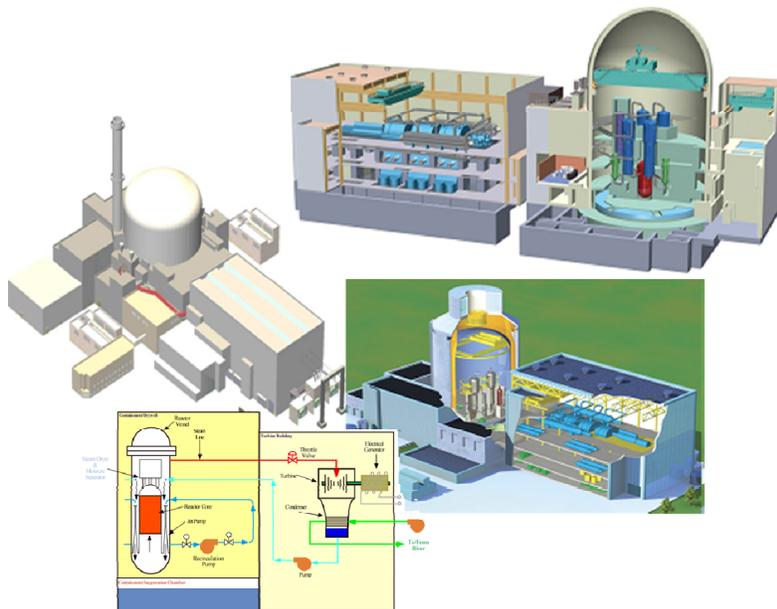




# NUCLEAR REGULATORY COMMISSION

---

## Reactor Technology Training Branch



## Part I

# Introduction to Reactor Technology - PWR

---

## Chapter 4.0 Babcock & Wilcox Plant Description



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. 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.

---

U.S. Nuclear Regulatory Commission  
Technical Training Center • Osborne Office Center  
5746 Marlin Road • Suite 200  
Chattanooga, TN 37411-5677  
Phone 423.855.6500 • Fax 423.855.6543

# Table of Contents

Table of Contents .....	4-3
List of Figures .....	4-3
4.0 BABCOCK & WILCOX PLANT DESCRIPTION .....	4-4
4.0.1 Introduction .....	4-4
4.0.2 Mechanical Systems .....	4-4
4.0.2.1 Reactor Coolant System .....	4-4
4.0.2.2 Once-Through Steam Generator .....	4-4
4.0.2.3 Emergency Core Cooling Systems .....	4-5
4.0.2.4 Control Rod Drive Mechanism .....	4-6
4.0.3 Control Systems .....	4-6
4.0.3.1 Integrated Control System .....	4-6
4.0.3.2 Reactor Protection System .....	4-7
4.0.4 Summary .....	4-7

## List of Figures

Figure 4.0-1, Babcock & Wilcox Reactor Coolant System .....	4-9
Figure 4.0-2, Cutaway View of B&W Once Through Steam Generator .....	4-10
Figure 4.0-3, Once Through Steam Generator Heat Transfer Regime .....	4-11
Figure 4.0-4, High Pressure Emergency Core Cooling System .....	4-12
Figure 4.0-5, Decay Heat Removal System .....	4-13
Figure 4.0-6, Core Flood Tanks .....	4-14
Figure 4.0-7, Control Rod Drive Mechanism .....	4-15
Figure 4.0-8, Integrated Control System (Simplified) .....	4-16
Figure 4.0-9, Integrated Control System (Detailed) .....	4-17
Figure 4.0-10, Reactor Protection System Channel Logic .....	4-18

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

## **4.0 BABCOCK & WILCOX PLANT DESCRIPTION**

### **4.0.1 Introduction**

This chapter provides a basic introduction to the Babcock & Wilcox (B&W) technology by discussing the major differences between a Westinghouse design and a B&W design. The first part of the discussion will be about the mechanical systems, specifically the Reactor Coolant system, the steam generator, the emergency core cooling systems, and the control rod drive mechanism. The second part will discuss the control systems, specifically the integrated control system and the reactor protection system.

### **4.0.2 Mechanical Systems**

#### **4.0.2.1 Reactor Coolant System**

The reactor coolant system consists of two heat transport loops, each of which has two reactor coolant pumps and one steam generator. The reactor coolant is transported through hot leg ( $T_h$ ) piping connecting the reactor vessel to the steam generators. The heat generated in the core inside the reactor vessel is transferred to the secondary system in the steam generators. The coolant leaves the steam generator through two cold leg ( $T_c$ ) connections, each containing a reactor coolant pump. In each loop, the coolant is returned to the reactor vessel.

Figure 4.0-1 shows the major components of a raised loop design of the reactor coolant system. The hot leg piping is 38" in diameter, and the cold leg piping is 32". The reactor coolant system is designed to 2500 psig, with normal operating pressure around 2195 psig.  $T_{avg}$  at 100% power is 601°F.

#### **4.0.2.2 Once-Through Steam Generator**

The purpose of the steam generator is to take the heat from the primary coolant flowing inside of the tubes and make steam using the secondary water flowing around the tubes. This purpose is accomplished in the once-through steam generators (OTSG), which are of a slightly different design than the Westinghouse U-tube design.

Instead of having U-shaped tubes, the OTSG (Figure 4.0-2) uses a straight tube design. There are approximately 16,000 tubes in the OTSG. The OTSG is a counterflow heat exchanger. That is, the primary coolant enters the tubes at the top of the OTSG and flows straight through the tubes to the bottom of the OTSG. The feedwater enters the OTSG tube bundle at the bottom and flows to the top. At the primary outlet, the flow splits into two paths, each going to a reactor coolant pump.

The operation of the OTSG is also slightly different from that of a U-tube steam generator design. The steam generated in a U-tube steam generator is saturated steam. Also, the U

tubes are completely covered with water at all power levels. Therefore, the mode of primary-to-secondary heat transfer is the same everywhere in the tube bundle. In an OTSG, the water level varies, multiple heat transfer regimes develop within the tube bundle, and the steam at the outlet of the OTSG has a minimum of 50°F superheat.

