15B Failure Modes and Effects Analysis (FMEA)

15B.1 Introduction

This appendix provides failure modes and effects analyses (FMEAs) for two ABWR systems and one major component which represent a significant change from past BWR designs. Specifically, FMEAs are provided for the following:

(1) Control Rod Drive System (with emphasis on the fine motion control rod drive)

(2) Data Communication Function (DCF) of the Reactor Trip and Isolation System (RTIS) and ESF logic and Control System (ELCS)

(3) Reactor internal pump

Regulatory Guide 1.70 requires FMEAs to be performed on selected subsystems of Chapters 6, 7 and 9. The plant nuclear safety operational analysis (NSOA) of Appendix 15A and the probabilistic evaluations of Appendix 19D adequately address single failures for those systems and components which are similar to past BWR designs and resources are best directed to conducting and reporting FMEAs for new systems and components noted above.

15B.2 Control Rod Drive System

15B.2.1 Introduction

The Control Rod Drive (CRD) System is comprised of the fine motion control rod drives (FMCRD), the hydraulic control units (HCUs), and the control rod drive (CRD) pumps. This analysis is focused on the FMCRD because the HCU and CRD pump equipment do not include substantial departure from the earlier BWR designs. Extensive FMEAs and reliability analyses have been performed on the earlier designs and many reactor years experience have accumulated. The key elements of the HCUs are included in the discussion for completeness.

The interfaces of the CRD System are identified and the potential impact of those interfaces is part of this analysis.

15B.2.2 Conclusion

The finding of this analysis is that there are no single failures which can prevent the CRD System from performing its safety functions. The FMEA is presented in Tables 15B-1 and 15B-2.

15B.2.3 Description

A simplified CRD System process flow diagram is shown in Figure 15B-1. CRD System water is taken from the condensate, feedwater and condensate air extraction system, or Condensate Storage Tank (CST) through a suction filter by a centrifugal pump and discharged through a drive water filter to the HCUs. (During shutdown the CST is the primary source.) Each of these components is independently redundant and only one of each is in operation at any one time. A portion of the pump discharge flow is diverted through a minimum flow bypass line to the CST. The pumped water is directed to the HCU to provide hydraulic scram and to furnish purging to the drive. This system also provides purge water for the reactor internal pumps, nuclear boiler instrument lines, and the reactor water cleanup pumps.

The HCUs are all supplied by the same operating CRD pump, but the HCUs are divided into four banks, A & D on one side of the reactor and B & C on the other side of the reactor. Each HCU serves two FMCRDs. The HCU P&ID is shown in Figure 15B-2. The purge water enters the HCU through valve 104, passes through a filter, a restricting orifice, and a check valve to the scram line. The flow passes into the FMCRD at a pressure slightly higher than vessel pressure and up through the drive to the vessel. This flow provides cooling for the drive and serves to prevent debris from entering the drive from the vessel. The charging water enters the HCU through valve 113, passes through a check valve, fills an accumulator against nitrogen pressure and is stopped from entering the FMCRD by an air-operated scram valve, 126. The accumulator capacity is adequate to scram two FMCRDs.

The scram valve is held closed by instrument air. The scram valve is controlled by a double solenoid pilot valve, 139. The solenoids are normally energized and both must be de-energized to scram the drive. The pilot valve is shown in the de-energized state. When energized, the pilot valve exhaust port is closed and the instrument air is applied to the scram valve diaphragm, holding the scram valve closed. De-energization of the pilot valve shuts off the instrument air and opens the scram valve diaphragm to exhaust, allowing the valve to open and apply accumulator pressurized water to a pair of FMCRDs. Scram is effected when the pressurized water is applied to the hollow piston of the FMCRDs. Another set of valves, the Air Header Dump Valves, also dump the air pressure during normal scrams. Under ATWS conditions, the instrument air header pressure can also be discharged by the Alternate Rod Insertion (ARI) valves.

The FMCRDs have three safety functions and one normal operating function. The safety functions are:

(1) Scram

(2) Rod Drop Prevention

(3) Rod Ejection Prevention

The normal operating function is the positioning of the control rod in response to the Rod Control and Information System (RCIS). The FMCRD also feeds back rod status and position information to the RCIS for performance monitoring by the RCIS.

The FMCRD assembly drawing is shown in Figure 15B-3. There are two major parts to the FMCRD: (1) the hydraulic scram actuation system and (2) the electric motor drive, which inserts or withdraws the control rod in response to the RCIS signals. The electric motor drive also fully inserts the rod as a backup to the hydraulic scram. During normal operation, the insertion and withdrawal of the FMCRD is under the direction of the RCIS. The FMCRD stepping motor turns a spindle (screw) which causes the vertical motion of a ball-nut. This linear motion is transferred to the control rod via a hollow piston which rests on the ball-nut. Thus, the piston and control rod are raised or lowered depending on the direction of rotation of the FMCRD motor and spindle. One design feature of the FMCRD is the automatic run-in of the ball-nut by the electric motor drive following the hydraulic scram. This use of the electric motor provides a backup to the hydraulic accumulator scram.

On loss of electric power to both scram pilot valve solenoids, the associated HCU applies insert forces to its respective drives using the precharged accumulator water contained within the HCU. Water enters the FMCRD through the scram port; the pressure differential between the hollow piston and the reactor vessel drives the piston upward. The water displaced from the drive is discharged into the reactor vessel through a labyrinth seal in the throttling sleeve at the buffer. During a scram, the hollow piston separates from the ball-nut as the control rod is driven into the core. Spring-loaded latch fingers in the hollow piston expand and engage notches in the guide tube. The fingers support the hollow piston and the control blade until the ball-nut can be driven up to support the hollow piston and release the latch finger.

A provision is made for integral, internal blow-out support to prevent the FMCRD ejection if failure of the FMCRD housing occurs at any of various locations. The drive motor brake and a ball check valve at the flange where the accumulator piping meets the FMCRD both provide protection against rod ejection. The valve prevents control rod ejection in case of a failure in the scram piping. If a scram line failure were to occur, a large pressure differential across the hollow piston could result in the ejection of the control rod. The ball check valve would be seated by the reverse flow through the scram port and ejection would be prevented. The FMCRD electromechanical brake is keyed to the motor shaft. The brake is normally engaged by spring force when the FMCRD is stationary. It is disengaged for normal rod movements by signals from the RCIS. The brake prevents a high pressure differential across the hollow piston from causing the reverse rotation of the lead screw and “run-out” of the control rod.

