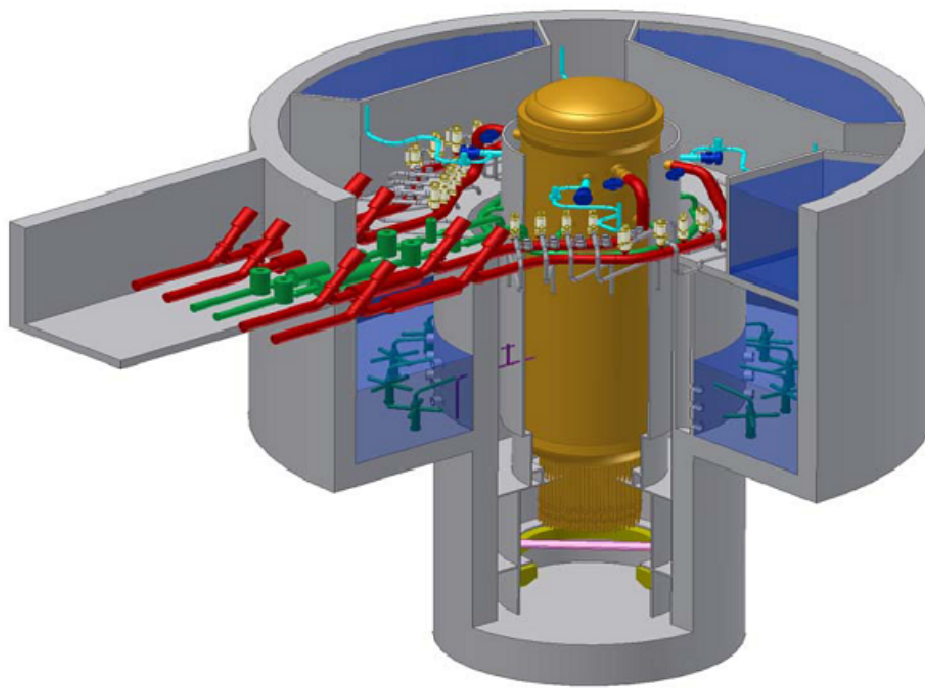




NUCLEAR REGULATORY COMMISSION

Reactor Technology Training Branch



Part II Introduction to Reactor Technology - BWR

Chapter 4.0, Control Rod Drive System

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.

4.0 CONTROL ROD DRIVE SYSTEM

The purposes of the Control Rod Drive (CRD) system are to position control rods to:

- change reactor power and
- rapidly shut down the reactor.

The Control Rod Drive system is functionally classified as a safety related system because of the Reactor Protection system scram function. Portions of the Control Rod Drive system not related to the scram function are functionally classified as power generation equipment.

4.1 System Description

The control rod drive mechanism, Figure 4.0-1, is a double acting, mechanically latched hydraulic cylinder using reactor quality water as operating fluid.

Control rod movement is accomplished by admitting water under pressure into the appropriate part of the control rod drive mechanism. The control rod drive mechanism movement is transmitted to the control rod blade which is coupled to the drive mechanism. The drive mechanism is capable of inserting or withdrawing a control rod at a slow controlled rate as well as providing scram insertion for rapid shutdown of the reactor.

The Control Rod Drive Hydraulic system provides the hydraulic fluid (water) for normal insertion and withdrawal of control rods. Additionally, the Control Rod Drive Hydraulic system provides cooling water for the control rod drive mechanisms and recirculation pump seals and maintains a source of stored energy for the scram function. Figure 4.0-1 shows the basic hydraulic water flow path which consists of centrifugal pumps, filters, control valves and headers which supply hydraulic fluid to the 137 control rod drive mechanisms.

4.2 Component Description

The major components of the CRD system are discussed in the paragraphs which follow.

4.2.1 CRD Pumps

The Control Rod Drive system has two fully redundant pumps, each with a rated capacity of 200 gpm at 1600 psig. The two 100% capacity pumps are motor driven, multistage centrifugal pumps. One pump is normally in service, taking suction from the condensate storage tank and providing approximately 50 to 60 gpm flow rate. The other pump is in standby.

4.2.2 Pump Discharge Filters

The control rod drive pump discharge filters prevent foreign material from entering the hydraulic control units. The two 100% capacity filters are redundant, with one in operation and the other manually valved out of service.

