

RCIC flow rate of Unit-2 after loss of the power supply for control

1. Overview of the incident and subjects for examination

The reactor water level of Unit-2 was maintained after the earthquake by operators repeating manual start-up and automatic shutdown due to the “high reactor water level” signals of the reactor core isolation cooling system (RCIC). Immediately after the third manual start-up, the station black out occurred due to tsunami flooding. Reactor water levels, reactor pressures, etc. measured thereafter indicate that the RCIC continued injecting water for about three days even after the power supply for control was lost by the tsunami.

The reactor pressure measured after the tsunami was maintained at the level lower than that during normal operations and did not reach the working pressures of the main steam safety relief valves (SRVs). The following question needs to be answered: What RCIC operating conditions with no power supply for control are possible to make such plant behavior true? One possibility is that the reactor water level increased, without being controlled, to the level close to the steam extraction point of the RCIC turbine, the two-phase flow of steam and water carried energy equivalent to that of the decay heat to the RCIC turbine and thus water was injected into the reactor at a lower flow rate than the rated value.

Based on this possibility, about one-third of the rated value, i.e., $30\text{m}^3/\text{h}$ was assumed in the MAAP analysis in order to reproduce the measured reactor pressures, and MAAP could well reproduce the overall behavior of the RCIC. On the other hand, when the value measured by the water level indicator as obtained by the temporary power supply was corrected, the reactor water level at about 22:00 on March 11th was at the top of active fuel (TAF) +6m, and that was close to the upper limit of measurement by the water level indicator. At this time point, MAAP underestimated the water level. When considerations are given to the RCIC turbine steam regulator valve, which had technical specifications to be fully opened upon loss of the control power supply, and to the big reduction in water inventory of the condensate storage tank (CST) used as the water source for injection, the amount of water actually injected by the RCIC was very likely to have been bigger than the $30\text{m}^3/\text{h}$ assumed in MAAP.

This document reviews the water injected by the RCIC after the tsunami, evaluates its influence on the accident progression, and examines necessary measures therefor.

2. Design of the RCIC turbine

Figure 1 shows a schematic diagram of the RCIC. The RCIC of Unit-2 had a turbine-driven pump, which extracted steam generated in the reactor from the main steam line and, by adjusting the steam flow by the steam regulator valve, controlled the amount of water injection to the reactor. As a means to control the amount of water injection, there is a way in which part of the cooling water discharged from the RCIC is returned back to the CST through the test line. But Unit-2 did

not use this means; rather the entire amount of water discharged from the RCIC was sent to the reactor.

It is necessary to consider the question: How can the amount of water injection be controlled by the steam regulator valve? During the RCIC operation, the water injection flow rate is controlled by the target flow rate signal from the flow controller. Corresponding to the deviation of flow rates detected, an aperture control signal (electric signal) for the regulator valve is issued to the EG-R actuator of the RCIC. The EG-R actuator controls the flow path of hydraulic oil, by which the pilot piston moves up (closing the valve) or down (opening the valve), corresponding to the change of aperture control signals. A servo piston controls the valve aperture by hydraulic oil pressure. It should be noted that the hydraulic oil is pressurized by the RCIC oil pump directly connected to RCIC turbine and does not lose its function even if the power supply is lost.

A centering spring is positioned above the EG-R actuator pilot piston. This spring holds the pilot position at its center when the flow rate is constant (the flow rate deviation is zero): it has asymmetric spring forces at its upper part and lower part (upper part force > lower part force) and a NULL voltage through the solenoid coil holds the spring at its mid position, and thus, the pilot piston at its center. When the pilot piston stays at its center, the hydraulic oil pressures for moving the servo piston up and down are balanced and the regulator valve maintains its states (Figure 2).

When the power supply for control is lost (no electric signals), the NULL voltage is lost and the pilot piston moves down due to the spring force, thus opening the regulator valve (Figure 3).

