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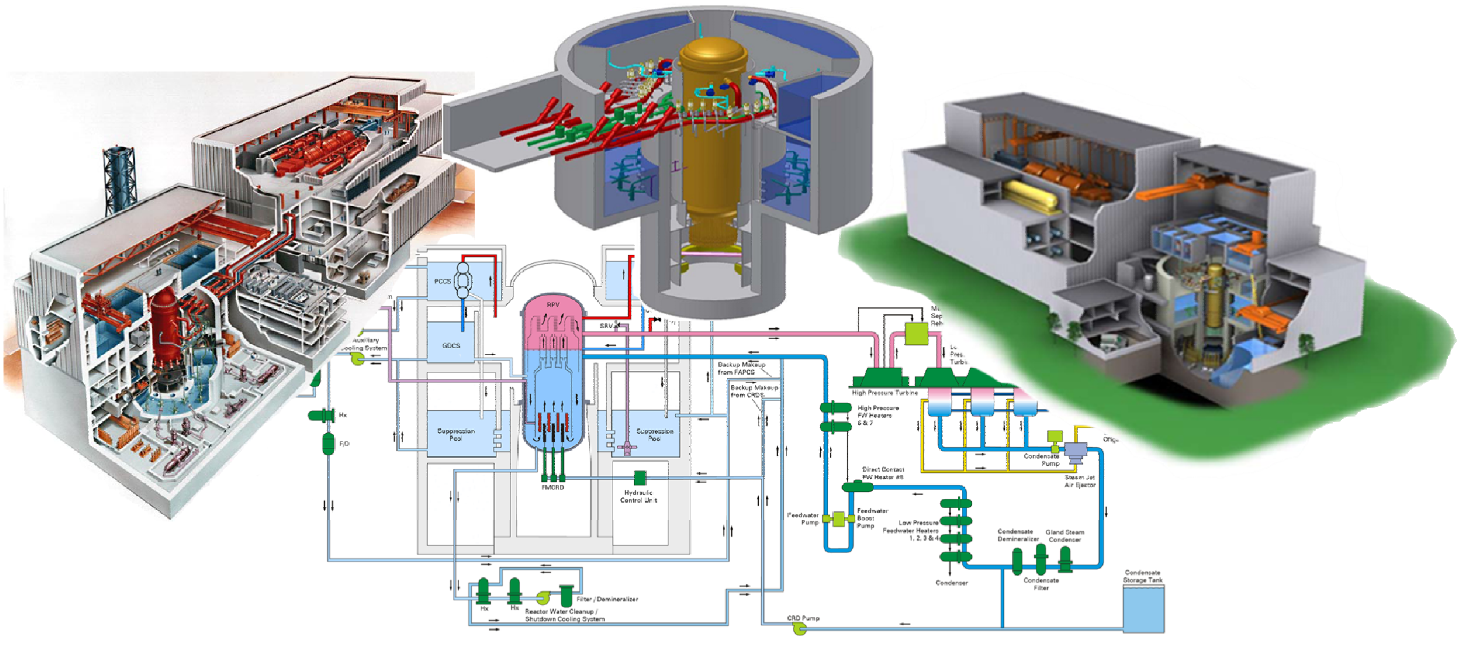

Part II
Introduction to Reactor Technology - BWR

Chapter 10.0, Emergency Core Cooling Systems

UNITED STATES

NUCLEAR REGULATORY COMMISSION

HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.
The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.
The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, "First of the Next Generation," GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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The information contained in this chapter pertains to current operational reactor designs. Advanced reactor designs are provided in separate chapters.

10.0 EMERGENCY CORE COOLING SYSTEMS

10.1 Introduction

The Emergency Core Cooling Systems (ECCS) package provided by a particular product line is dependent on the vintage of the plant and the regulations during that period of time. In all cases, there are high pressure and low pressure ECCS. The Automatic Depressurization system is functionally the same for all facilities.

The purpose of ECCS, in conjunction with the containment systems, is to limit the release of radioactive materials to the environment following a loss of coolant accident so that the resulting radiation exposures are within the limits of 10 CFR 100.