Feedwater is sprayed into the annulus between the shell and the shroud of the OTSG (Figure 4.0-3), where it is heated to approximately a saturated condition by aspirated steam from the tube bundle region. The feedwater then enters the tube bundle region at the bottom of the generator and begins to boil in the nucleate boiling region; at the outlet of this region, the secondary fluid is about 90% steam. The steam then enters the film boiling region, where the steam quality is increased to 100%. Finally, the steam enters the superheat region and receives enough energy to provide the minimum of 50°F superheat.

The sizes of these heat transfer regions change with power. As power increases, the feedwater flow increases, and the nucleate boiling region increases in size. The size of the film boiling region is approximately constant at all power levels. The increase in size of the nucleate boiling region results in a decrease in the size of the superheat region as power increases. However, the steam at the outlet of the OTSG still has a minimum of 50°F superheat. These changes in the sizes of the heat transfer regions allow the operator to actually control primary temperature by varying feedwater flow if the control rods are not available.

#### **4.0.2.3 Emergency Core Cooling Systems**

The emergency core cooling systems consist of the High Head Injection System, the Low Head Injection System, and the Core Flood System.

The High Head Injection System (Figure 4.0-4) consists of two trains. Water is taken from the borated water storage tank and pumped to the cold legs through motor operated valves. The valves can be throttled to control high pressure injection flow. The pumps in the high head system are used as the makeup pumps during normal operation.

The Low Pressure Injection System (Figure 4.0-5), or decay heat removal system, consists of two trains. Water can be taken from the borated water storage tank during the injection phase or from the recirculation sump during the recirculation phase. The pumps discharge to the core flood nozzles on the reactor vessel.

The Core Flood System (Figure 4.0-6) consists of two tanks. The core flood tanks are filled with borated water and pressurized with nitrogen. The normal pressure in the tanks is approximately 600 psig. The tanks discharge into the core flood nozzles on the reactor vessel.

#### **4.0.2.4 Control Rod Drive Mechanism**

The control rod drive mechanism for a B&W plant is also slightly different from a Westinghouse drive mechanism. Instead of using a stepping motor, the mechanism uses a leadscrew and roller nut assembly.

The major parts of the B&W drive mechanism are shown in Figure 4.0-7. A synchronous reluctance motor is used to provide the driving force for the control rod drive mechanism. The motor stator is located outside of the motor tube and the rotor on the inside of the motor tube. When energized, the upper part of the segmented arms of the rotor are pulled out, which pivots the roller nuts on the opposite end of the arms into the leadscrew. For every rotation of the roller nuts around the leadscrew, the leadscrew will move 0.750 inches. To prevent the leadscrew from rotating during rod motion, there is a torque taker on the top of the leadscrew. The torque taker transmits the torque to the torque tube and prevents rotation of the leadscrew. The torque taker also has a permanent magnet on it to close reed switches for rod position indication.

The control rod drive mechanisms are designed to drop the rods upon a loss of power. With no power to the drive mechanism, the segmented arms will pivot to the inward position due to springs. This causes the roller nuts to disengage the leadscrew, and the rod will fall.

### **4.0.3 Control Systems**

#### **4.0.3.1 Integrated Control System**

The B&W plants use an Integrated Control System (ICS) to simultaneously control the main turbine, main feedwater flow control valves, main feedwater pumps, and the control rods. The ICS is shown in simplified form in Figure 4.0-8 and more detailed in Figure 4.0-9. The basic function of the system is to match generated megawatts to desired megawatts.

There are four major subassemblies in the ICS. These are:

- Unit load demand
- Integrated master
- Feedwater demand
- Reactor demand

The unit load demand subassembly acts as the setpoint generator for the ICS. The operator can input the desired load and the desired rate of load change into this subassembly, and these signals are transmitted to the remainder of the ICS.

There are several functions of the integrated master subassembly. First, this subassembly controls the load of the turbine generator by positioning the turbine control valves. Another function is to feed the demand signal to the feedwater and reactor demand subassemblies. To do this, the integrated master modifies the signal being sent. This subassembly also controls the position of the steam dump valves. The final purpose is to maintain a constant

load on the turbine, even when plant conditions are changing. For example, if circulating water temperature is higher than normal, the vacuum in the main condenser will be lower (higher absolute pressure). The output of the turbine will be less due to the loss of efficiency. The number of megawatts generated will be less than the desired megawatts. The error signal will cause an increase in the output of the feedwater and reactor demand subassemblies. The integrated master performs its functions by controlling at a constant steam pressure. If pressure goes up, the turbine valves will open to lower pressure (pick up more load), and vice versa.

The feedwater demand signal originates in the unit load demand and is modified by the integrated master. There is a separate control for each OTSG. The demand signal controls the position of the startup feedwater regulating valve and the main feedwater regulating valve, which are operated in sequence. That is, the startup feedwater regulating valve opens first and then the main valve. To maintain the proper differential pressure across the feedwater regulating valves, the feedwater demand subassembly also controls the speed of the main feed pumps.

The reactor demand subassembly controls the position of the control rods for the purpose of controlling reactor coolant system temperature. The demand signal again comes from the unit load demand and is modified by the integrated master.

#### **4.0.3.2 Reactor Protection System**

The reactor protection system for a B&W plant (Figure 4.0-10) is significantly different from that of a Westinghouse plant.

If one of the monitored parameters exceeds its trip value, the associated contact in that channel will open. This will deenergize the trip relay in that channel, which tells the other channels that one channel has seen a trip condition. If a second channel receives a trip signal (from the same or a different parameter), the reactor will trip.

Therefore, the reactor protection system for a B&W unit is two-out-of-four Reactor Protection System channels, and not based upon a certain coincidence of only one parameter.

#### **4.0.4 Summary**

This chapter discussed the major differences between a Westinghouse design plant and a Babcock and Wilcox design plant. The B&W plant has two reactor coolant loops, each of which has two reactor coolant pumps and one steam generator. B&W plants use once-through steam generators.

