions meet the acceptance criteria.

Evaluate the parameters and judge whether or not meeting acceptance criteria

- the reactor power
- the PCS coastdown flow

<u>Recovery of Reactor to the Full Power</u>
Check and record the parameters (after recovery)
Judge if the fuel integrity is ensured

3.3 Acceptance Criteria

After LOEP, the followings shall be achieved:

1) The safety systems and components to achieve the fundamental safety functions shall be worked as designed and described in the final SAR.
2) The result of analysis about LOEP event in the final SAR shall be proved to be conservative in terms of the reactor power and the PCS pumps coastdown flow.
3) The fuel integrity shall be ensured during and after this test.

4. Analysis of LOEP

A conventional open tank-in-pool research reactor is modelled by using the RELAP 5/Mod3.3 [3]. The model constitutes reactor structure assembly, the core, the primary cooling circuit, and so on.

For the analysis of LOEP, the calculation modeling is established only for the PCS. The SCS is only modeled as the boundary condition.

4.1 Conservative estimation

Analysis method and major assumptions used in this analysis are as follows:

1) Reactor is tripped by the free drops of control rods due to de-energizing of the electromagnet and the trip delay time is assumed to be about 0.1 seconds.
2) CARs are inserted with a condition that one CAR with the largest reactivity is extracted from the core.
3) Cooling water flow in the secondary side is assumed to be reduced to zero within 1 second following a loss of electric power.
4) Negative reactivity feedback effects by fuel and coolant temperature rises are not considered.
5) Flap valves are open when the pressure difference across the flap valves is smaller than 1.5kPa. In the simulation one of the two flap valves is assumed to open.

When a loss of normal electric power occurs, which is one of very common AOOs, the reactor is tripped by the free dropping of CARs even without considering the Reactor Protection System action.

In this case, core power (fig. 2) and PCS flow (fig. 3) decreases rapidly after the initiation of a loss of electrical power by insertion of control rods.

The flow through the flap valves are well established (fig. 4), where decay heat is removed by the natural circulation through the reactor pool for the long term cooling. The minimum critical heat flux ratio [4] in a hot channel is far from the design limits (fig. 5). The coolant temperatures at inlet/outlet of the core show the direction of flow path through the core changed from down (forced flow) to up (natural circulation).

Therefore, fuel cooling does not make any safety problem.

4.2 Best estimation

1) The trip delay time is not greater than 0.1 seconds.
2) All of SSR as well as all of CAR are inserted into the core due to LOEP.
3) The decay power is selected as a best estimate.
4) Negative reactivity feedback effects by fuel and coolant temperature rises are considered.
5) Flap valves works as designed.

With reduced initial core power (fig. 2), increased PCS flow (fig. 3) at nominal condition and flow through both flap valves (fig. 4). The minimum critical heat flux ratio in a hot channel is far bigger than the result from the conservative safety analysis (fig. 5). The coolant temperatures at inlet/outlet of the core are lower than the results from the conservative analysis by about 3 degree.