10.2 BWR/2 ECCS

The BWR/2 product line ECCS consists of the Isolation Condenser system, Automatic Depressurization system and the Core Spray system. The three ECCS operate in various combinations to maintain peak cladding temperature below 2200^{0}F and within the limits specified in 10 CFR 50.46 for any size break LOCA. They must also meet single failure criteria. The Isolation Condenser system is a passive high pressure system which consists of two independent natural circulation heat exchangers that are automatically initiated by high reactor pressure or low-low (level-2) water level. The Feedwater system can supply an adequate amount of cooling water to replace that lost through an extended range of pipe break sizes, providing normal station power or offsite power is available.

10.2.1 Automatic Depressurization System

The Automatic Depressurization System (ADS) consists of five automatically activated relief valves that depressurize the reactor vessel during a small break LOCA to permit the low pressure Core Spray system to inject water on top of the core.

The five ADS valves are actuated by low-low-low (level-1) reactor water level, high drywell pressure, indication that a core spray booster pump has started and a 120 second time delay. Only four of the five SRVs are required to achieve depressurization in the allowable time period.

10.2.2 Core Spray System

The Core Spray system provides an adequate supply of cooling water independent of the Feedwater system and can be powered from the emergency power system.

The Core Spray system is a low pressure system which supplies cooling water after reactor pressure is reduced to 285 psig. This system will prevent the reactor from overheating following intermediate or large breaks. To accommodate some intermediate to small pipe breaks when feedwater is not available, the ADS will depressurizes the reactor thus permitting the Core Spray system to provide core cooling.

The Core Spray system consists of two identical loops. Each loop contains two main pumps, two booster pumps, two sets of parallel isolation valves (one set inside and the other outside the drywell), a spray sparger and associated piping, instrumentation and controls. Each pump is rated at 3400 gpm full flow capacity.

Water is supplied to the system from the suppression pool. Also, the Fire Protection system is connected to each of the core spray loops to provide a backup supply of water. Each loop has a test recirculation line to the suppression pool for full flow testing without discharging into the reactor vessel. The piping up to the test valve is carbon steel, designed for 400 psig and 350^0F. From the injection isolation valves to the reactor vessel, the piping is stainless steel designed for 1250 psig and 575^0F. A core spray filling system maintains the Core Spray system full to preclude any danger of water hammer when the system goes into operation.

The discharge from each of the main pumps flows through a check valve to a common header that supplies water to the booster pumps and a bypass line around the booster pumps. The booster pumps discharge piping contains motor operated isolation valves outside the drywell and air operated testable check valves inside the drywell. Flow from each loop is directed from the pumps through two, parallel, normally closed motor operated valves; a single line at the containment penetration; two parallel check valves; one locked open, manually operated valve; and into the sparger.

Both Core Spray systems and their diesel generators will automatically start upon the detection of one high drywell pressure or one low-low reactor vessel level condition. These conditions generally indicate a pipe break. The system can also be manually initiated by the control room operators.

10.3 BWR/3 ECCS

The BWR/3 product line high pressure ECCS consists of an ADS system and either a Feedwater Coolant Injection (FWCI) system or a turbine driven High Pressure Coolant Injection system. The low pressure ECCS consists of two Core Spray system loops and two Low Pressure Coolant Injection loops (either as a separate system or as a mode of the Residual Heat Removal system). A system composite drawing is shown in Figure 10.0-2.

10.3.1 High Pressure Coolant Injection System

The High Pressure Coolant Injection system (HPCI) supplies adequate reactor vessel water inventory for core cooling on small break LOCA, assist in depressurization of the reactor vessel to allow the low pressure ECCS to inject on intermediate break LOCA, and backs up the Isolation Condenser or Reactor Core Isolation Cooling system under reactor isolation conditions.

The HPCI system is an independent ECCS requiring no AC power, plant service and instrument air or external cooling water systems to perform its purposes. The HPCI system consists of a single turbine that drives a main pump and a booster pump on a single shaft.

