

APPENDIX F

Safety System Descriptions for Station Blackout Mitigation: Isolation Condenser, Reactor Core Isolation Cooling, and High-Pressure Coolant Injection

NOTE: Unless otherwise indicated, all dates in this appendix are for 2011.

Important systems that can remove decay heat and/or add water to the boiling water reactor (BWR) reactor pressure vessel (RPV) without the need for alternating-current (AC) power are

- the isolation condenser system, which is used in BWR/2s and some BWR/3s, including Fukushima Daiichi Unit 1
- the reactor core isolation cooling (RCIC) system, which is used in BWR/4s, BWR/5s, BWR/6s, and the Advanced Boiling Water Reactor (ABWR)¹
- the high-pressure coolant injection (HPCI) system, which is used in BWR/3s and BWR/4s.

Summary descriptions of these systems are given below. Other safety systems, such as the core spray, residual heat removal (RHR), and containment cooling systems, rely on significant AC power for operation and are not discussed here because the focus of this appendix is on systems that could be available in an extended station blackout (SBO).

I. THE ISOLATION CONDENSER SYSTEM

The primary purpose of the isolation condenser system (Fig. 1) is to remove decay heat and conserve reactor water inventory when the reactor becomes isolated from the turbine condenser. The isolation condenser system consists of two trains of equipment. Each train consists of a large heat exchanger located in the reactor building, outside of containment and above the RPV in elevation, which condenses steam produced by decay heat and returns it to the reactor by natural circulation.

The primary side of the heat exchanger is fed by a steam line from the RPV, and a condensate return line that returns the condensed steam back to the RPV through one of the recirculation pump lines, together with appropriate isolation valves. In the ready state, the steam line is open and the condensate return line is closed, which allows the condensate line to be kept filled and eliminates the potential for water hammer during start-up. When the appropriate signal (high reactor pressure) is given, the condensate return valve is opened and a natural-circulation circuit is completed. The secondary (shell) side of the isolation condenser consists of a large tank of water with sufficient capacity for several hours of decay heat removal by boiling and venting to the atmosphere. From this point the system can operate without any electrical power or operator action for several hours. Longer term, the shell side can be replenished by the nuclear power plant (NPP) operators using the NPP makeup water system, the fire protection system, or fire trucks.

¹ In ABWR, the RCIC system is also an emergency core cooling system (ECCS).