Interfaces

Required inputs:

(1) Water from the condensate, feedwater and condensate air extraction system and from the CST

(2) Instrument air

(3) Signals from RPS channels A & B

(4) Electrical power to the FMCRD motors and brakes

Outputs:

(1) Purge flow water into the vessel

(2) Rod position signal from the synchro

(3) Rod position indication signal from reed switches

(4) Rod separation signal from reed switches

(5) Scram full insert signal

The only substantive problem which has occurred in any of the interfaces in history has been the disabling of scram solenoid valves by contaminated instrument air. The contaminates caused the deterioration of the valve seats and prevented the valves from opening. This problem was corrected by the incorporation of Viton-A seat material which is impervious to the contaminates. Viton-A has been specified for the ABWR solenoid valve seats.

15B.2.4 FMCRD Failure Modes Evaluation

The following evaluation and discussion of failure modes which threaten the ability of the FMCRD to perform its safety functions is presented as extensive expansion on the FMEA and system description above.

15B.2.4.1 Evaluation of Failures Relating to Scram

There are no known single failures/malfunctions that result in a loss of scram function for more than one pair of ganged control rod drives. High scram reliability is a result of a number of features of the CRD System. For example:

(1) Each accumulator provides sufficient stored energy to scram two CRDs at any reactor pressure.

(2) Each pair of drive mechanisms has its own scram valve and a dual solenoid scram pilot valve; therefore, only a single scram valve needs to open for scram to be initiated. Both pilot valve solenoids must be de-energized to initiate a scram.

(3) The Reactor Protection System (RPS) and the HCUs are designed so that the scram signal and mode of operation override all others.

(4) The FMCRD hollow piston and guide tube are designed so they will not restrain or prevent control rod insertion during scram.

(5) The electric motor drive insertion of each control rod is initiated simultaneously with the initiation of hydraulic fast scram. This provides a diverse means to assure control rod insertion.

Failures in the pressure boundary of an individual FMCRD or scram insert line can, at most, result in loss of scram capability only for the two drives sharing the associated ganged accumulator. The plant is capable of achieving cold shutdown under this failure condition. Additionally, the HCUs located in each quadrant will be physically separated into two groups. One group consists of the A-sequence HCUs (HCUs connected to the A-sequence rods only) and the other group consists of the B-sequence HCUs (HCUs connected to the B-sequence rods only). With this separation arrangement, the potential for the failure of two HCUs (one failing as a consequence of the other failing first) resulting in the failure of two face adjacent rods within the core is avoided. This assures the capability to achieve hot shutdown with two HCUs failed (one HCU failed plus an adjacent HCU failed due to consequential effects).

Failures in individual HCUs which lead to low charging pressure on the nitrogen side are alarmed if pressure in the HCU drops below a predetermined setpoint. In this case, only the two drives grouped to the affected HCU are potentially incapable of scramming when required. As described above, the failure of two drives connected with one HCU to scram does not prevent the plant from achieving cold shutdown. However, a loss of charging water header pressure, resulting from a failure of the header piping or a CRD pump, affects the charging capability of all HCUs. Instrumentation is provided on the charging water header to monitor line pressure. In the event of loss of charging pressure, this instrumentation sends signals to the RPS which, in turn, generates a scram initiating signal.

The low pressure scram setpoint is set high enough to assure adequate charge pressure is available in the individual HCUs to complete the scram, but low enough to minimize unwanted scrams from normal pressure fluctuations in the line.

15B.2.4.2 Evaluation of Failure Relating to Rod Drop

The failure paths resulting in a rod drop accident (RDA) are shown in Figure 15B-4. The combination of multiple failures of protective features to reach a control rod drop condition by any failure path is considered to be so low in probability that RDA can be categorized as an incredible event for the FMCRD design. Some of these protective features are described as follows:

(1) Two redundant and separate Class 1E switches are provided to detect the separation of the hollow piston from the ball-nut. This means two sets of reed switches physically separated from one another with their cabling run through separate conduits. The separation switch is classified Class 1E, since its function detects a detached control rod and causes a rod block, thereby preventing a rod drop accident.

The principle of operation of the control rod separation mechanism is illustrated in Figure 15B-5. During normal operation, the weight of the control rod and hollow piston resting on the ball-nut causes the spindle assembly to compress a spring on which the lower half of the splined coupling between the drive shaft and spindle assembly rests (the lower half of the splined coupling is also known as the “weighing table”). When the hollow piston separates from the ball-nut, or when the control rod separates from the hollow piston, the spring is unloaded and pushes the weighing table and spindle assembly upward. This action causes a magnet in the weighing table to operate the Class 1E reed switches located in a probe outside the lower housing.

(2) Two redundant, spring-loaded latches on the hollow piston open to engage in windows in the guide tube within the FMCRD to catch the hollow piston if separation from the ball-nut were to occur. These latches open to support the hollow piston (and control rod) following scram until the ball-nut is run up to provide the normal support for the hollow piston (and control rod).

(3) A bayonet coupling between the control rod and FMCRD is provided. The coupling spud at the top end of the hollow piston engages and locks into a mating socket at the base of the control rod. The coupling requires a
45 degree rotation for engaging or disengaging. Once locked, the drive and rod form an integral unit that must be manually unlocked by specific procedures before the components can be separated.

Coupling integrity is verified by pull test of the control rod upon initial coupling at refueling and by an “overtravel” test in which the ball-nut is driven down beyond the “full out” position into overtravel. After the weighing spring has raised the spindle to the limit of its travel, further rotation of the spindle in the withdraw direction will drive the ball-nut down away from the piston (assuming the coupling is engaged). Piston movement, if any, can then be detected by a reed switch at the overtravel position.

The control rod can only be uncoupled from the FMCRD by relative rotation, which is not possible during operation. The control rod cannot rotate, since it is always constrained between four fuel assemblies and the hollow piston has rollers which operate in a track within the FMCRD. Only structural failure would permit or result in control rod-to-FMCRD uncoupling.

(4) An automatic rod block is provided in the RCIS. Each channel of the RCIS monitors one of the Class 1E separation switches. If control rod separation is indicated by either switch, the associated RCIS channel will initiate a rod withdrawal block. Both channels of the RCIS would have to fail for a rod withdrawal operation to continue under these conditions. Additionally, indication and alarm is provided in the control room to alert the operator of a separation.