The HPCI system is normally aligned to remove water from the condensate storage tank and pump the water at high pressure to the reactor vessel via the feedwater piping. The suppression pool is an alternate source of water with automatic selection on high suppression pool water level or low condensate storage tank water level. A test line permits functional testing of the system during normal plant operation. A minimum flow path to the suppression pool is provided for the HPCI pump in the event the pump is operated with a closed discharge path.

High pressure emergency core cooling for small and intermediate line breaks is provided by the HPCI system. During such breaks, reactor water level could drop to a level where the core is not adequately cooled while the reactor remains at or near rated pressure. With reactor pressure high, the low pressure ECCS would not be capable of supplying water to the reactor vessel. The HPCI system can supply makeup water to the reactor vessel from above rated reactor pressures to a pressure below that of the low pressure ECCS injection pressures.

System initiation can be accomplished by automatic signals or manually by the control room operator. Receipt of either a reactor low-low water level or high drywell pressure will automatically start the HPCI system.

10.3.2 Core Spray System

The Core Spray system pumps water from the suppression pool into the reactor vessel via spray nozzles located on independent ring spargers located within the core shroud above the fuel assemblies. The nozzles are positioned to provide a uniform distribution of coolant to the fuel assemblies.

The Core Spray system consists of two independent loops. Each loop contains a motor operated injection stop valve outside the drywell and a testable check valve plus a manual stop valve within the drywell. Each loop also contains suction isolation valves, test line, minimum flow line and a keep-fill line.

The Core Spray system is initiated automatically to provide core cooling upon receipt of either high drywell pressure or low-low vessel water level with low reactor pressure.

10.3.3 Low Pressure Coolant Injection (LPCI) System

The LPCI system is a closed loop system of piping, pumps, and heat exchangers that are designed to remove post power operation energy from the reactor under both operational and accident conditions. The LPCI system accomplishes this function in several but independent modes of operation;

- LPCI Mode - The LPCI mode operates in conjunction with the HPCI, ADS, and Core Spray systems to restore, if necessary, the water level in the reactor vessel following a LOCA.
- Suppression Pool Cooling Mode - This mode of the LPCI system is manually initiated following a LOCA to prevent pool temperature from exceeding 170°F.
- Containment Cooling Mode - The containment cooling mode permits spray cooling of the drywell and suppression chamber to remove additional heat energy from the primary containment following a LOCA. This is accomplished through the condensation of steam and spray cooling of noncondensables.

The LPCI system includes two separate circulating loops. Each loop includes a heat exchanger, two main system pumps in parallel and associated piping. The two loops maybe cross-connected by a single header, making it possible to supply either LPCI loop from the pumps in the other loop.

The LPCI system pump discharge piping is maintained full of water during normal plant operation by a safety system jockey pump or the condensate system.

The LPCI system employs both automatic and manual operation as well as a combination of both, depending on the mode being used. Water is supplied from the LPCI system to the core by injecting into the reactor recirculation system discharge lines.

LPCI Mode

The LPCI mode is established either automatically or manually to restore and maintain water level in the reactor vessel to at least two-thirds core height following a LOCA. A LOCA, indicated by vessel level sensing devices or pressure sensing devices in the drywell, actuates the automatic action of the LPCI mode. A combination reactor vessel low-low water level and vessel pressure low or high drywell pressure will provide signals for the following:

- Start LPCI pumps
  - If normal auxiliary power is available all four pumps start with no time delay
  - If standby AC power is supplying the bus, pumps A and C start immediately and pumps B and D start after a five second time delay
- Stop service water pumps, if running
- Opens LPCI heat exchanger valves (inlet, outlet, and bypass)
- Close containment spray valves, if open

During LPCI operation, suction is taken from the suppression pool and pumped into the core through the recirculation loops. When reactor pressure drops to LPCI pump discharge pressure, a check valve in the injection line opens, admitting LPCI flow into the recirculation pump discharge line.