4.2.3 Recirculation Pump Seal Purge Supply

The control rod drive system supplies a regulated 3 to 5 gpm flow to each of the recirculation pumps. The cool, clean, high quality water minimizes the crud buildup in the recirculation pump seals thus increasing seal life.

4.2.4 Charging Water Header

The charging water header supplies the high pressure water required for charging the water side of the scram accumulators on the hydraulic control units.

4.2.5 Flow Control Station

The flow control station consists of a flow element, a transmitter, a flow controller and two 100% capacity air operated flow control valves.

The flow controller establishes a flow setpoint, set by the operator to maintain the proper cooling water header flow. The flow control valve will automatically react to deviations in the flow, sensed by the flow element, and make necessary adjustments in flow from the drive water pump. Only one flow control valve is in service with the other manually valved out.

4.2.6 Drive Water Pressure Control Station

The drive water pressure control station consists of a motor operated valve and two sets of stabilizing valves.

The motor operated pressure control valve is throttled to maintain approximately 260 psid above reactor pressure in the drive water header. Drive water, as its name implies, is the operating hydraulic fluid used for normal movement of the control rod drive mechanism and its associated control rod into or out of the core. For this reason, there is flow in the drive water header only during drive movement.

Two duplicate sets of stabilizing valves are installed in parallel with one set in operation and one in standby. Each set consists of two solenoid operated valves. The stabilizing valves bypass a regulated flow around the motor operated pressure control valve equivalent to the flow needed for both insertion and withdrawal of a control rod.

When a control rod is moved, the Reactor Manual Control system signals one of the stabilizing valves to close and its flow is diverted to the drive water header. One of the solenoid operated valves is used for drive insertion and the other for drive withdrawal. Thus flow remains constant in the system.

4.2.7 Cooling Water Header

The Control Rod Drive system cooling water header supplies cooling water, 0.25 gpm, to each control rod drive mechanism. The cooling water being supplied to the drive mechanisms is used to cool the drives when they are stationary, prolonging the life of the seals on the drive piston.

The cooling water pressure is maintained slightly above reactor pressure by the action of the automatic flow control valve and the pressure drop across the drive water pressure control station.

4.2.8 Directional Control Valves

The purpose of the directional control valves is to direct drive and exhaust water for control rod movement. The Reactor Manual Control system, upon command, provides the proper sequencing and duration of signals used to operate the directional control valves.

4.2.9 Scram Inlet and Outlet Valves

The scram inlet and outlet valves control the flow of water necessary for rapid rod insertion. The scram valves are held closed during reactor operation by instrument air pressure being applied to the tops of their actuators. The scram valves open by removing the air pressure and allowing spring force to push the valve open. Control of the air supplied to the scram valves is accomplished with the use of scram solenoid valves. The scram solenoid valves are normally energized and controlled by the Reactor Protection system.

4.2.10 Scram Accumulators

The scram accumulator is a piston type water accumulator pressurized by a volume of N₂ gas in a N₂ cylinder. The accumulators and their instrumentation occupy the lower part of the hydraulic control units. The piston in the scram accumulator forms a barrier between the high pressure N₂ gas used as the source of stored energy and the water used to initiate the scram. Under normal plant operating conditions the piston is in the full down position. The control rod drive pump continuously pressurizes the scram accumulators through the charging water header.

4.2.11 Scram Discharge Volume

The scram discharge volume consists of header piping which connects to each Hydraulic Control Unit and drains into two independent, redundant instrument volumes. The scram discharge volume is sized to receive and contain approximately twice the volume of water discharged by all 137 control rod drive mechanisms during a scram, independent of the instrument volumes. During normal operation, the scram discharge volume is empty and vented to atmosphere by air operated globe valves that automatically close on a scram signal from the Reactor Protection system.

4.2.12 Hydraulic Control Unit (HCU)

The HCU, shown in Figure 4.0-2, includes all the hydraulic, electrical and pneumatic equipment necessary to move one control rod drive mechanism during normal or scram operation. There are 137 HCUs, divided into approximately two equal sets, which are located in the reactor building on each side of the drywell.

Each HCU performs three specific functions:

- Stores energy (accumulators) and contains the valving necessary (scram inlet and outlet valves) to permit the control rod to scram,
- Contains valving necessary for normal movement (solenoid operated directional control valves) and
- Provides a cooling water flow path to the control rod drive mechanism.