Because of the features described above, it is evident from Figure 15B-4 that multiple component/structural failures would have to occur before an RDA is possible. The most severe scenario, with respect to uncontrolled insertion of reactivity, is the case where the blade becomes separated from the hollow piston and sticks in the core as the hollow piston is withdrawn. If the blade subsequently unsticks, the rate of drop could exceed acceptable reactivity insertion rates. However, to reach this point requires several failures: (1) an undetected miscoupling during assembly or a structural failure of the coupling, (2) a sticking of the blade, and (3) a double failure of the separation switches or a double failure of the automatic rod block logic and failure of the operator to acknowledge the separation alarm. For the case where the blade remains coupled to the hollow piston and they stick as an assembly, the subsequent drop velocity is below the maximum allowable reactivity insertion rate. This scenario also requires multiple failures: (1) a sticking of the blade, (2) a double failure of the separation switches or a double failure of the automatic rod block logic and failure of the operator to acknowledge the alarm, and (3) a double failure of the latches on the hollow piston.

The number of failures associated with each event described above is considered to be so numerous as to result in a probability of occurrence low enough for rod drop to be categorized as an incredible event for the ABWR design.

15B.2.4.3 Evaluation of Failures Relating to Rod Ejection

15B.2.4.3.1 Drive Housing Failures

The bottom head of the reactor vessel has a penetration for each CRD location. A drive housing is raised into position inside each penetration and fastened by welding to a stub tube (Figure 15B-6). The drive is raised into the drive housing and bolted to a flange at the bottom of the housing.

In an unlikely event that a failure occurs of (a) the drive housing below the vessel/stub tube attachment weld, or (b) the weld itself but not the housing, ejection of the CRD and attached control rod is prevented by the integral internal blowout support. The postulated failure locations are identified by points A and B schematically in Figure 15B-6. With failure assumed at point A or B, the mechanical load plus the pressure load acting on the drive and housing would tend to eject the drive. The details of this support, which replaces the support structure of beams, hanger rods, grids, and support bars below the vessel used in previous product lines, are described in the following paragraphs.

The internal blowout support consists of the bayonet type support internal to the housing (Figure 15B-6). The internal blowout support catches the ejecting outer tube if failure (a) defined above occurs. This tube (which is welded at its lower end to the drive middle flange), is attached as shown in Figure 15B-6 at the top to the support, which is bayonet locked to the control rod guide tube base. The guide tube base, being supported by the housing extension, prevents downward movement of the outer tube and the drive. The internal blowout support catches the cap of the ejecting housing if failure (b) defined above occurs, and becomes a part of support chain consisting of the guide tube base, the guide tube and core plate, as shown in Figure 15B-7.

The internal blowout support prevents ejection of a CRD and attached control rod in the unlikely event of a drive housing failure. In both cases, the FMCRD motor brake function

(Section 15B.2.4.3.3) would be unimpaired and the motor spindle would not rotate and allow descent of the rod.

15B.2.4.3.2 Total Failure of All Drive Flange Bolts or Lower Housing

If a failure were to occur in the flange bolts or the spool piece (points C and D on Figure 15B-6), the drive would be prevented from ejecting downward also by the integral internal blowout support. The drive middle flange welded to the outer tube is prevented from ejecting by the internal support (similar to case (a) above). The middle flange retains the drive as described below.

The FMCRD design provides an anti-rotation device which engages when the lower housing (spool piece) is removed for maintenance. This device prevents rotation of the spindle which, in turn, holds the control rod in position when the spool piece is removed. The two components of the anti-rotation device are (1) the upper half of the coupling between the lower housing drive shaft and ball spindle, and (2) the back seat of the middle flange (Figure 15B-6). The coupling of the lower housing drive shaft to the ball spindle is splined to permit removal of the lower housing. The under side of the upper coupling piece has a circumferentially splined surface which engages with a mating surface on the middle flange back seat when the spindle is lowered during spool piece removal. When engaged, spindle rotation is prevented. In addition to preventing rotation, this device also provides sealing of leakage from the drive while the spool piece is removed.

In the unlikely event of the total failure of all the drive flange bolts, the anti-rotation device will engage the middle flange back seat, thus preventing rod ejection. The middle flange welded to the outer tube is supported by the internal support at the top as described in Subsection 15B.2.4.3.1.

15B.2.4.3.3 Rupture of Hydraulic Line to Drive Housing Flange

The FMCRD design provides single-failure-proof protection against the consequences of a scram line break by incorporating two diverse means for prevention of rod ejection. The first is a testable ball check valve located in the FMCRD flange. Under conditions of a scram line break, reverse flow will cause the ball to lift and seal the scram inlet port, thereby preventing rod ejection. The second feature is a testable, electromechanical brake located between the FMCRD motor and the synchromechanism. The electromechanical brake is designed to be a “safe-as-is” component that is normally in an engaged position when de-energized (rod ejection prevented), except when normal motor-driven rod movement is required. The brake is released (disengaged) when the motor is energized. The risk of a rod ejection occurring during rod motion is judged as acceptable due to the low probability of a coincident scram line failure and check valve failure occurring during the time the brake is disengaged.

15B.3 Reactor Internal Pump

15B.3.1 Introduction

Reactor internal pumps (RIPs) were first put in use by the Swedish NSSS supplier ASEA-ATOM in the late 1960s. Several plants are now in operation with RIPs. These RIPs have become the reference design for the ABWR RIPs. This FMEA addresses the following major aspects of potential failures:

(1) RIP impeller missiles

(2) RIP seizure

(3) RIP motor housing break, including consideration of shaft ejection

(4) RIP motor housing external loads

(5) Loss of RIP purge flow including purge pipe break

(6) Loss of secondary flow (reactor cooling water — RCW) to RIP heat exchanger

(7) Loss of primary RIP motor cooling including primary cooling water pipe break

(8) RIP loose parts

15B.3.2 Conclusions

The finding of this analysis is that there is no single failure which would impact the safety of the plant.

15B.3.3 Description

15B.3.3.1 Overall

The Reactor Recirculation System (RRS) P&ID is shown in Figure 5.4-4. The RRS is comprised of 10 pumps that collectively provide forced circulation of the reactor coolant through the lower plenum of the reactor and up through the lower grid, the reactor core, steam separators, and back down the downcomer annulus.

In addition to the RIPs, several subsystems are also included as part of the RRS to provide closely related, or closely supporting, functions to the RRS in composite or to the RIPs as individual components. The subsystems and reactor coolant pressure boundary (RCPB) are also shown on Figure 5.4-4. These subsystems are:

(1) Recirculation motor cooling (RMC) subsystem

(2) Recirculation motor purge (RMP) subsystem

(3) Recirculation motor inflatable shaft seal (RMISS) subsystem

The RIP and its auxiliary components have one safety function which is pressure retention (passive).

15B.3.3.2 RIP

The RIP consists of pumping components (impeller and diffuser) which are located inside the RPV and the driving component (motor), which is housed inside a casing. The casing is an extension of the RPV. The pumping unit and the motor have one common shaft. The shaft penetrates the RPV and extends into the motor's hollow rotor. The pump impeller and the motor rotor are assembled by various fasteners.