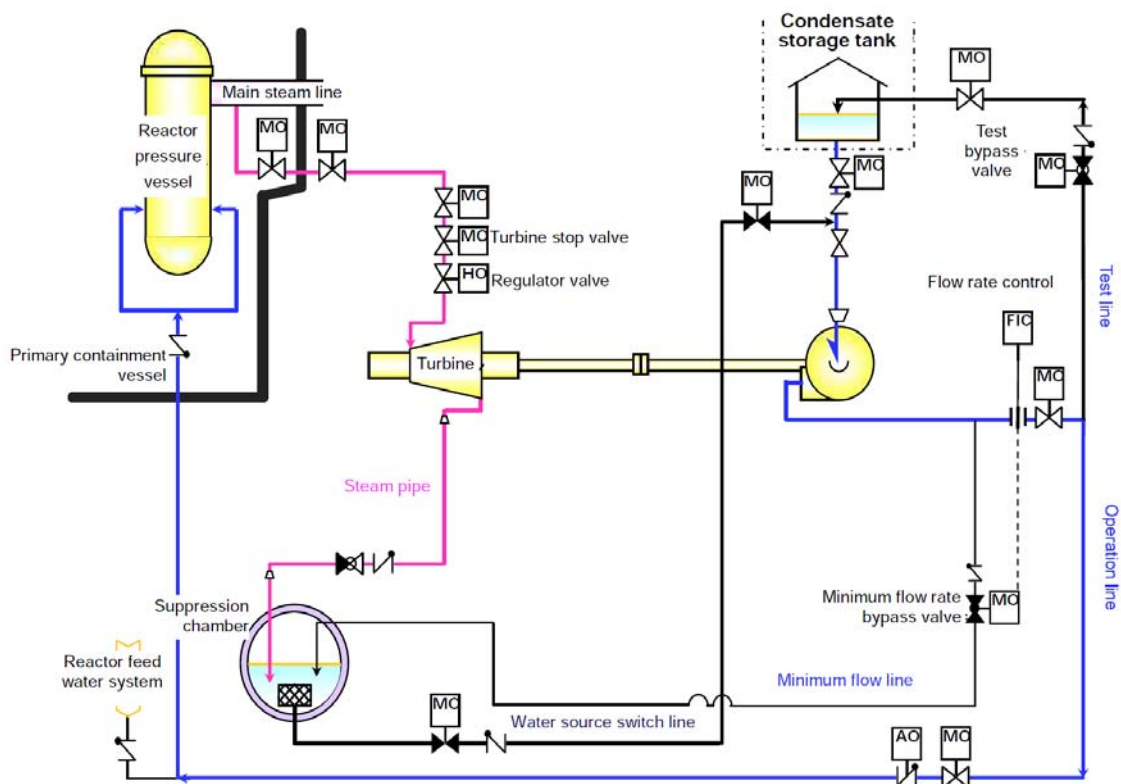


Figure 1 Schematic diagram of the RCIC

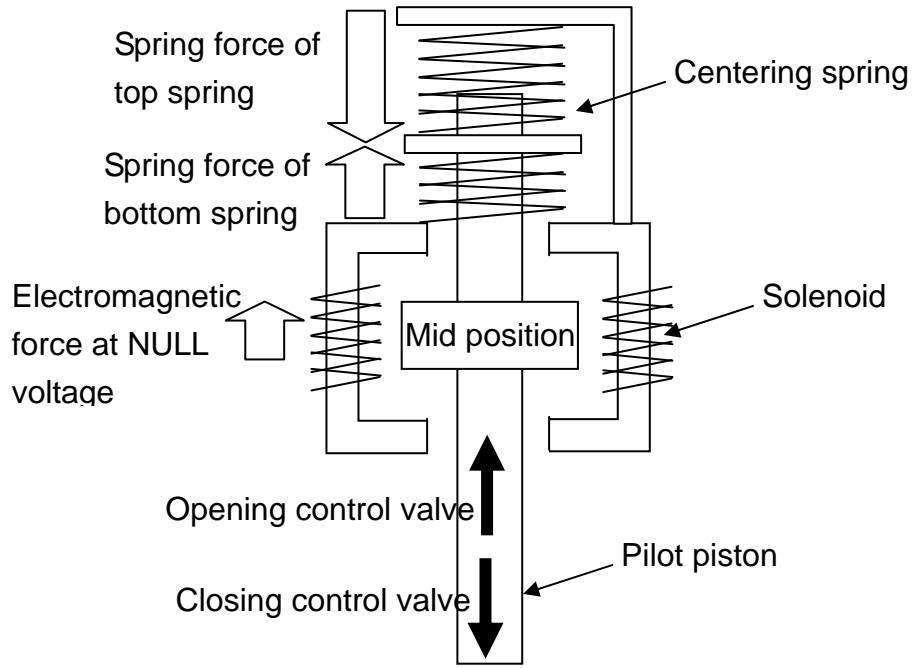


Figure 2 Illustration of EG-R actuator

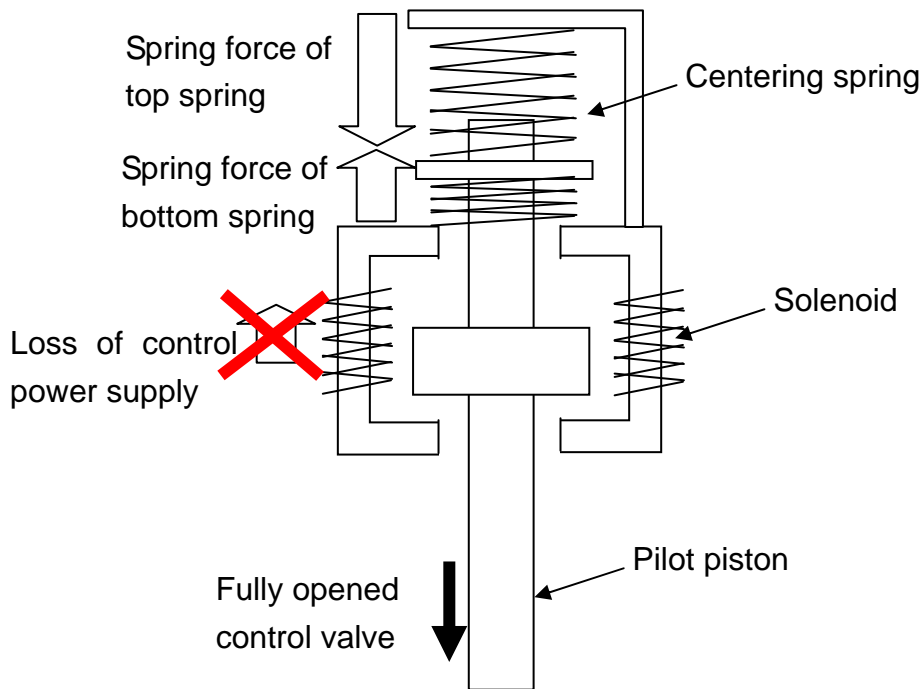


Figure 3 Response of EG-R actuator upon loss of power supply for control

3. RCIC behavior at Unit-2 upon loss of power supply for control

The loss of the DC power supply at Unit-2 was later than that at Unit-1 and the RCIC could be started up at 15:39 on March 11th. The Unit-2 process computer could monitor plant parameters until about 15:50 and the water injection behavior around this time has been recorded (Figure 4).

The changes of the amount of water injected are consistent with the behavior (mechanism) described above in Chapter 2 at the time of loss of the DC power supply. It can be understood, therefore, that the loss of the DC power supply due to the tsunami caused the RCIC turbine steam regulator valve to move to the fully opened position and water injection to the reactor was increased.