4.2.13 Control Rod Drive Mechanism (CRDM)

The CRDM is shown, functionally, in Figure 4.0-1. Figure 4.0-3 illustrates the normal latch condition of the mechanism and the cooling water flow path.

The CRDM is a double acting, mechanically latched hydraulic cylinder assembly using reactor quality water as its operating fluid for normal and scram control rod operation. The CRDM is capable of inserting or withdrawing a control rod at a slow, controlled rate, as well as providing a rapid insertion in the event of an off-normal condition. A locking mechanism in the CRDM permits the control rod to be positioned at 6 inch increments of stroke and to be held in a set position for indefinite periods of time.

The basic parts of a CRDM consist of a control rod drive housing, an outer tube, an inner cylinder, an index tube, a piston tube, a drive piston, a collet locking mechanism and a position indicating tube.

Control rod position is obtained from reed switches mounted inside of the position indication probe, that open or close during rod movement. The reed switches are provided at three inch increments of drive piston travel. Since a notch is six inches, indication is available for each half notch of rod travel. Even numbered readouts, 00 to 48, are provided at each latched drive position. Odd numbered readouts, 01 to 47, indicate the midpoints between the latched positions of the outer tube, inner cylinder and flange is a single piece unit. The flange provides the means of mounting the CRDM to the control rod drive housing flange. The outer tube and inner cylinder form an annulus through which water is applied to the collet locking mechanism to unlock the index tube.

The drive piston and index tube provide the driving link with the control rod as well as notches for the collet locking mechanism fingers. The notches are machined to engage the collet fingers, providing 25 increments (at 6 inch intervals) at which a control rod may be positioned.

The collet locking mechanism is contained in the upper portion of the outer tube and ensures the index tube is locked to hold the control rod at a selected position in the reactor core.

4.2.14 Control Rod Drive Housing Support

The control rod drive housing support network is an engineered safety feature designed to limit the ejection of a control rod to less than 3 inches in the unlikely event of a control rod drive housing failure with the reactor pressurized. This network consists of support beams on the inside of the reactor pedestal, with hanger rods and spring washers suspended from beams.

4.3 System Features

A short discussion of system features for normal operations, rod insertion, withdrawal and settle are listed below.

4.3.1 Normal Operation

During normal power operation, the control rod drive system is providing cooling water flow to all of the control rod drive mechanisms and both recirculation pumps. Cooling water enters through the insert port of each CRDM and is allowed to flow between the outer tube and thermal sleeve via a cooling water orifice. The cooling water flow rate is regulated by the restricting orifice and allows approximately 0.25 gpm to pass. Cooling water is provided to ensure longer seal and bushing life. Cooling water flow is normally maintained to each CRDM at all times except when a control rod is moved.

4.3.2 Control Rod Insert Operation

Control rod insert operation is accomplished by opening both insert directional control valves 121 and 123. Opening of the directional control valves applies drive water pressure to the under side of the drive piston and allows water from the area above the drive piston to exhaust to the exhaust header. The water displaced into the exhaust header is then returned to the reactor vessel.

The differential pressure that is created across the drive piston forces the drive mechanism into the core, inserting the control rod. With the drive moving upward, the collet fingers move outward and provide no restriction to the drive.

4.3.3 Control Rod Withdraw Operation

Control rod withdraw requires a brief insert signal to relieve the axial load on the collet locking mechanism. The area of the collet piston is designed to ensure unlocking is not possible when opposed by the forces of its collet spring, the weight of the drive components and the driving pressure applied to the area above the drive piston.

Immediately following the brief insert signal, a withdraw signal is applied to the drive mechanism by opening the 120 and 122 directional control solenoid valves. Drive water pressure is simultaneously applied to the collet piston and the area above the drive piston while the area below the drive piston is aligned to the exhaust header.

With the area below the drive piston aligned to the exhaust header and the area above the piston pressurized with drive water pressure, a differential pressure is created to move the control rod out of the core.

4.3.4 Settle Operation

At the termination of any control rod insert or withdraw signal, the Reactor Manual Control system automatically energizes and opens the withdrawal directional control solenoid valve 120 for several seconds. This opens the area under the drive piston to the exhaust header, permitting the drive to settle downward to a new latched position.