In order to reduce the bypass leakage of the pump, the piston rings are incorporated in the RIP between the outside of the diffuser and the pump deck. An optional diffuser wear ring may be provided on the diffuser.

15B.3.3.3 Adjustable Speed Drives

The adjustable speed drives (ASD) will be used to supply variable voltage/variable frequency electrical power to the reactor recirculation pumps. The recirculation pumps are single stage, vertical pumps driven by three-phase, four-pole, wet-type, squirrel cage, AC induction motors. Each ASD will supply power to one recirculation pump motor. The ASD receives electrical power from a supply bus at a relatively constant AC voltage and frequency. The ASD converts this constant supply power to a variable frequency/variable voltage output which is supplied to the recirculation pump motor. The output frequency is modulated in response to a demand signal from the system controller in order to vary pump speed.

15B.3.4 RIP Failure Modes Evaluation

The following evaluations and discussions of failure modes which are relevant to the safety of the plant are presented here as summary of detailed analyses.

15B.3.4.1 Missiles Generation

Since the parts of the RIP (impeller) are rotating inside the reactor pressure vessel (RPV), an evaluation has been made to assess the integrity of the RPV should an "impeller missile" occur. Although the rated speed for the RIPs is 157 rad/s, an initial speed of 188.5 rad/s is used for this evaluation. For unidentified reasons, the RIP impeller located approximately 3m below the reactor core bottom is assumed to disintegrate.

The acceptance criterion for a missile striking the RPV cylindrical shell or reactor core shroud is that the kinetic energy (KE) of the missile is less than the critical energy (CE) of the shell and shroud and, therefore, the missile will not degrade the integrity of the core or pressure boundary. The acceptance values are:

(1) RPV shell CE -9.41 MN·m

(2) Core shroud CE -0.24 MN·m

Calculations show that the energy of the impeller missile is:

$$0.09 \text{ MN·m} \tag{15B-1}$$

Comparing the information above, the impeller missile KE is approximately one-half the shroud CE and one-tenth the RPV shell CE.

In conclusion, the integrity of the core and RCPB are maintained in the event of a RIP impeller disintegration.

15B.3.4.2 Pump Seizure

Pump seizure causes rapid reduction of core flow and torsional loads on the RIP casing, RPV RIP nozzle, and RIP motor bottom flange. Several modes of pump seizure have been considered.

The RIP is assumed to be operating at 157 rad/s and for unidentified reasons the following seizures are assumed to occur:

(1) Impeller to diffuser seizure

(2) Rotor winding to stator winding seizure

(3) Thrust bearing seizure

(4) Radial bearing seizure

Any of these seizures will trip off the motor power and transfer the rotating kinetic energy of the impeller and motor rotor shaft into the RPV bottom head RIP nozzle directly or up through the motor housing into the nozzle.

The acceptance criterion for this event is that the torque load resulting from the seizure be less than value specified as the design basis for this event in the reactor vessel loading specification. This value is 42 T-M.

Depending on the location of the seizure in the pump or motor, the impeller-shaft kinetic energy will shear off one set of several bolts and pins in the motor structure. The torque load which shears the bolts and pins is transferred into the bottom flange of the motor housing and up through the housing cylinder into the RPV bottom head RIP nozzle.

In conclusion, any of the calculated torque loads transferred into the RPV RIP nozzles by a RIP or motor seizure are more than a factor of 4 less than the (42 T-M) design torque load specified by the reactor vessel loading specification for this faulted condition. The pump seizure torque will produce stresses in the motor housing and RPV RIP nozzle which are significantly less than Code allowable stresses.

15B.3.4.3 RIP Motor Housing Break

The motor housing and bottom flange are part of the RCPB and therefore are designed not to fail or rupture during normal, upset, emergency, or faulted plant conditions. Regardless of these criteria, and for the purpose of this evaluation, it is assumed that the housing fails creating a temporary small LOCA.

First it is assumed that the RIP impeller and shaft remain intact. The vertical blowout restraint rods prevent the motor and broken housing from being ejected from the RPV and damaging FMCRD piping and other equipment. The restraints are designed to elongate enough to close the 6 mm clearance of the impeller nozzle back seat and stop the discharge of reactor coolant out of the housing break.

Even if the impeller does not back seat, the discharge of reactor coolant will be restricted by the annular flow area between the pump shaft and stretch tube, etc. The ejection of the pump shaft is not credible because the pressure force resulting from a motor housing break pushes the shaft downward, and its upper diameter is larger than the penetration. The motor housing also prevents shaft ejection because, even when the housing has a complete circumferential break, the vertical restraints will not allow it to move away from the penetration.

The acceptance criterion for this event from the viewpoint of nuclear plant safety is that equivalent break size not exceed 20 cm^2, which is the design basis bottom break. The actual flow area is 20 cm^2 around the gap between the upper part of stretch tube and pump shaft. This small LOCA is detected by temperature, pressure, and/or level instrumentation for the RPV, drywell and/or RIP motor cooling circuit.

There are several different seals and sealed penetrations of the RIP motor housing which could be assumed to fail during reactor operation and would result in a very small LOCA. These seals include the RIP motor bottom flange, including the smaller auxiliary cover, motor power terminals, and motor speed detector. The failure of any of these seals would result in hot reactor coolant flowing down through the motor windings and damaging the winding insulation. This motor damage is not a nuclear safety problem.

In conclusion, the RPV RIP nozzle motor housing and associated seals, housing restraint system, and the normal makeup systems and ECCS are adequately designed to mitigate the consequences of a RIP motor housing break or housing seal failures.

15B.3.4.4 RIP Motor Housing External Loads

The motor housing, connected piping, and RIP motor heat exchanger are considered part of the RCPB and are therefore designed in accordance with the same codes and standards as the RPV. The housing is subjected to external loads from cooling water piping reactions or lateral seismic restraints (if they are used) during certain plant design conditions i.e., safe shutdown earthquake.

The RIP to Hx piping is designed with adequate flexibility between the fixed RIP motor heat exchanger and the motor housing to limit the loads and moments applied to the motor housing and consequently into the RPV bottom head to those specified in the reactor vessel loading specification.

Likewise, if lateral motor seismic restraints are incorporated in the design, the loads and moments applied to the motor housing will not exceed the values specified in the reactor vessel loading specification.

With the above criteria, the integrity of the RCPB can be assured under any plant conditions.