10.4 BWR/4 ECCS

The BWR/4 product line high pressure ECCS consists of a HPCI system and ADS. The low pressure ECCSs consists of a Core Spray system and a Residual Heat Removal system with a LPCI mode. The high pressure ECCSs are the same as the BWR/3 product line with the exception of the number of SRVs used for automatic depressurization. The Core Spray system is the same as a BWR/3 except for the initiation signals and number of pumps per loop. Initiation signals used for the low pressure ECCS is high drywell pressure or low-low-low (level-1) vessel water level. The LPCI mode of the Residual Heat Removal system was divided into two separate and independent loops for most of the BWR/4s due to their higher power density cores and the need to meet the requirements of 10 CFR 50.46. A system composite drawing is provided on figure 10.0-2.

10.4.1 Residual Heat Removal System (LPCI Mode)

The Residual Heat Removal (RHR) system is a multipurpose system which has five operational modes, each with a specific purpose. The RHR system consists of two separate piping loops, designated system 1 and system 2. Each loop contains two pumps, a heat exchanger and associated piping, valves and instrumentation.

The low pressure coolant injection (LPCI) mode is the dominant mode and normal valve lineup configuration of the RHR system. The LPCI mode operates automatically to restore and maintain, if necessary, the reactor water level. During LPCI operation, the RHR pumps take suction water from the suppression pool and discharge to the reactor vessel via their respective recirculation system discharge piping.

The exception to the above mode description is that two of the BWR/4 plants have four separate and independent LPCI loops which discharge directly into the reactor vessel shroud.

10.5 BWR/5 & BWR

The BWR/5 and BWR/6 product line ECCSs consists of a High Pressure Core Spray system, ADS, Low Pressure Core Spray system, and LPCI mode of the RHR system. Due to the unreliability of the HPCI systems on earlier BWRs, the BWR/5 and 6 were designed with a motor driven high pressure makeup system. A composite system drawing is provided on Figure 10.0-3.

10.5.1 High Pressure Core Spray System

The High Pressure Core Spray System (HPCS) provides high pressure emergency core cooling for small, intermediate, and large line breaks. The HPCS, shown in Figure 10.0-3 is a single loop system and consists of a suction shutoff valve, one motor drive pump, discharge check valve, motor operated injection valve, minimum flow valve, full flow test valve to the suppression pool, two high pressure flow test valves to the condensate storage tank, discharge sparger and associated piping and instrumentation. HPCS takes suction from the condensate storage tank or suppression pool and pumps the water into a sparger located on the upper core shroud.

Spray nozzles mounted on the sparger are directed at the top of the fuel assemblies to remove decay heat following a LOCA. The suppression pool is the alternate source of water for the HPCS system.

HPCS initiates automatically on either high pressure in the drywell or low water level in the reactor vessel (level-2). In the event HPCS is in any mode other than standby and an automatic initiation signal is received, all valves realign for the injection mode of operation. Normal power for the HPCS system is provided from the Standby Power system division 3 diesel generator.

10.5.2 Low Pressure Core Spray System

The low pressure core spray system is a single loop system and consists of a suction shutoff valve, one motor driven pump, discharge check valve, motor operated injection valve, minimum flow valve, full flow test valve to the suppression pool, discharge sparger and associated piping and instrumentation. LPCS takes suction from the suppression pool and discharges the water through the core spray sparger ring directly on top of the fuel assemblies. This provides core cooling by removing the decay heat generated from the fuel bundles following a postulated LOCA.

The LPCS, along with other ECCS, is automatically initiated by either high pressure in the drywell or a low reactor water level (level-1). The motor operated valves automatically align for emergency mode of operation upon a system initiation signal regardless of the alignment unless the system has been removed from service for maintenance by closing the motor operated suction valve.

10.5.3 LPCI Mode of RHR System

The RHR system is a multipurpose system which has five operational modes, each with a specific purpose. The RHR system consists of three separate piping loops, designated A, B, and C. Loops A and B each have a pump and two heat exchangers. Loop C is used exclusively for LPCI mode and is not equipped with a heat exchanger.