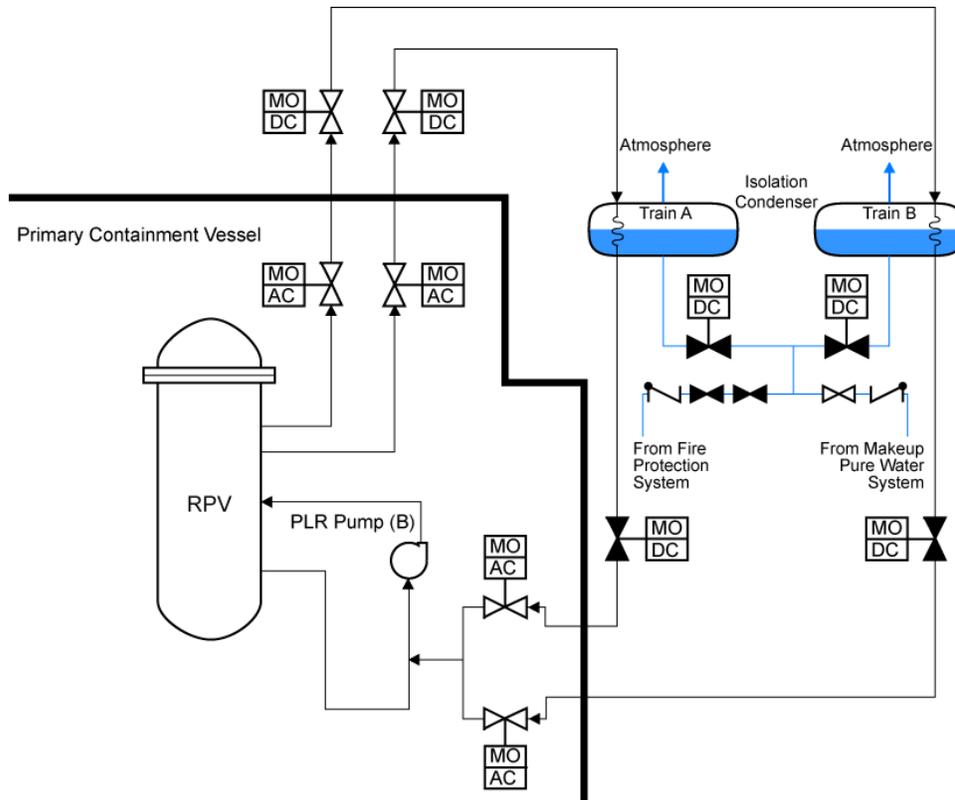


Figure 1. Schematic of typical isolation condenser system.

II. THE RCIC SYSTEM

The primary purpose of the RCIC system (Fig. 2) is to provide makeup water to the RPV when the RPV is isolated from the turbine-condenser. The RCIC system uses a steam-driven turbine-pump unit and operates automatically in time and with sufficient coolant flow to maintain adequate water level in the RPV for the following events:

- RPV isolated and maintained at hot standby
- complete NPP shutdown with loss of normal feedwater before the reactor is depressurized to a level where the shutdown cooling system can be placed in operation
- loss of AC power.

The RCIC system is sized to keep up with decay heat inventory losses from the RPV [90 to 180 m³/hour (400 to 800 gal/minute), depending on reactor design power level]. Since the reactor decay heat reduces rapidly after an NPP scram, the RCIC system quickly has more than enough capacity to keep up with decay heat steam production losses through the safety and relief valves (SRVs)—the RCIC system does not control reactor pressure, so the generated steam from decay heat lifts the SRVs, and the steam is routed to the suppression pool.

The RCIC system is contained within one electrical division and consists of a steam-driven turbine that drives a pump assembly and the turbine and pump accessories. The RCIC system also includes piping, valves, and instrumentation necessary to implement several flow paths. The RCIC system steam supply

line branches off one of the main steam lines (leaving the RPV) and goes to the RCIC turbine with drainage provision to the main condenser. The turbine exhausts to the suppression pool with vacuum breaking protection. Makeup water is supplied from the condensate storage tank (CST) or the suppression pool with the preferred source being the CST. RCIC system flow is discharged to the feedwater injection line.

Following a reactor scram, steam generation in the reactor core continues, although at a reduced rate because of the core fission product decay heat. The turbine condenser and the feedwater system supply the makeup water required to maintain RPV inventory. In the event the RPV is isolated and the feedwater supply is unavailable, SRVs automatically maintain the RPV pressure within desirable limits. The water level in the RPV drops because of continued steam generation by decay heat. Upon reaching a predetermined low level, the RCIC system is initiated automatically. The turbine-driven pump supplies water from the CST (preferred) or from the suppression pool to the RPV. The turbine is driven with a portion of the decay heat steam from the RPV and exhausts to the suppression pool.