15B.3.4.5 Loss of Purge Flow

The RIPs are equipped with a shaft purge system which will provide a very small flow of clean demineralized CRD System water upward along the rotating RIP shaft (inside the stretch tube) into the RPV. The purpose of the purge system is to prevent the migration of radioactive reactor water down into the RIP motor. The purge flow enters the RIP shaft from two locations as shown in Figure 5.4-4.

Purge system piping from the RIP motor housing out to and including an outside containment isolation excess flow check valve is designed to maintain its integrity for all plant conditions, including safe shutdown earthquake. However, for the purposes of this evaluation, the following events are analyzed which result in loss of purge flow:

(1) Break of the purge piping inside or outside the containment

(2) Infrequent shutdown of the CRD pumps, including loss of power accident (LOPA)

(3) Inadvertent closure of valves in the purge supply flow path

Purge line break inside the containment is treated as a very small size LOCA. The event is mitigated by the normal ABWR coolant makeup systems to maintain proper RPV coolant inventory. The acceptance criterion for this event from the viewpoint of nuclear plant safety is that equivalent break size not exceed 20 cm^2, which is the design basis bottom break. The actual flow area of the double purge line break is 6 cm^2. This small LOCA is detected by temperature, pressure, and/or level instrumentation for the RPV, drywell and/or RIP motor cooling circuit. The normal makeup systems are designed to mitigate the consequences of this small LOCA.

Purge flow stoppage by CRD pumps stopping or purge line valve closure may result in damaging of the secondary seal, which would be replaced during the next scheduled maintenance of the RIP(s). The loss of purge flow could result in radioactive contamination of the motor which would be decontaminated during the next scheduled maintenance of the RIP(s). Purge flow stoppage will not result in additional stresses in the RPV nozzle.

In conclusion, the failure of the purge flow to the RIP will be mitigated by the normal makeup or normal maintenance procedures for secondary seal replacement.

15B.3.4.6 RIP Heat Exchanger Secondary Water Flow Loss

The RIPs are designed to operate normally in the following situations which are the acceptance criteria for these events:

(1) **Failure of Secondary Cooling Water—**The RIP motor shall be capable of continued rated power operation for 5 minutes following failure of the RCW. This time period allows corrective action to prevent an all-pump trip.

(2) **Hot Standby Without RCW—**With the RIP stopped, the motor shall withstand hot standby conditions for one hour with the RCW to the RIP motor heat exchanger (RMHx) shut off. This allows adequate time to take corrective action.

The evaluation of the RCW cooling water failure shows the motor water temperature increase will be as follows:

Time (min.)	Temp. (°C)	Status
0	55	RIP at maximum rated power and cooling water is shut off
2	60	Alarm
4	65	RIP auto runback and trip
65	70	Maximum motor cooling outlet temperature

The entire RIP motor housing, RIP motor heat exchanger, and interconnecting piping is designed for minimum 302°C at 8.62 MPa pressure. Therefore, an indefinite loss of RCW to the RIP motor heat exchanger will not affect the integrity of the RCPB.

The operator will receive a low RCW flow alarm and RMHx primary side inlet and outlet water temperature high alarm. If the RCW cannot be restored to the tripped motor, some damage to the winding insulation and/or secondary shaft seal, may occur. These components can be replaced according to normal RIP maintenance procedures.

15B.3.4.7 RIP Primary Cooling Water Loss

The RIP motor housing, RIP motor heat exchanger, and connecting piping are designed in accordance with the same codes and standards as the RPV. This design precludes the rupture of any of the RCPB components during any plant service condition. Regardless of this design criterion and for the purpose of this evaluation, it is assumed that a rupture of the 65A motor cooling water piping occurs or the RIP motor heat exchanger tubes fail.

Rupture of the motor cooling water piping will result in a small LOCA. This discharge of reactor coolant from the pipe break is restricted by the annulus between the pump shaft and the stretch tube. The acceptance criterion for this event from the viewpoint of nuclear plant safety is that equivalent break size not exceed 20 cm^2, which is the design basis bottom break. The actual flow area of the cooling water piping is restricted by the lower part of the stretch tube flow area is 10 cm^2. This small LOCA is detected by temperature, pressure, and/or level instrumentation for the RPV, drywell and/or RIP motor cooling circuit. The normal makeup systems are designed to mitigate the consequences of this small LOCA.

An RIP motor heat exchanger tube break will result in reactor coolant being discharged into the Reactor Cooling Water (RCW) System. This event will be detected by high motor cooling water temperatures, high RCW temperatures, high RCW surge tank level and/or high RCW radioactivity levels. The radioactivity will be contained in the RCW system and not discharged to the environment. As the reactor is being shut down, the discharge of reactor coolant into the RCW can be terminated by closing the primary containment RCW isolation valves after the RIPs have been stopped.

The heat exchanger tube leak rate will be the same as or less than the leak rate for motor cooling the pipe break. This is due to the fact that the leak rate is controlled by the annulus between the shaft and stretch tube.

It is assumed that any cause of RIP motor primary cooling water due to a rupture in the motor coolant circuit will damage the RIP motor winding insulation by the 278°C RPV water entering the motor. The motor can be replaced according to normal RIP maintenance procedures.

In conclusion, the ABWR RIP motor cooling system and normal ABWR coolant makeup systems are designed to detect and mitigate the consequences of a loss of RIP primary cooling water and consequent loss of reactor coolant.

15B.3.4.8 ABWR RIP Loose Part Prevention and Monitoring

The ABWR RIP is an assembly of many parts, some of which are inside the RPV. The parts in a majority of cases are held together by threaded fasteners such as studs, bolts, nuts, and screws. Although these types of fasteners make disassembly possible, they can become loose due to random vibration of the running pump and lead to gross failure of the other parts. Fragments of broken components can be transferred to the reactor internals and fuel. Due to criticality of loose parts, the RIP fasteners are engineered to be positively locked as described below:

(1) A lock sleeve and pin prevent loosening and disassembly of the impeller.

(2) Coupling stud has counter rotation thread to make it self-tightening. A locking mechanism prevents loosening and disassembly of the shaft-impeller-thrust bearing disk subassembly.

(3) The stretch tube, which has the function of securing the diffuser to the RIP nozzle, is tightened with hydraulic tensioning. The preload of the stretch tube is maintained by the stretch tube nut. The stretch tube nut is locked in place by a locking sleeve to the stretch tube.

(4) The optional diffuser wear ring is held in place by a retaining ring which is captured inside a groove in the diffuser.

(5) Piston rings are retained with grooves on the outside diameter of the diffuser.

In addition to positively locking of the most likely sources of loose parts, the ABWR RIP is adequately instrumented to provide early warning to the operator that failures within the RIP may be developing. The RIP is equipped with the following sensors/detectors:

(1) Vibration sensors which can detect effects of loosening, wear, unbalance, and dynamic changes.