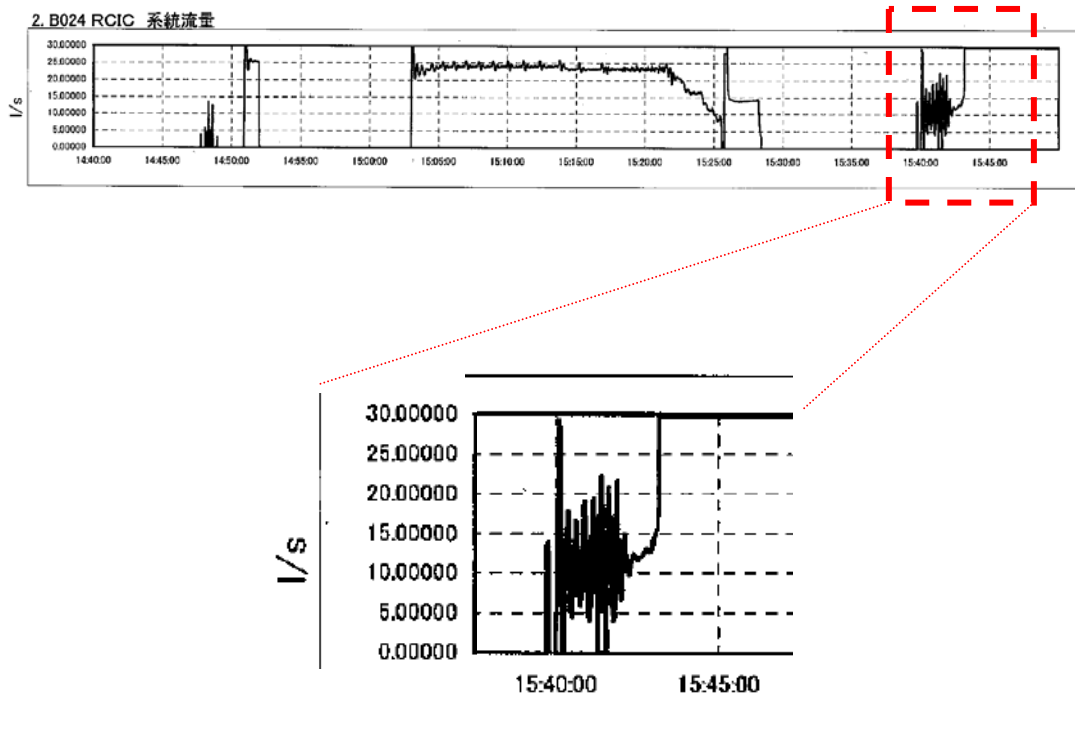


Figure 4 RCIC flow rate change upon loss of power supply for control

But the cause of oscillatory behavior in the amount of water injected before the flow rate increase still needs to be examined.

As mentioned earlier, currently, the flow rate of water injection assumed in the analysis was $30\text{m}^3/\text{h}$ (about 8.3L/s), or about 30% of the rated flow rate. However, the flow rate of the RCIC after the loss of control power supply might have been almost at the rated level, from the following facts: the water injection flow rate was measured to have increased to the rated value; and about 1,000t of the CST water inventory had been consumed during the time period of about 11.5 hours before the water source was switched over. On the other hand, when the RCIC continues its operation without control, the reactor water level will increase and the reactor water may flow into the main steam line. No information is available now concerning whether the steam-driven RCIC can be operated with rated flow rates in such circumstances. Therefore, the RCIC operating performance will be examined by, for example, flow rate parametric surveys.

It should be noted that, as far as the accident progression is concerned, if the information were to become known on the pressure and water level at one time point after the loss of cooling capabilities, the progression thereafter can be analyzed, regardless of the states prior to the time

point (a slight impact will be the reduction of gaseous volume in the suppression chamber (S/C) if the amount of water injection has to be changed).

4. Considerations of the measures to be taken

There is a possibility for the RCIC turbine to trip due to overspeed, depending on the operating conditions, when the regulator valve is fully opened upon loss of the control power supply. There is a mechanical turbine trip mechanism that can function even without the control power supply. Unit-2 could avoid the turbine trip after loss of the control power supply, but nevertheless the turbine trip possibility should be reduced to the extent possible.

At the Kashiwazaki-Kariwa Nuclear Power Station, the following measures are being taken for strengthening the RCIC reliabilities in an accident: to empower the DC power supply with a function for preventing loss of the control power supply; to rebuild the organizational system so that the operators are distributed throughout the site and are able to reset the trip mechanism for early restoration, in the event that the turbine trips; and to clarify operational actions in the operational procedures for reducing the steam flow rate by manual valve maneuvering, making the flow rate checks by rpm, and confirming the reactor water level in the reactor building.

5. Summary

The RCIC behavior after the loss of the control power supply (DC) due to the tsunami has been examined using design information and measured data. It has been shown that the RCIC water injection rate increased after the tsunami arrival. However, unclear issues concerning the RCIC behavior after the reactor water level increased still remain that require continuation of the examinations.