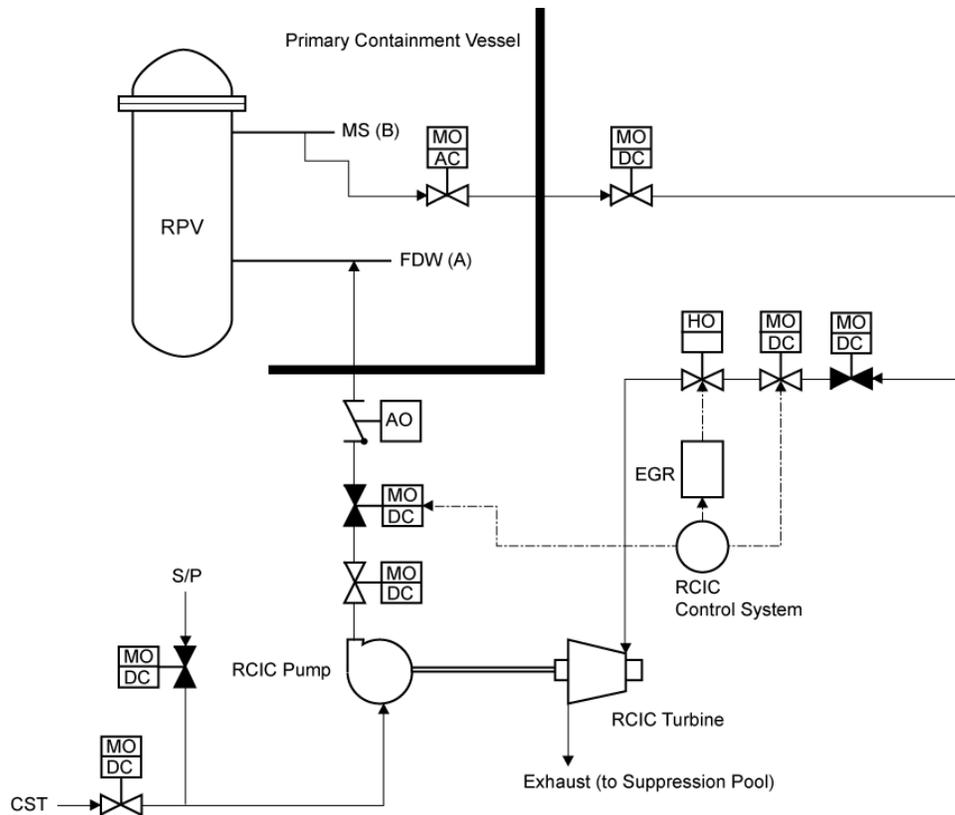


Figure 2. Schematic of typical RCIC system flow.

The RCIC system is designed to pump water into the RPV from full operating pressure down to ~ 1 MPa (150 psia). During RCIC operation, the wetwell suppression pool acts as the heat sink for steam generated by reactor decay heat. This results in a rise in the suppression pool water temperature. When AC power is available, heat exchangers in the RHR system are used to maintain the suppression pool water temperature within acceptable limits by cooling the suppression pool water directly.

A design flow functional test of the RCIC system may be performed during normal NPP operation by drawing suction from the CST and discharging through a full flow test return line to the CST (not shown in Fig. 1).² The discharge valve to the reactor feedwater line remains closed during the test, and reactor operation remains undisturbed. If the system requires initiation while in the test mode, the control system automatically returns to the operating mode.

Cooling water for pump and turbine operations and for the lube oil cooler and the gland seal condenser is supplied from the discharge of the pump.

Two turbine control systems include a speed governor limiting the speed to its maximum operating level and a control governor with automatic set-point adjustment that is positioned by a demand signal from a flow controller. Manual operation of the control governor is possible when in the test mode but is automatically repositioned (the governor valve goes back to its normal operating position) by the demand signal from the controller if system initiation is required. The operator has the capability to select manual control of the governor and adjust the power and flow to match decay heat steam generation. Several U.S. NPPs have developed procedures to override RCIC system valves and controls and manually run the RCIC system in case of an SBO.

The turbine and pump automatically shut down upon

- turbine overspeed
- high water level in the RPV
- low pump suction pressure
- high turbine exhaust pressure
- automatic isolation signal.

The steam supply system to the turbine is automatically isolated upon

- high pressure drop across two pipe elbows in the steam supply line
- high area temperature
- low reactor pressure
- high pressure between the turbine exhaust rupture diaphragms.