(2) Motor cooling temperature sensors which can detect effects of abnormal load on the motor.

(3) Speed sensors which can detect effects of excessive wear, unbalance, and dynamic changes.

(4) Electrical power input (current and voltage) which provides the information about the overall performance of the RIP motor.

(5) Acoustic monitor—A high frequency response accelerometer is attached to the RIP motor casing which will provide signal of impacts and rubs within the motor.

15B.4 Data Communication Function of the RTIS and the ELCS

The FMEA is described by the PRA fault tree analyses in Chapter 19 (see Subsections 19D.6.4.3 and Section 19Q.5) and the analysis of common-cause failure of data communication equipment in Appendix 19N. The system configuration fault definitions and provisions for fault tolerance are discussed and analyzed in the PRA. The FMEA is presented in Table 15B-3.

Table 15B-1 Failure Modes and Effects Analysis for FMCRD

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
1.	CRD housing	Provides CRD pressure boundary and mounting	Rupture, inside or outside vessel	Stress corrosion; weld failure	Forced outage	Possible rod ejection. May have scram failure on affected rod	Rod ejection protection by integral internal blowout support	Drywell leakage; failure to scram
2.	Middle housing	Houses mechanisms of CRD						
2.a	Ball check valve	Prevents rod ejection if scram line breaks	Stick open	Foreign object; misassembly	Insert rod and render inoperative	Loss of rod ejection prevention function	Brake	Surveillance test
2.b	O-ring	Seal joint between middle and lower housing	Leaks	Misassembly; age	Possible outage extension for repair	None	Dual O-rings	Drywell leakage
3.a	Lower housing	House shaft and seal assembly	Rupture	Stress corrosion	Forced outage	Possible rod ejection. May have scram failure on affected rod	Rod ejection protection by engagement of anti-rotation device with backseat of middle flange; brake	Drywell leakage
			Distortion	Residual stress	Possible outage extension for repair	Minor; may have scram failure on affected rod	Not required	Inspection

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
3.b	Flange bolts	Couple housings	Break	Overstress; material failure	Forced outage	Possible rod ejection; failure of affected rod to scram	Rod ejection protection by engagement of anti-rotation device with backseat of middle flange	Drywell leakage
4.	Seal housing	Support and house bearings, seals, shaft	Distortion	Residual stress	Reduced CRD life; outage extension for repair	None	Not required	Inspection
4.a	Lower radial ball bearings	Support drive shaft	Wear, ball or race failure	Misassembly; dirt, material defect	Reduced CRD life; outage extension for repair	None	Dual bearing	High motor current, inspection
4.b	Upper radial ball bearing	Support drive shaft	Wear, ball or race failure	Misassembly; dirt, material defect	Thrust bearing loaded radially; increased friction	None	None	High motor current, inspection
4.c	Thrust bearings	Carry rotating assembly weight	Wear, ball or race failure	Misassembly; dirt, material defect	Radial bearings thrust loaded; increased wear	None	None	High motor current, inspection
4.d	Drive shaft and seal system	Connect motor and spindle; seal reactor pressure	Wear	Dirt; aging	Possible outage extension for drive repair	None	Seal drain; dual seals	Drywell leak rate; inspection

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
4.e	Seal rings	Compress seals	Break	Stress corrosion	Possible outage extension for drive repair	None	Seal drain; dual seals	Drywell leak rate, inspection
4.f	Seal retainer pins	Prevent seal rotation	Break	Misassembly	Possible outage extension for drive repair	None	None	Leakage around drain path, inspection
5.	Drive shaft	Couples motor and spindle	Break	Misassembly; stress corrosion	Insert rod and render inoperative	Possible loss of drive-in capability. Does not affect scram function.	Only one rod affected	Rod position indication
6.	Key R, pins	Couples motor, shaft	Break, shear	Misassembly; faulty part	Insert rod and render inoperative	Possible loss of drive-in capability. Does not affect scram function.	Only one rod affected	Rod position indication
7.	Key B	Couples motor, shaft, spindle	Break, shear	Misassembly; faulty part	Insert rod and render inoperative	Possible loss of drive-in capability. Does not affect scram function.	Only one rod affected	Rod position indication

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
8.	Thrust bearing locknut	Takes vertical load of rod, rotary drive parts	Unscrew	Misassembly	Possible extended outage for drive repair	Possible loss of drive-in capability. Does not affect scram function	Only one rod affected	Inspection, radial bearing wear
9.	Spring washers, withdraw buffer	Absorb impact of full rod withdrawal	Break	Stress corrosion	Possible extended outage for drive repair	None	None	Inspection
10.	Weigh spring	Part of rod separation detection system	Break; loss of separation signal	Stress corrosion; low cycle fatigue	Insert rod and render inoperative	Possible rod drop	Latches on hollow piston	Rod position indication, scram
11.	Spindle adapter	Couples spindle to driving system	Outer keyway jams key. Loss of or false separation signal	Crud, corrosion, galling	Insert rod and render inoperative	Possible rod drop	Rod scram, latches on hollow piston	Rod position indication, scram
12.	Spindle adapter seat	Spindle backseat and lock when mechanism is removed	Splines shear or otherwise damaged	Misassembly	Whole drive must be removed, requiring rod withdrawal; possible extended outage	Loss of rod ejection protection function for total failure of all flange bolts	Low probability of total failure of all flange bolts coincident with backseat spline failure	On drive removal, spindle does not seal; high Rx leak

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
13.	Weigh spring retainer	Restrains the weigh spring	Breaks; possible loss of separation signal	Stress corrosion; misassembly	Not detectable until separation is indicated by position indication anomaly	Slight separation w/o indication; possible rod drop	Latches on hollow piston	Rod position indication error
14.	Ball nut and hollow piston rollers	Support ball nut	Breaks, seizes, increases friction	Impact at scram	Possible rod insertion and switchout	None	Excess motor torque available	High drive motor current
15.	Lead screw (spindle)	Drives ball nut & rod	Distorts; increased friction & wear	Residual stress	Insert rod and switchout drive	None	Excess torque available	High drive motor current
16.	Ball nut	Translate spindle rotation to rod linear motion	Balls jam, friction, wear	Ball failure, crud, foreign object	Insert rod and switchout drive	None	Three ball paths; excess torque available	High drive motor current
16.a	Ball nut return tube	Retain and recirculate balls	Breaks, balls released	Stress corrosion; over–tension at assembly	Rotation interference; insert and switchout drive	None	Redundant return tubes	High motor current
16.b	Ball nut return tube	Retain and recirculate balls	Breaks, balls released	Stress corrosion; overtension at assembly	Interference with weighing system, loss of separation signal	Possible slight separation w/o signal; possible rod drop	Latches on hollow piston	Rod position indication anomaly