The low pressure coolant injection (LPCI) mode is the dominate mode and normal valve alignment of the RHR system. The LPCI mode operates automatically to restore and maintain, if necessary, water level to maintain the fuel clad temperature below 2200^0F. During LPCI operation, the RHR pumps take water from the suppression pool and discharge to the reactor vessel inside the core shroud via their own individual penetrations. The LPCI mode initiates automatically on either high pressure in the drywell or reactor vessel water level low (level-1). In the event the RHR system is any mode other than standby or shutdown cooling and an automatic initiation signal is received, all valves realign for the LPCI injection mode of operation.

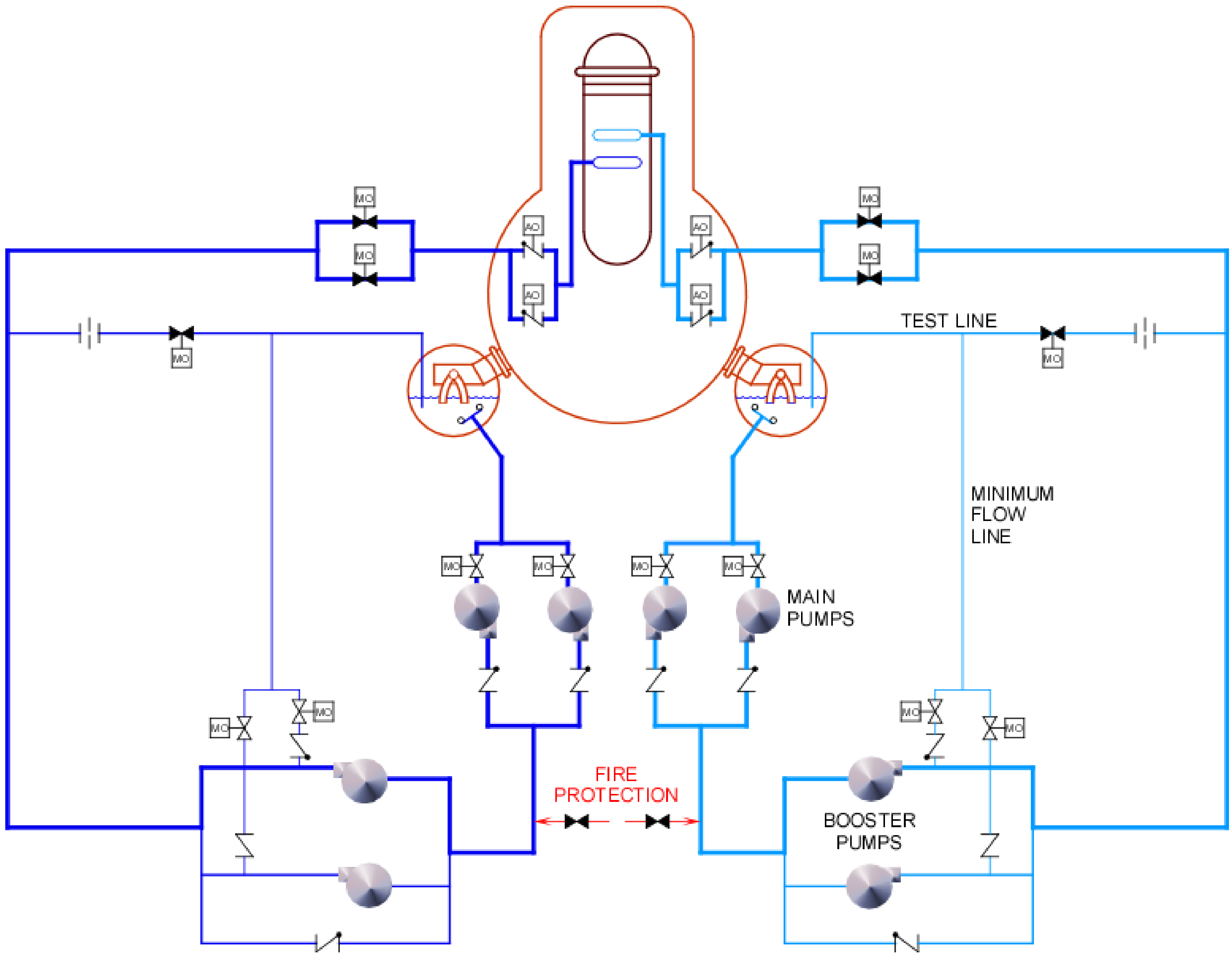

Figure 10.0-1, Core Spray System

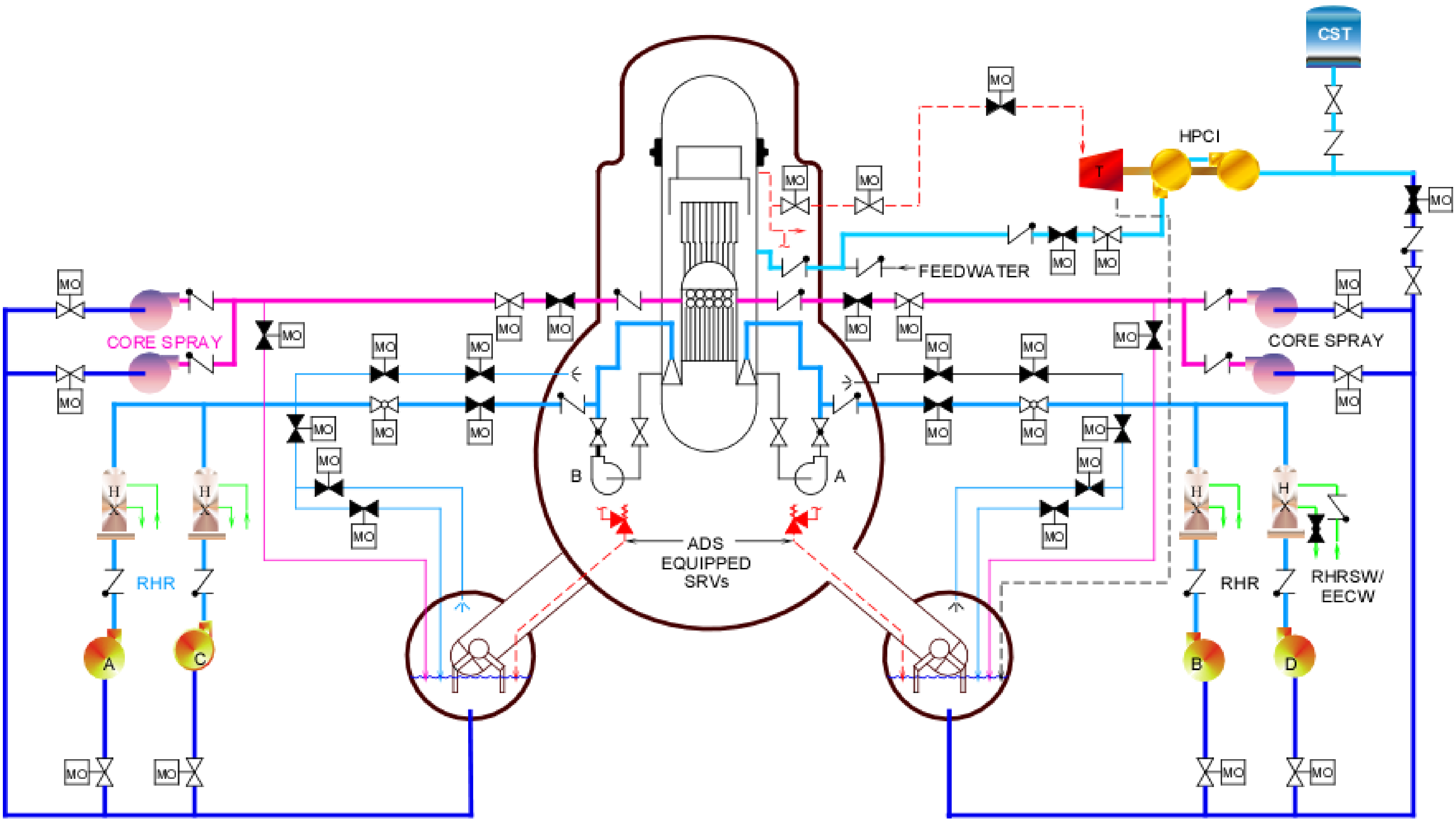

Figure 10.0-2, Typical Emergency Core Cooling System (BWR/3 & BWR/4)