The emergency core cooling systems in a B&W plant consist of a high pressure injection system (which is also used for normal makeup to the reactor coolant system), a low pressure injection system (which is also used for decay heat removal), and a core flood system.

An integrated control system is used to control the main turbine, main feedwater flow control valves, main feedwater pumps, and the control rods in the B&W design plant. The reactor protection system coincidence for a B&W unit is two-out-of-four channels of any combination of monitored parameters exceeding their setpoints.

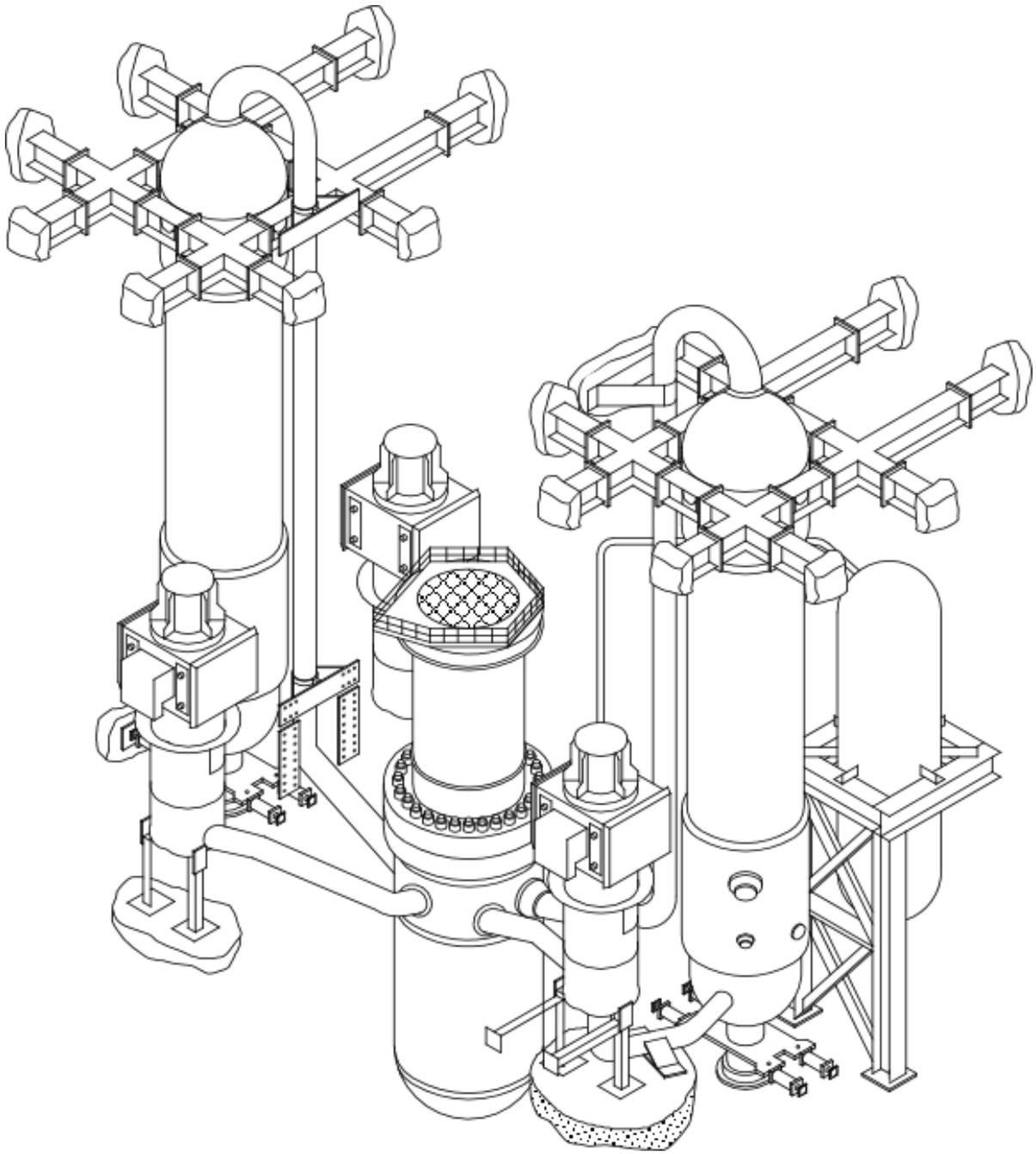


Figure 4.0-1, Babcock & Wilcox Reactor Coolant System

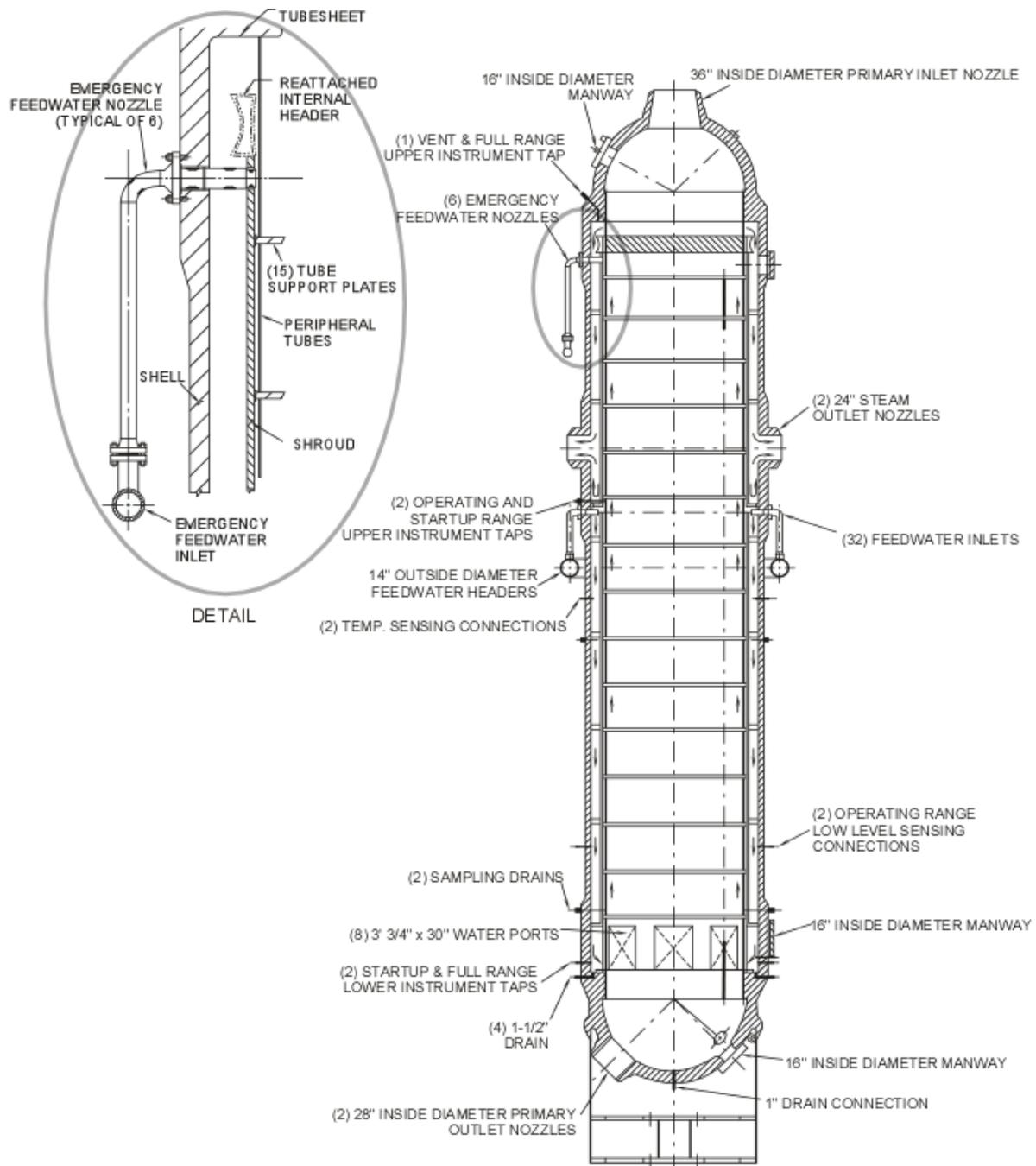