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
17.	Hollow piston	Piston for hydraulic scram	Tube distorts	Residual stress	Increased friction; insert rod and switch out	Possible increase in scram time	Shutdown margin	Slow scram, friction test; rod separated during withdrawal
17a	Hollow piston	Piston for hydraulic scram	Binds in labyrinth seal	Trapped crud	Possible forced outage	Possible failure to scram	Shutdown margin	Position indication, scram time; rod separates during withdrawal
18.	Latch fingers	Support hollow piston (and control rod) after scram	Jam due to crud/foreign object	Crud, foreign object	Rod fallback after scram; forced outage	Fail to maintain scram on one rod	Redundant fingers; shutdown margin	No scram indication; rod position
18.a	Latch fingers	Support hollow piston (and control rod) after scram	Break	Overstress; material problem	Rod fallback after scram; forced outage	Fail to maintain scram on one rod	Redundant fingers; shutdown margin	No scram indication; rod position
19.	Latch springs	Position latch fingers to hold rod in scram position	One or more break	Low cycle fatigue; misassembly	Rod fallback after scram; forced outage	Fail to maintain scram on one rod	Triple redundant springs on each latch	No scram indication; rod position
20.	Hollow piston assembly screws	Attach fittings to hollow piston	Loosen, jam against guide tube, slow scram	Vibration misassembly	Possible outage extension for drive repair	None	Shutdown margin	Scram time; drive motor current

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
21.	Screw, tie bar	Mount for rod position magnet	Break, loss of rod scram indication	Low cycle fatigue; misassembly	Possible outage extension for drive repair	None	Rod position indication	No scram confirmation
22.	Scram buffer springs	Absorb impact of scram stroke	Break, lower spring constant	Low cycle fatigue, stress corrosion	Possible outage extension for drive repair	None	Drive designed for inoperative buffer	Overhaul; inspection
22.a	Scram buffer springs	Absorb impact of scram stroke	Jam in the compressed position, reduced buffering	Foreign material	Possible outage extension for drive repair	None	Drive designed for inoperative buffer	Overhaul; inspection
23.	Scram switch	Provide confirming scram completion signal	Fail open, loss of full insertion and scram signal	Bad contacts; broken parts	Possible outage extension for drive repair	None	Redundant switches; drive synchro position indication	Loss of signal
23.a	Scram switch	Provide confirming scram completion signal	Fail closed, continuous full insertion signal	Stuck contacts	Possible outage extension for drive repair	None	Detected on rod withdrawal	Position indication anomaly
24.	Separation switch	Indicates hollow piston/ball nut separation	Fail open, loss of separation signal	Bad contacts broken parts	Rod insertion required; possible outage extension to repair drive	Precursor to rod drop	Redundant switches	Position indication anomaly

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
24.a	Separation switch	Indicates hollow piston/ball nut separation	Fail closed, false separation signal	Stuck contacts	Rod withdrawal block; rod insertion required; possible outage extension to repair drive	None	Fail safe mode	Position indication anomaly
25.	Upper housing roller	Hollow piston guide	Freeze on shaft	Crud; corrosion	None immediate	None	Other close clearances	Scram time; motor current
26.	Spindle roller	Stabilizes spindle rotation	Freeze on shaft; wear	Crud; corrosion	None immediate	None	Redundant on hollow piston	Scram time; motor current
27.	Spindle bushing	Supports spindle roller assembly	Seizes or binds on bolt	Crud, improper heat treatment	Drive replacement required	None	None	Motor current; in extreme, motor stalls
28.	Spindle adapter bolt	Attaches spindle to spindle adapter	Loosens	Backlash in drive train; vibration	Drive replacement required	None	None	Position indication anomaly
29.	Guide tube	Provides cylinder for hollow piston	Distort; higher friction	Residual stress	Reduced drive life	None	Excess motor torque available	Motor current
30.	Guide rail	Align ball nut and hollow piston	Becomes loose	Misassembly; fatigue	Drive replacement may be required	None	None	Unable to withdraw rod

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
31.	Labyrinth seal	Forms seal between reactor pressure and drive pressure	Distort, friction increase	Residual stress	Possible outage extension for drive repair	Possible increase in scram time	Excess drive scram water pressure and motor torque; shutdown margin	Scram time; friction test
32.	Motor	Drive spindle to set rod position	Stall	Short, open winding; bearing seizure	Insert rod and switch out	Motor-driven insertion function following scram lost on affected drive	Only one rod affected; shutdown margin	Rod position indication
33.	Synchro	Generate and transmit rod position information	Electrical failure	Short/open	Insert rod and switch out	None	Only one rod affected; shutdown margin	Rod position anomaly; signal lost
34.	Brake	Hold rod drive spindle to prevent rod drift	Lockup	Brake electrical failure; jam	Insert rod and render inoperative	Motor-driven insertion function following scram lost on affected drive	Only one rod affected; shutdown margin	Rod position indication; brake surveillance test
34.a	Brake	Hold rod drive spindle to prevent rod drift	Fail to brake	Wear, wet, mechanism jammed	Insert rod and render inoperative	Possible rod ejection	Ball check valve	Rod position indication, brake surveillance test

Table 15B-1 Failure Modes and Effects Analysis for FMCRD (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
35.	Screw (ring flange)	Attaches shaft bearing retainer to shaft housing	Break; seal and bearing shoot-out	Overtorque; material/ manufacturing flaw	Possible outage extension for drive repair	None	None	Inspection

Table 15B-2 Failure Modes and Effects Analysis for HCU Charging Water

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
1.	Charging water header accumulator	Maintain charging water header pressure	Leak, rupture	Material failure, overstress	Loss of charging pressure causes scram	None	Two pumps; low pressure alarm	Charging water header pressure alarm
2.	Suction filter	Filter suction water before CRD pump	Plug	Contamination	Loss of charging pressure requires scram	None	Redundant, independent filters	Differential pressure
3.	CRD pump	Provides purge and charging water for CRDs	Seize, stall	Trash, motor failure	Loss of charging water requires scram	None	Alarmed, redundant, independent pumps	Charging pressure, purge flow
4.	CRD pump discharge filter	Filters charging and purge water	Plug	Contamination	Loss of charging water requires scram	None	Redundant, independent filters	Differential pressure
5.	Flow element	Measure total flow to HCUs	Blocked	Trash	May require plant shutdown for repair	None	Low pressure alarm	Loss of flow measurement
6.	Purge water flow control valve	Control purge water flow	Fail closed	Crud; controls	May require plant shutdown for repair	None	Redundant, independent flow control valves	CRD flow
6.a.	Purge water flow control valve	Control purge water flow	Fail open	Crud; controls	May require plant shutdown for repair	None	Flow restricting orifices in each HCU; redundant, independent flow control valves	CRD flow