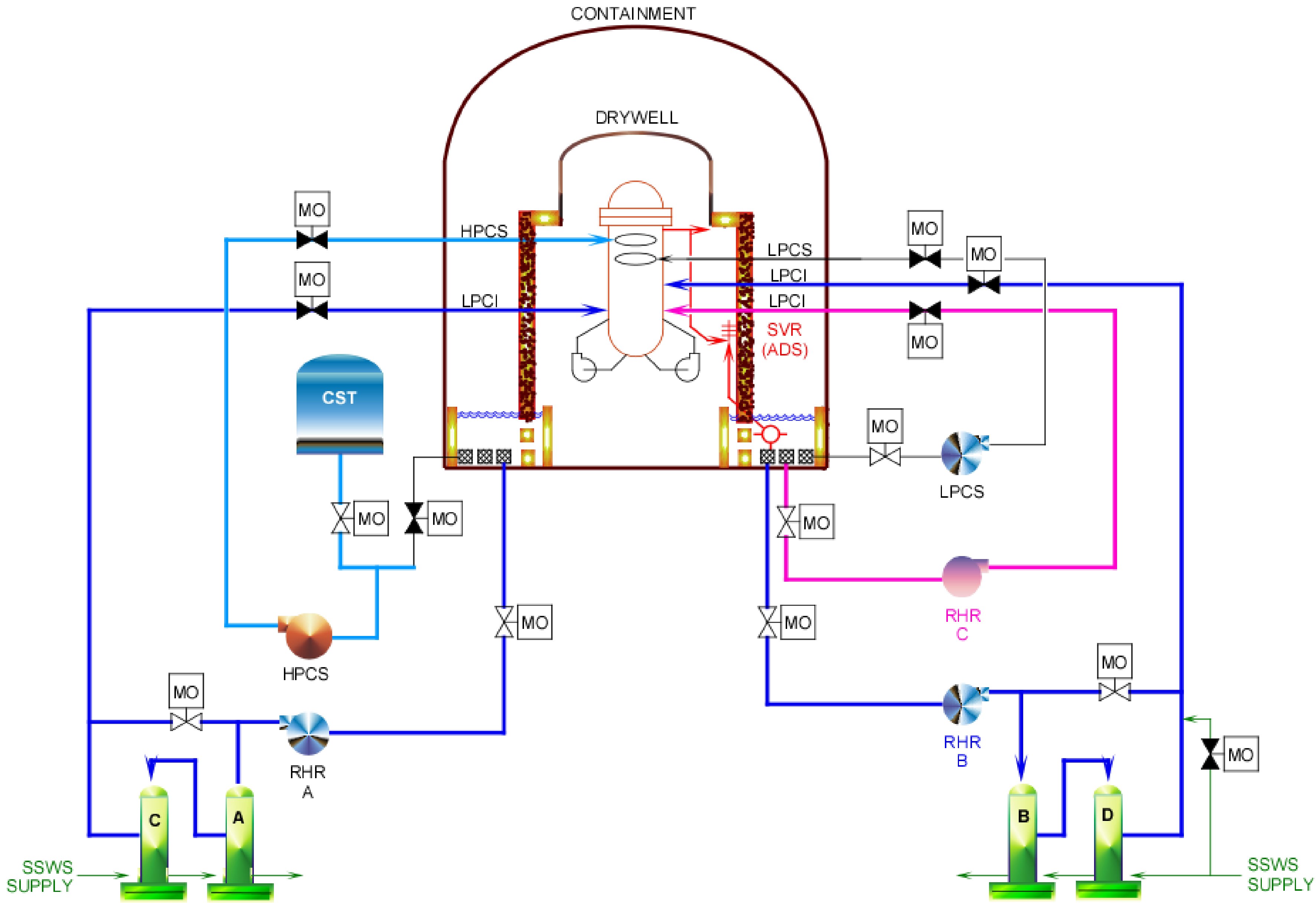

Figure 10.0-3, Typical Emergency Core Cooling System (BWR/5 & BWR/6)