Figure 4.0-2, Cutaway View of B&W Once Through Steam Generator

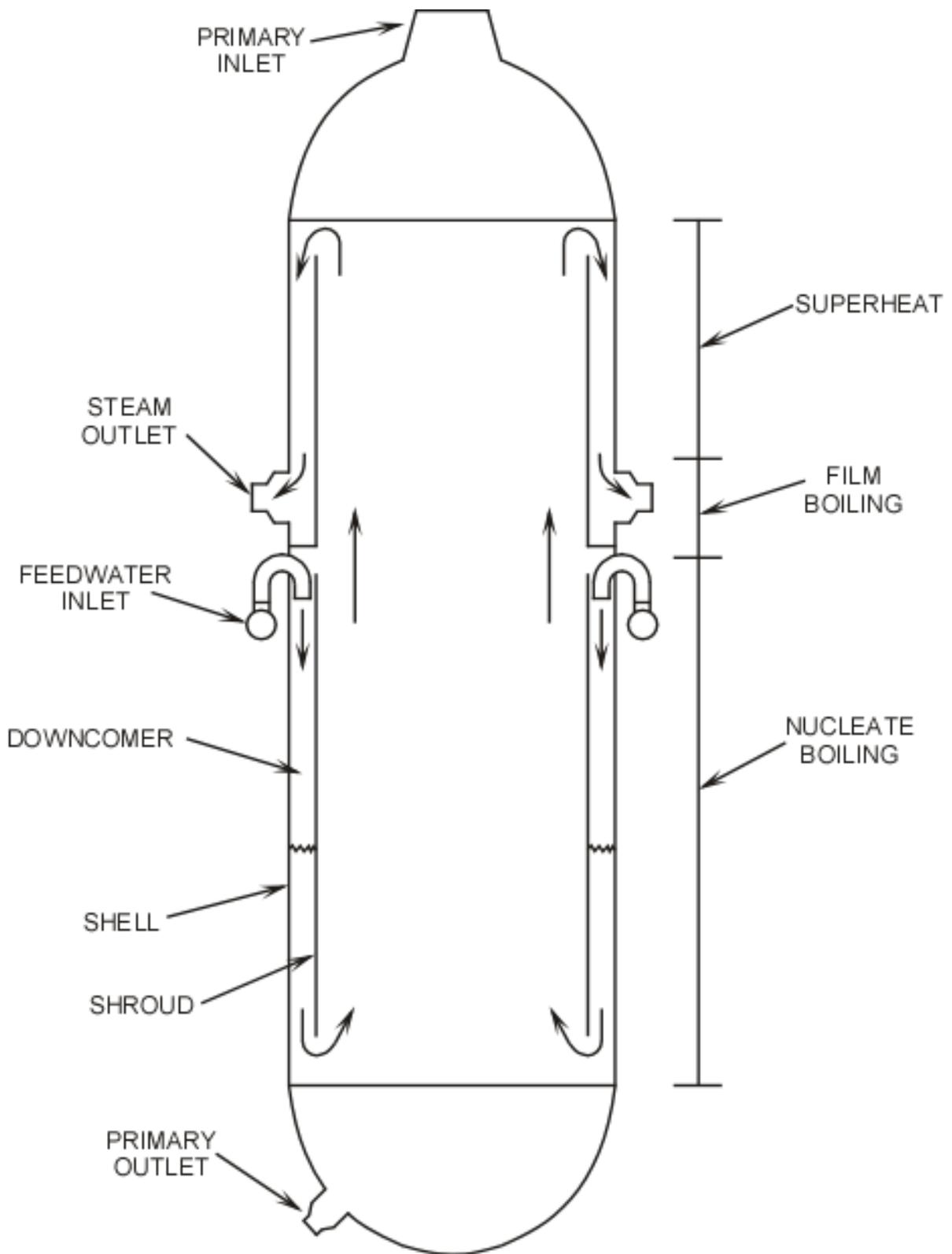


Figure 4.0-3, Once Through Steam Generator Heat Transfer Regime

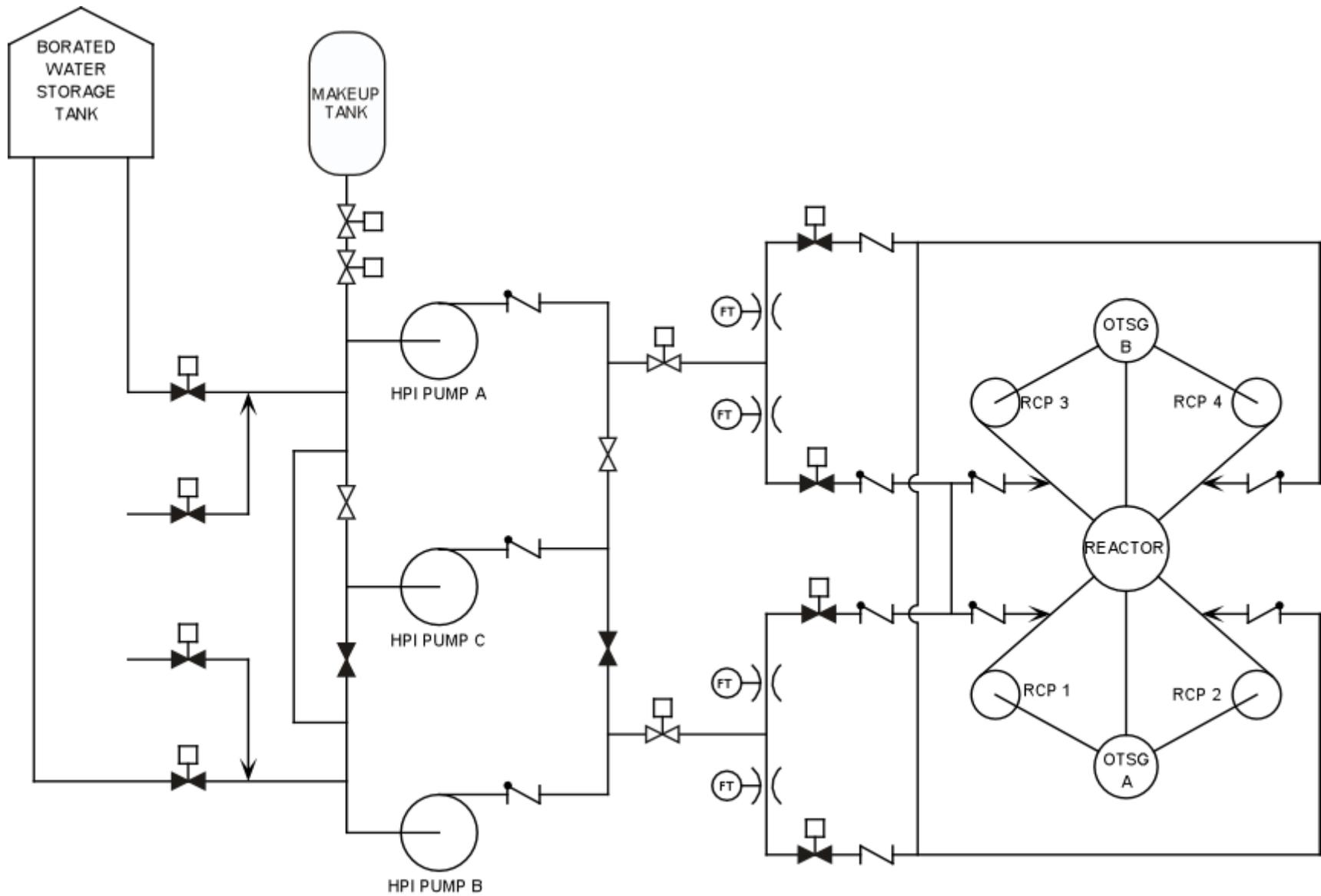