The RCIC system operates independently of auxiliary AC power, NPP service air, or external cooling water systems. System valves and auxiliary pumps are designed to operate by direct-current (DC) power from the nuclear power station batteries, except for the inboard containment isolation valve, which is powered by AC power (fail as-is), and the hydraulically operated valves, which are operated by the turbine control system through mechanical linkages.

In the case of an extended SBO, the RCIC system may stop operation for one of a number of reasons:

- The DC power for valves is available, but the DC power for instrumentation has failed, causing the DC-controlled valves to close.

² In the case of an ABWR, it is suppression pool to suppression pool.

- The suppression pool temperature is too high, leading to inadequate pump net positive suction head or inadequate lube oil cooling.
- The containment pressure is too high, causing the RCIC system turbine to trip.

III. THE HPCI SYSTEM

Philosophically, the HPCI system is similar to the RCIC system, except that the HPCI system has about seven times the flow (680 to 1270 m³/hour) and is part of the ECCS network (see Fig. 3). In ECCS use, small breaks in which the reactor does not depressurize through the break are helpful. However, the ECCS can also act as a backup to the RCIC system for isolation transients. Because of the larger steam consumption, the HPCI system can be manually controlled to use the full flow test line to limit the water being pumped to the reactor while depressurizing the reactor through the HPCI turbine.

The same types of signals initiate and terminate the HPCI system as do the RCIC system, and DC power is needed to operate some of the HPCI system valves.

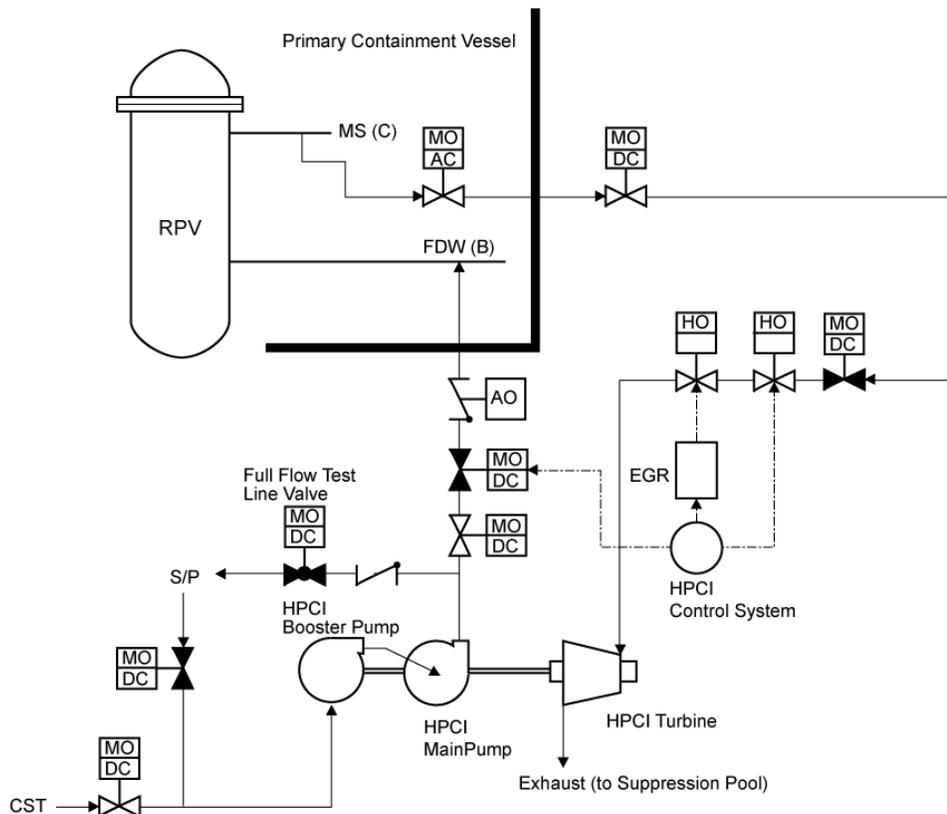


Figure 3. Schematic of typical HPCI system flow.