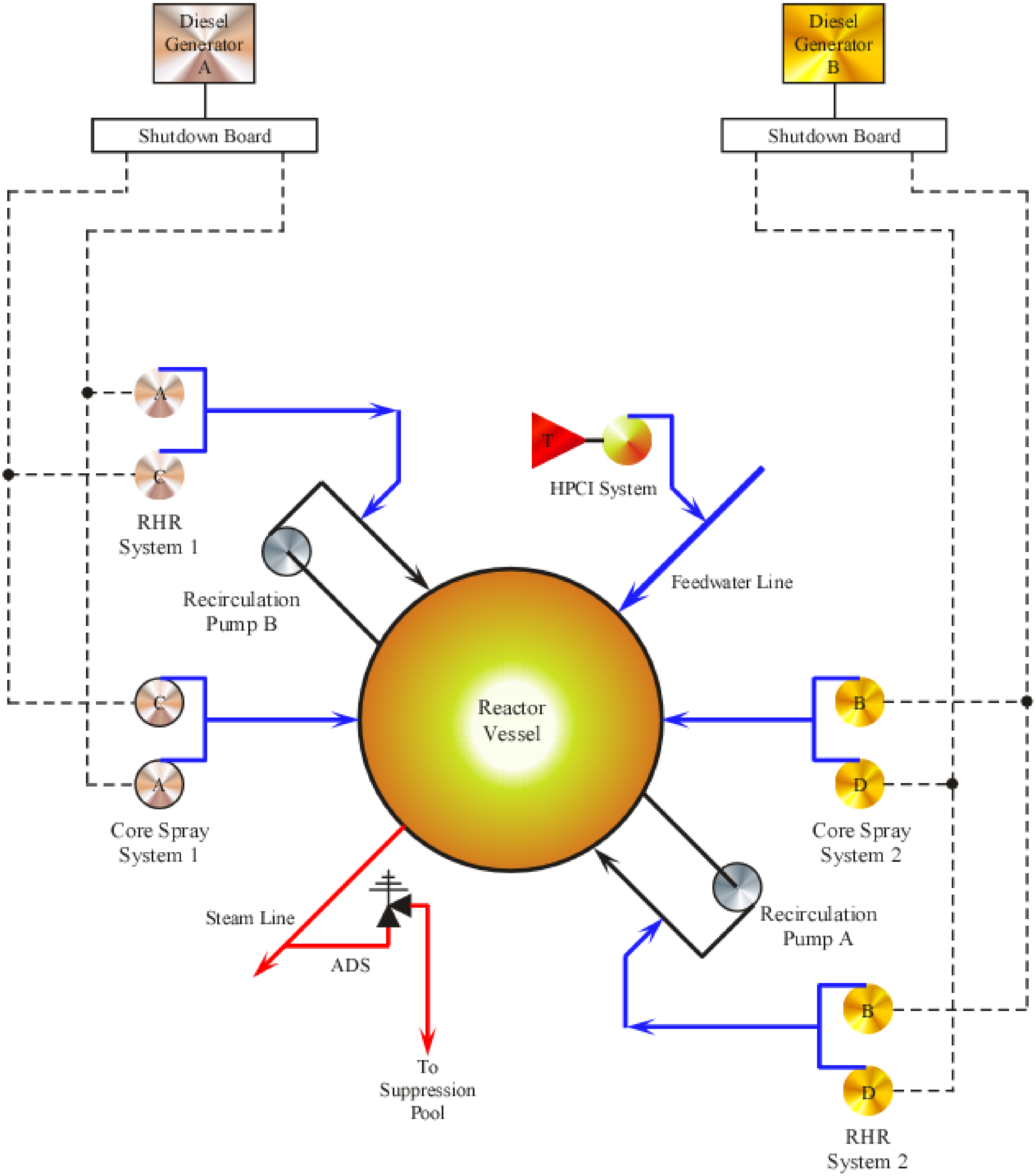

Figure 10.0-4, Emergency Core Cooling Network