Figure 4.0-4, High Pressure Emergency Core Cooling System

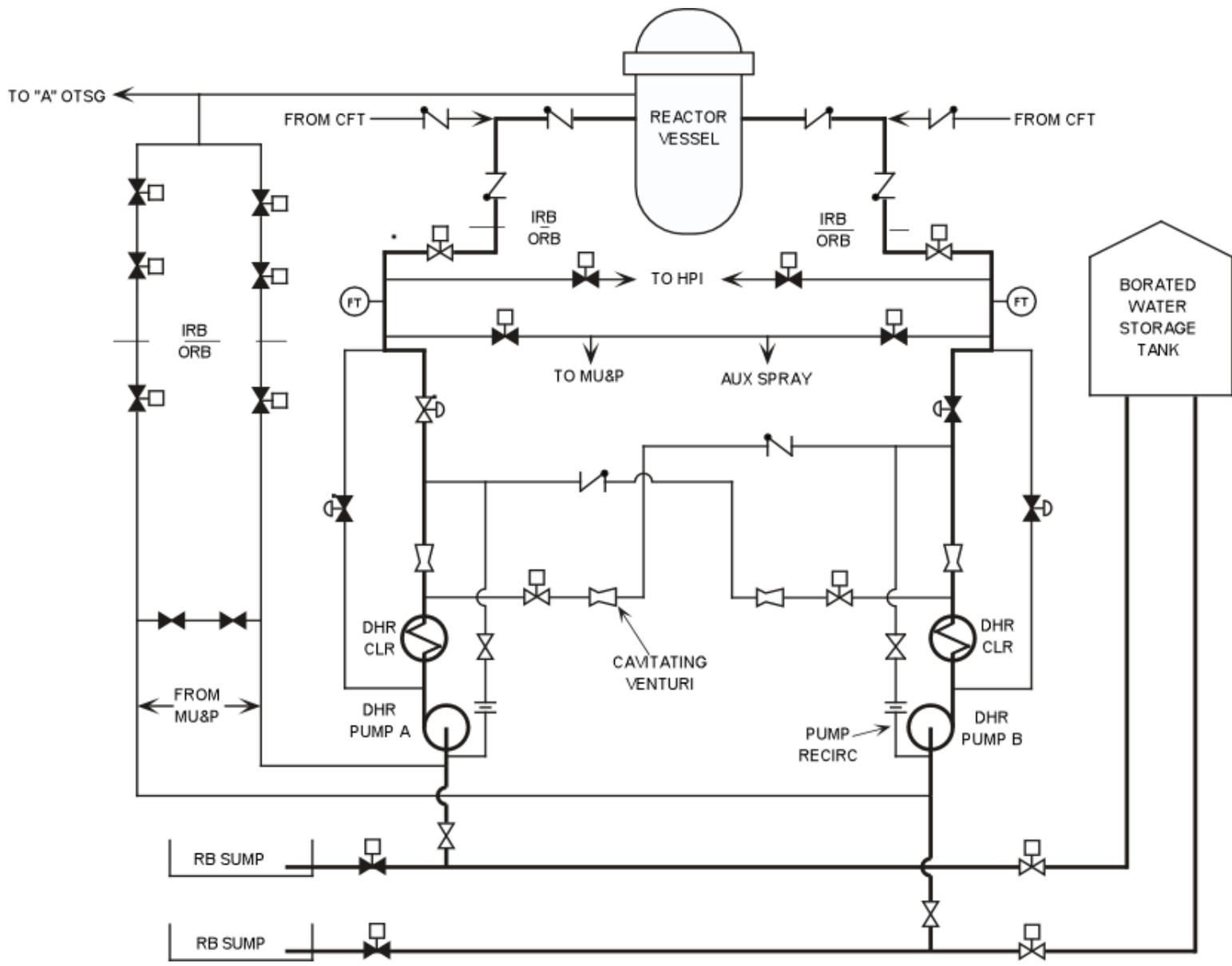


Figure 4.0-5, Decay Heat Removal System

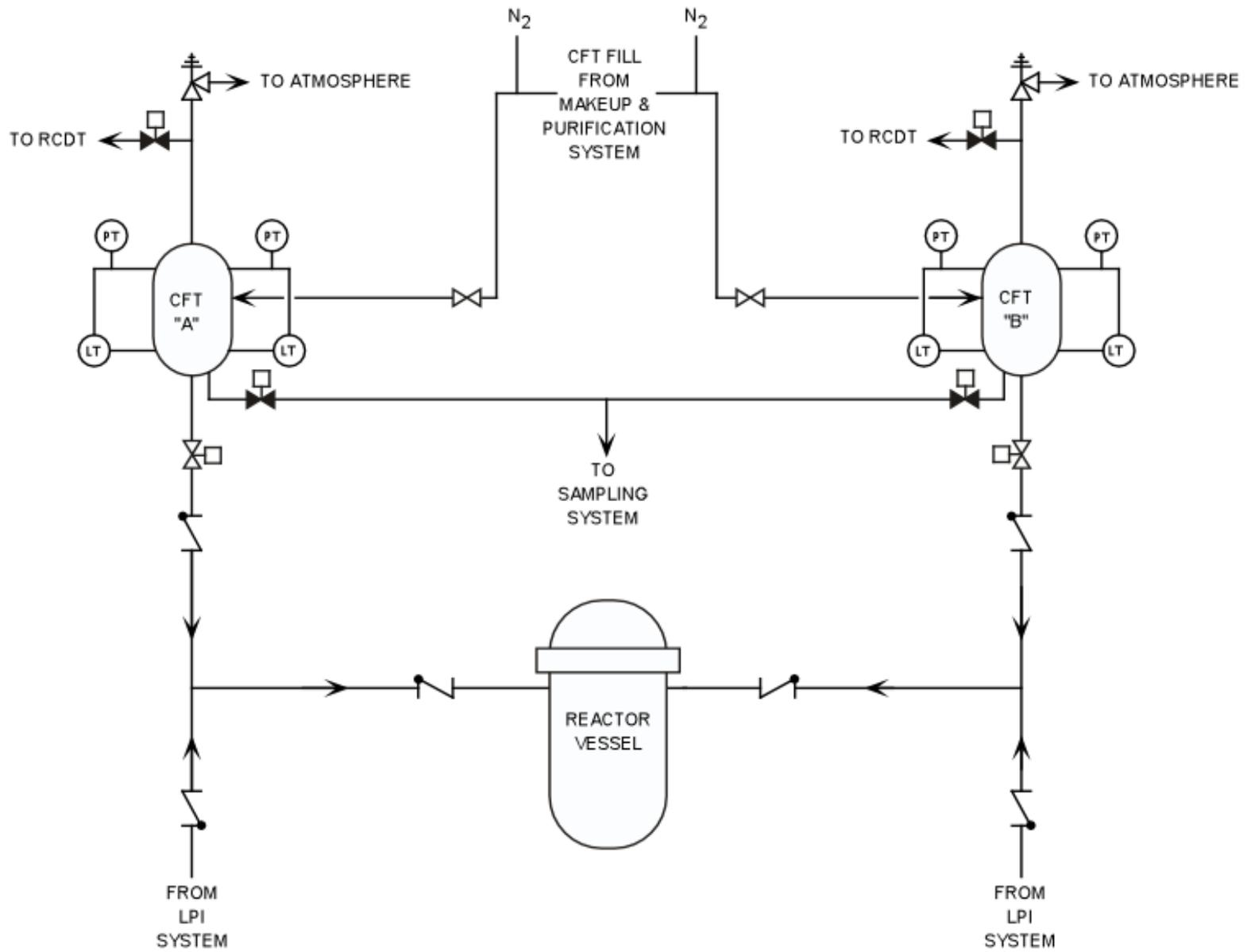


Figure 4.0-6, Core Flood Tanks

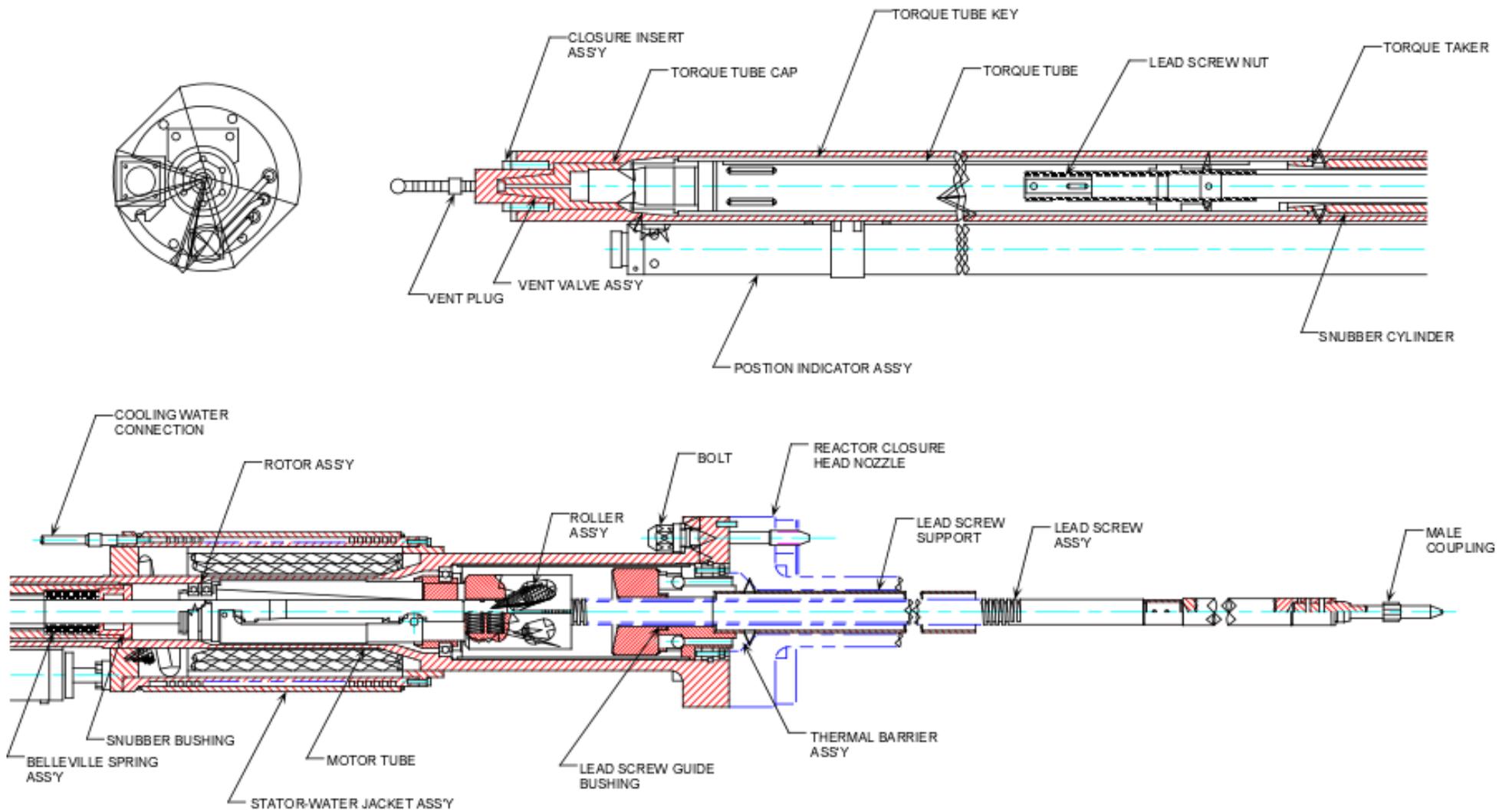