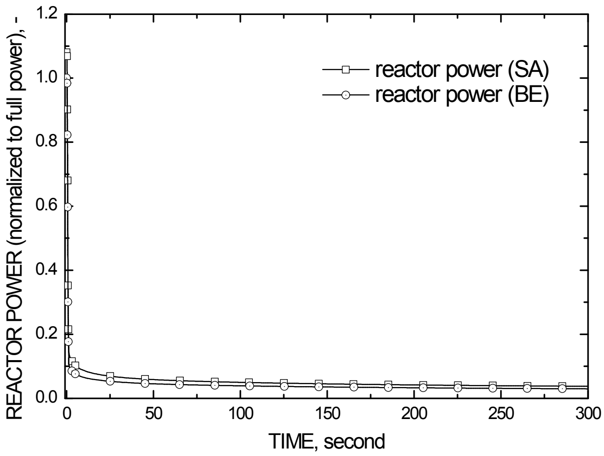

FIG. 2 Reactor power transient

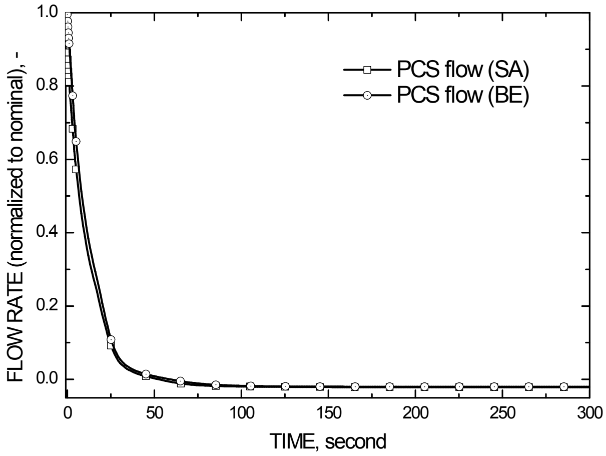

FIG. 3 PCS flow transient

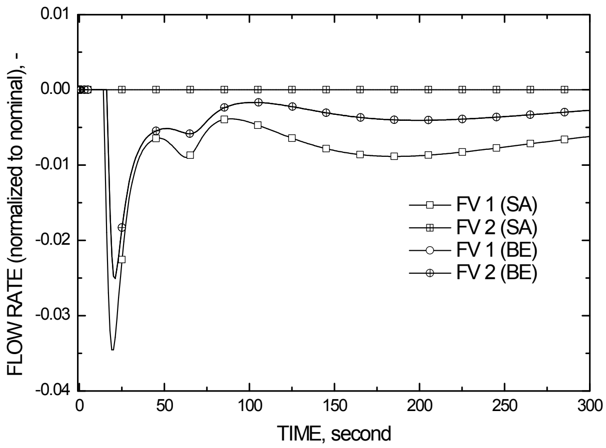

FIG. 4 Flow through valves

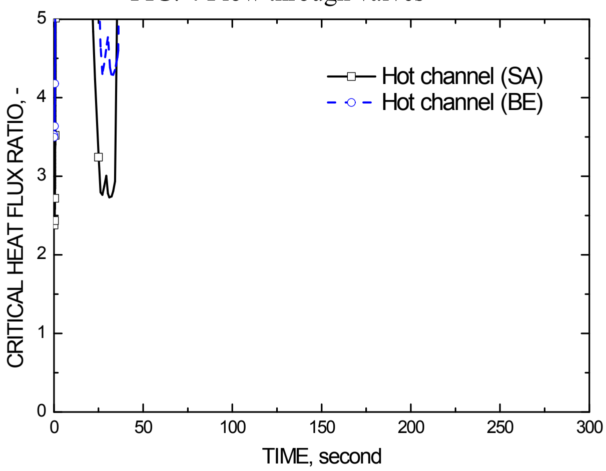

FIG. 5 CHFR transient

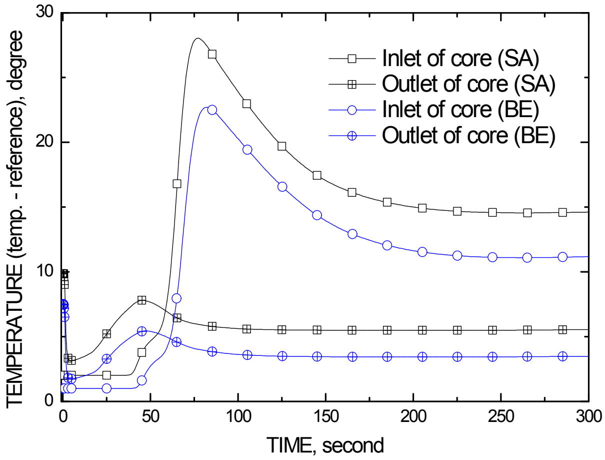

FIG. 6 Temperature transient

5. Concluding remarks

Commissioning procedure was developed to show the safety of the research reactor. Both indirect and direct indicators were selected to show that the safety is ensured: 1) indirect parameters which imply success of safety functions: power, flow, opening valves, system response as-designed; 2) direct parameters which shows no failure of safety functions: no meaningful increase in level of neutron in the cooling system.

Preliminary analyses have shown all probable thermal-hydraulic transient behavior of importance as to opening of flap valve, minimum critical heat flux ratio, the change of flow direction, and important values of thermal-hydraulic parameters.

A preliminary comparison to conservative estimation has shown that the nuclear reactor safety of the research reactor will be assured by verifying that the reactor power and the PCS flow rate are conservative.

REFERENCES

[1] Commissioning of Research Reactors, IAEA Safety Standards, NS-G-.1, 2006.

[2] Research Reactor (Design, Management and Utilization), KAERI, 2009.

[3] RELAP5-3D Code Manual Volume IV: Models and Correlations, INEEL-EXT-98-00834, Revision 1.1b, July 1999.s

[4] Kaminaga, M., Yamamoto, K., and Sudo, Y., Journal of Nuclear Science and Technology, 35 (12), pp. 943-951, 1998.