4.3.5 Control Rod Scram Operation

When a reactor scram is initiated by the Reactor Protection system, the scram inlet valves open to admit pressurized water from the scram accumulator to the area below the drive piston, and the scram outlet valves open to vent the area above the drive piston to the scram discharge volume. The large differential pressure applied to the drive piston produces a large upward force on the control rod drive, giving it a high initial acceleration and provides an excess amount of force to overcome friction forces within the control rod drive mechanism.

The drive internals provide an additional pressure source to back up or aid accumulator pressure during a scram. The ball check valve, located in the insert port, will unseat and maintain the pressure under the drive piston at reactor pressure via internal ports in the drive. At a reactor pressure greater than 800 psig, reactor pressure alone is capable of scrambling the drive. At reactor pressures less than 800 psig, the accumulator is necessary to scram the drive.

During and following a scram condition, a large flow condition exists to the charging water header. The large flow signal closes the flow control valve thus directing all water to the charging water header for accumulator charging.

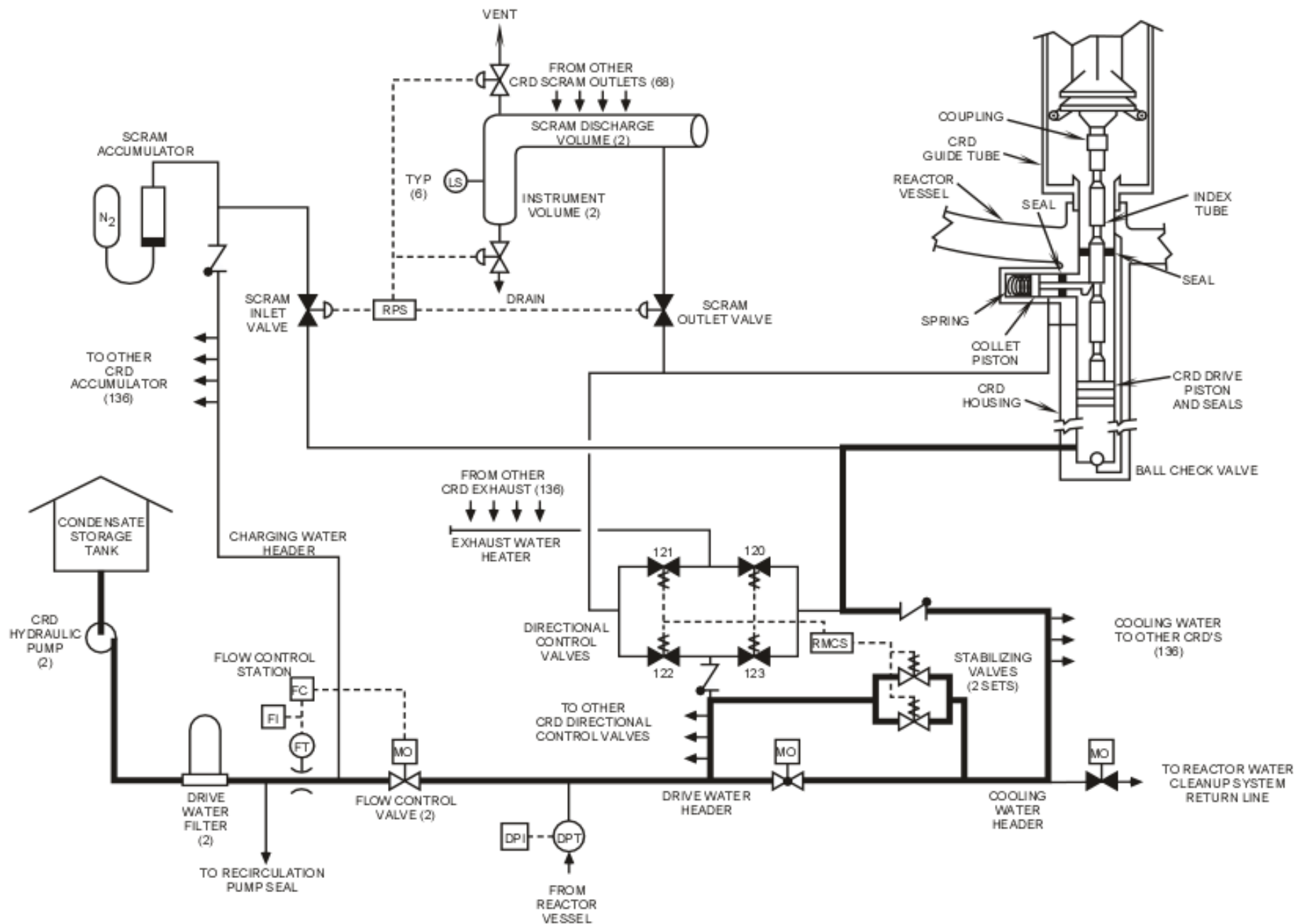


Figure 4.0-1, Control Rod Drive Hydraulic System

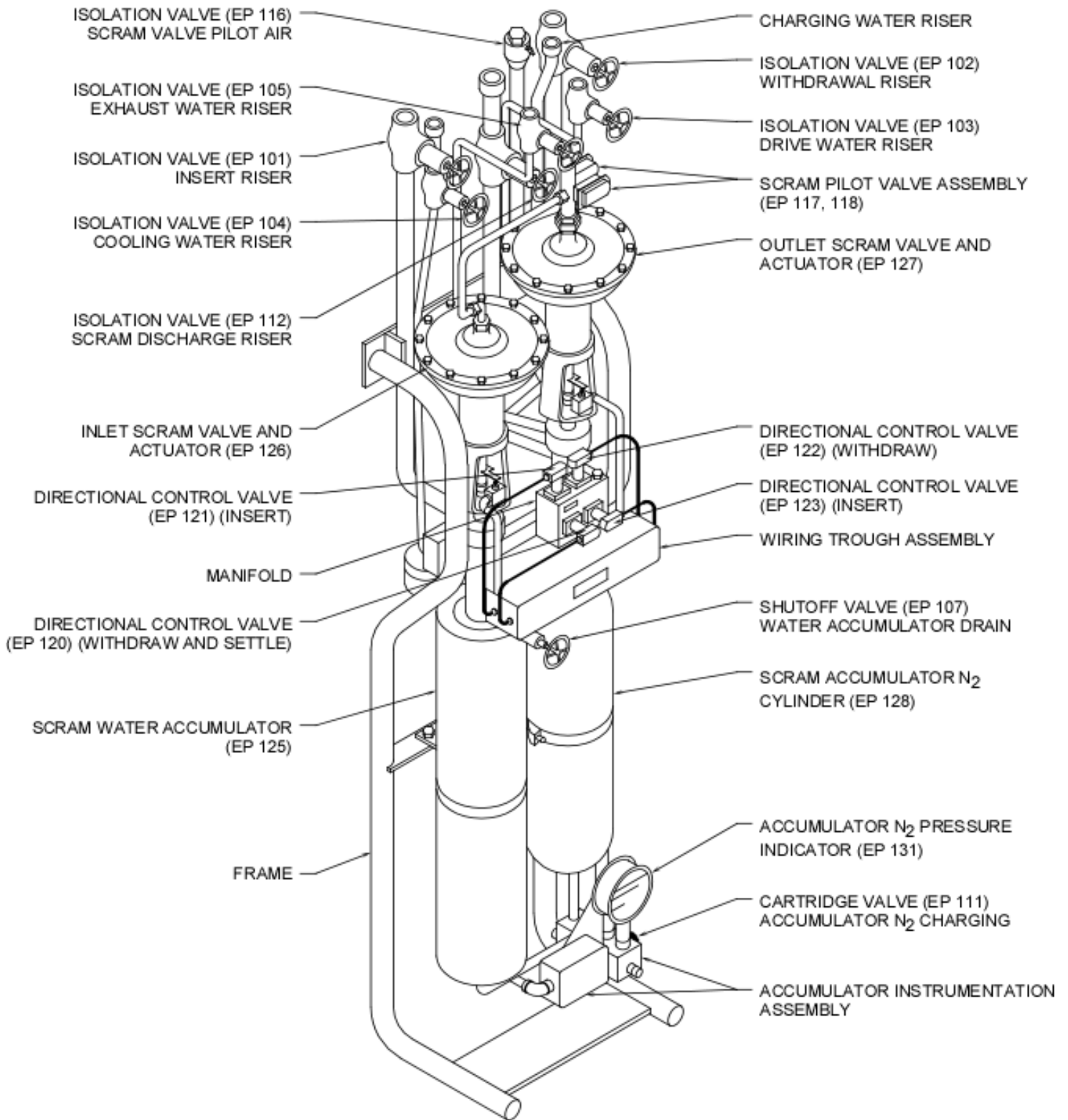


Figure 4.0-2, Hydraulic Control Unit

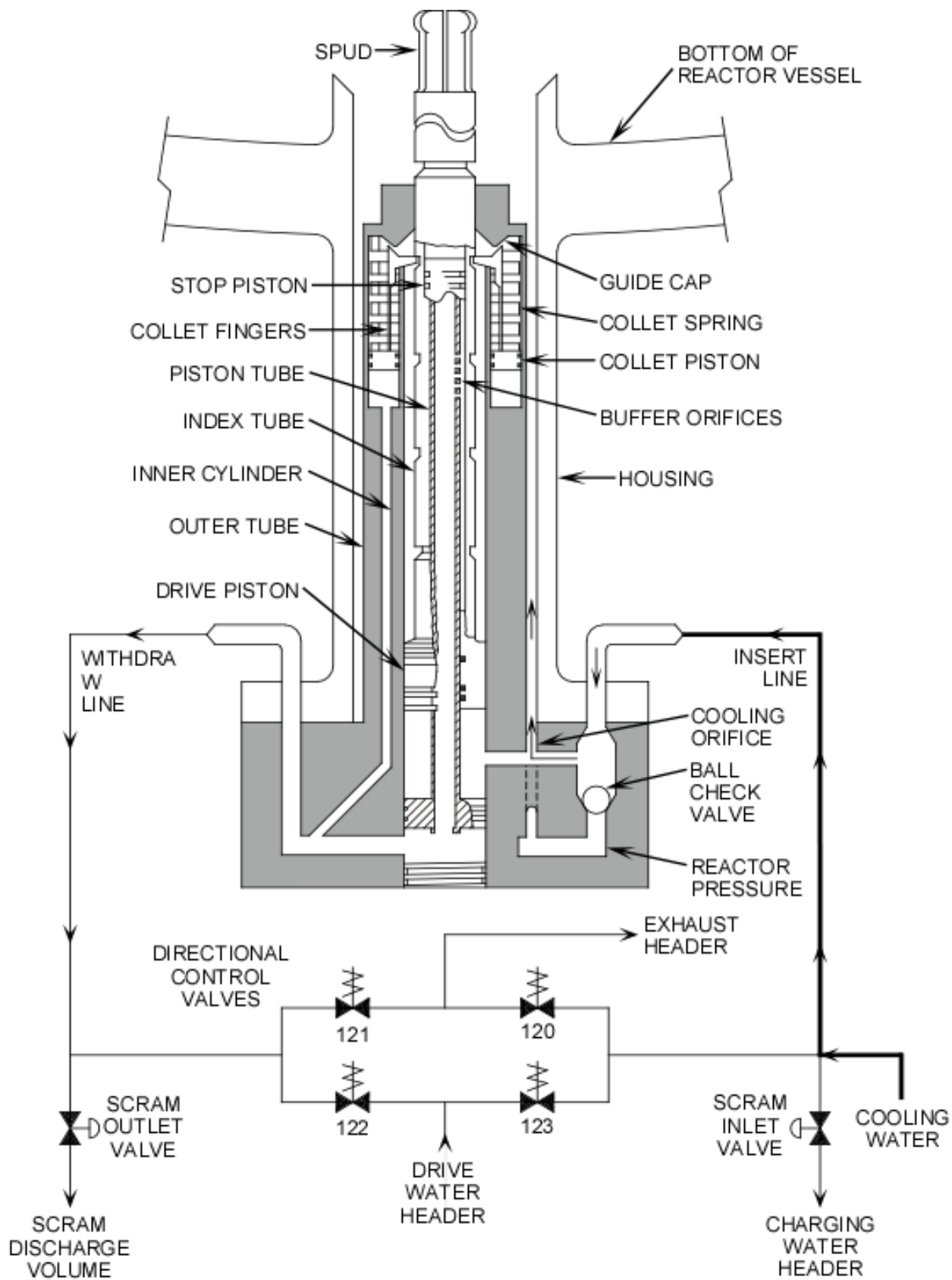


Figure 4.0-3, Control Rod Drive Mechanism