Figure 4.0-7, Control Rod Drive Mechanism

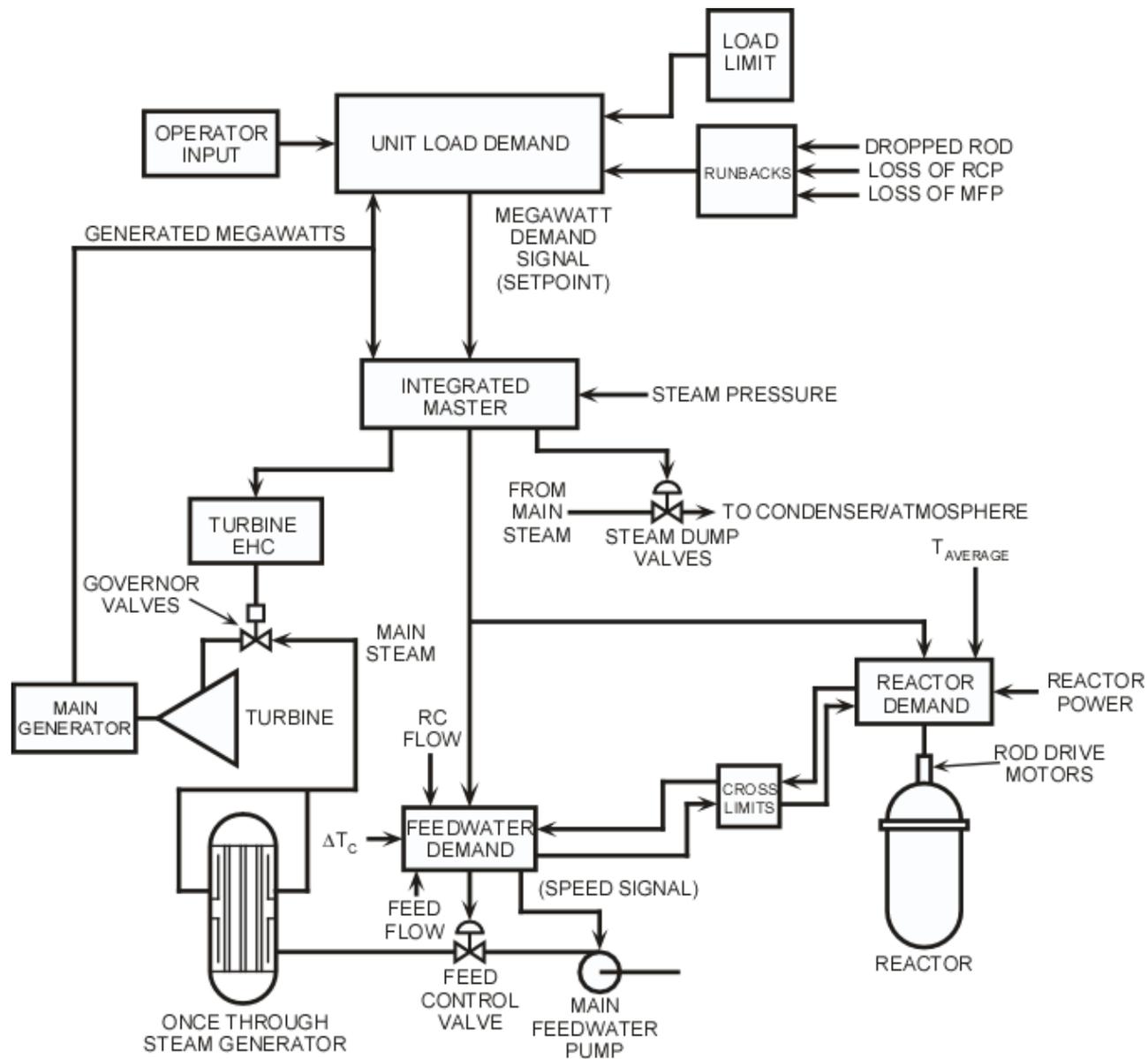


Figure 4.0-8, Integrated Control System (Simplified)



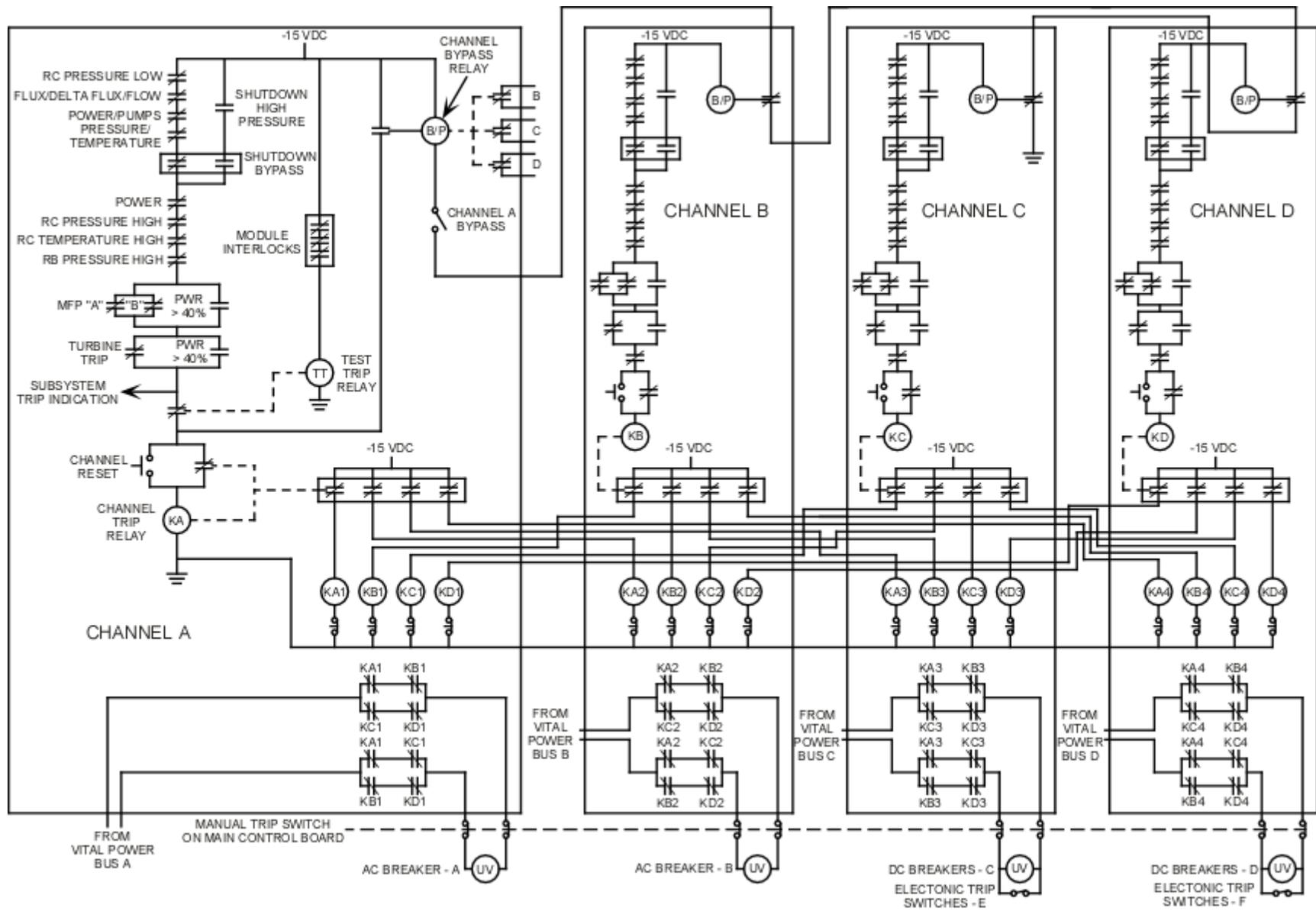


Figure 4.0-10, Reactor Protection System Channel Logic