Table 15B-2 Failure Modes and Effects Analysis for HCU Charging Water (Continued)

Item	Component Identification	Function	Failure Modes	Causes of Failure Mode	Effect on Availability	Effect on Safety	Compensating Provisions	How Detected
7.	Filters, check valves, accumulators within HCU	Various	All	All	Loss of scram or purge water on two drives; rod insert and switch out may be required	None	Shutdown margin	Instrumented and alarmed parameters
8.	Scram valve	Initiate hydraulic scram	Scram solenoid pilot valve fails closed	Contaminated air, debris accumulation	Rod insertion and switch out	None, only two rods affected on individual HCU	Shutdown margin	Position indication
			Scram solenoid pilot valves fails closed (common mode)	Dirty or contaminated air supply	Plant shutdown for repair	Common mode loss of normal scram	ARI for ATWS; air header dump valves for normal scram. Electric driven insertion for all drives. Viton-B solenoid valve seats.	Position indication
			Scram valves leak (common mode)	Slow drop in scram air header pressure	Plant shut down for repair	None. Excessive leakage will result in low HCU charging pressure alarm and scram before HCU accumulators are depleted.	Low charging water header pressure alarm and scram	Low scram air header pressure indication and alarm. Low charging water header pressure indication/ alarm and scram.

Table 15B-3 Failure Modes and Effects Analysis of DCF of the RTIS and ELCS

Component Identification	Function	Failure Mode	Failure Mechanism	Effect on System	Method of Failure Detection	Remarks
Remote Digital Logic Controller (RDLC)	Condition, format and transmit sensor and control signals	Loss of signal or false signal	Loss of electrical power, solid state device failure, loose connection, broken wire	Loss of sensor/ control signal or false signal rejected	Self-test feature and device annunciation in control room	Immediate detection of loss of signal, system test for false signal
Digital Logic Controller (DLC)	Condition, format and transmit sensor and control signals	Loss of signal or false signal	Loss of electrical power, solid state device failure, loose connection, broken wire	Loss of sensor/ control signal or false signal rejected	Self-test feature and device annunciation in control room	Immediate detection of loss of signal, system test for false signal
Fiber optic cable	Transmit optical signals	Severed cable or misalignment of junctions	External force to break cable or bend junctions	Loss of signal on damaged cable only	Continuous, automatic system self-test	One cable in each loop must fail

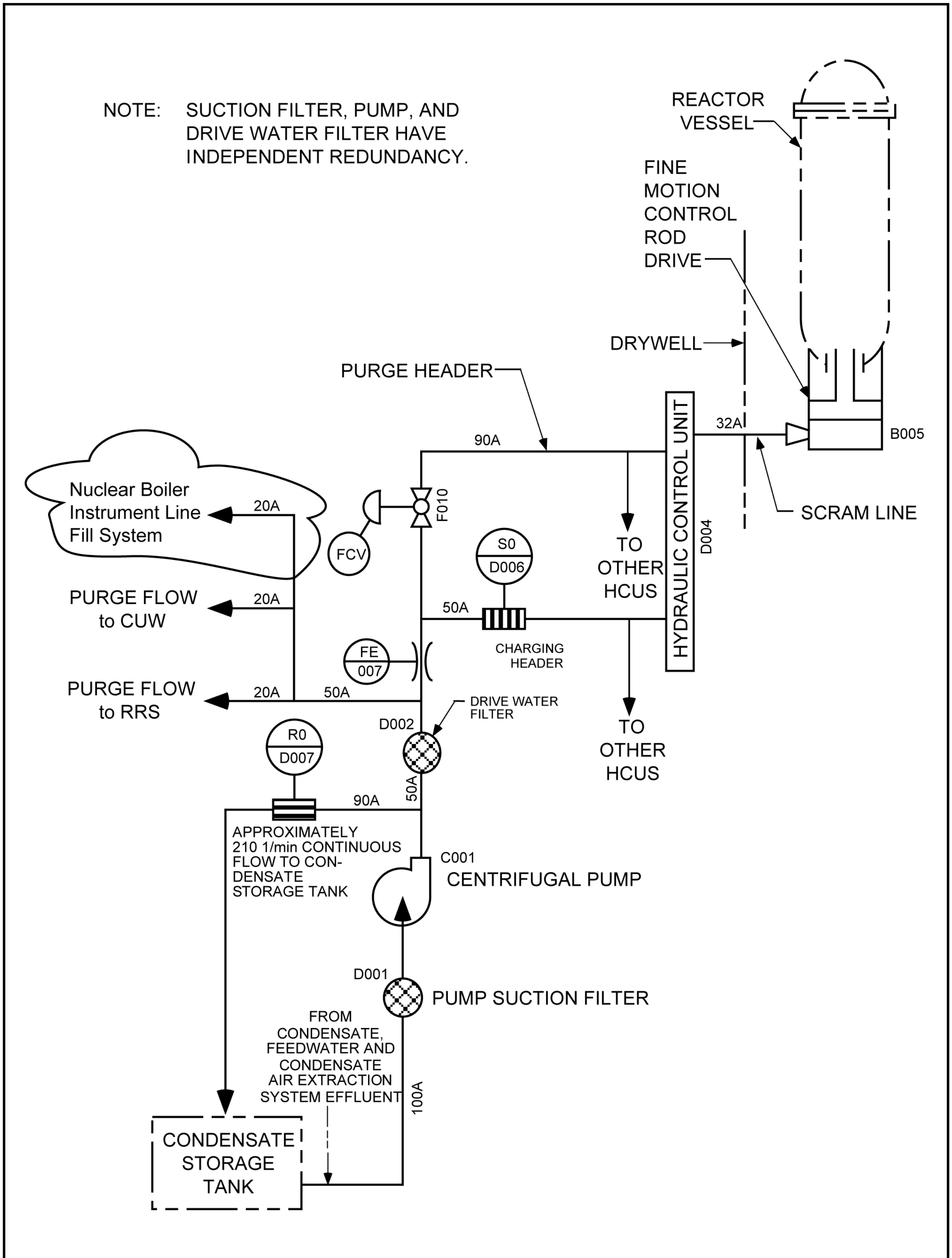

Figure 15B-1 Simplified CRD System Process Flow Diagram

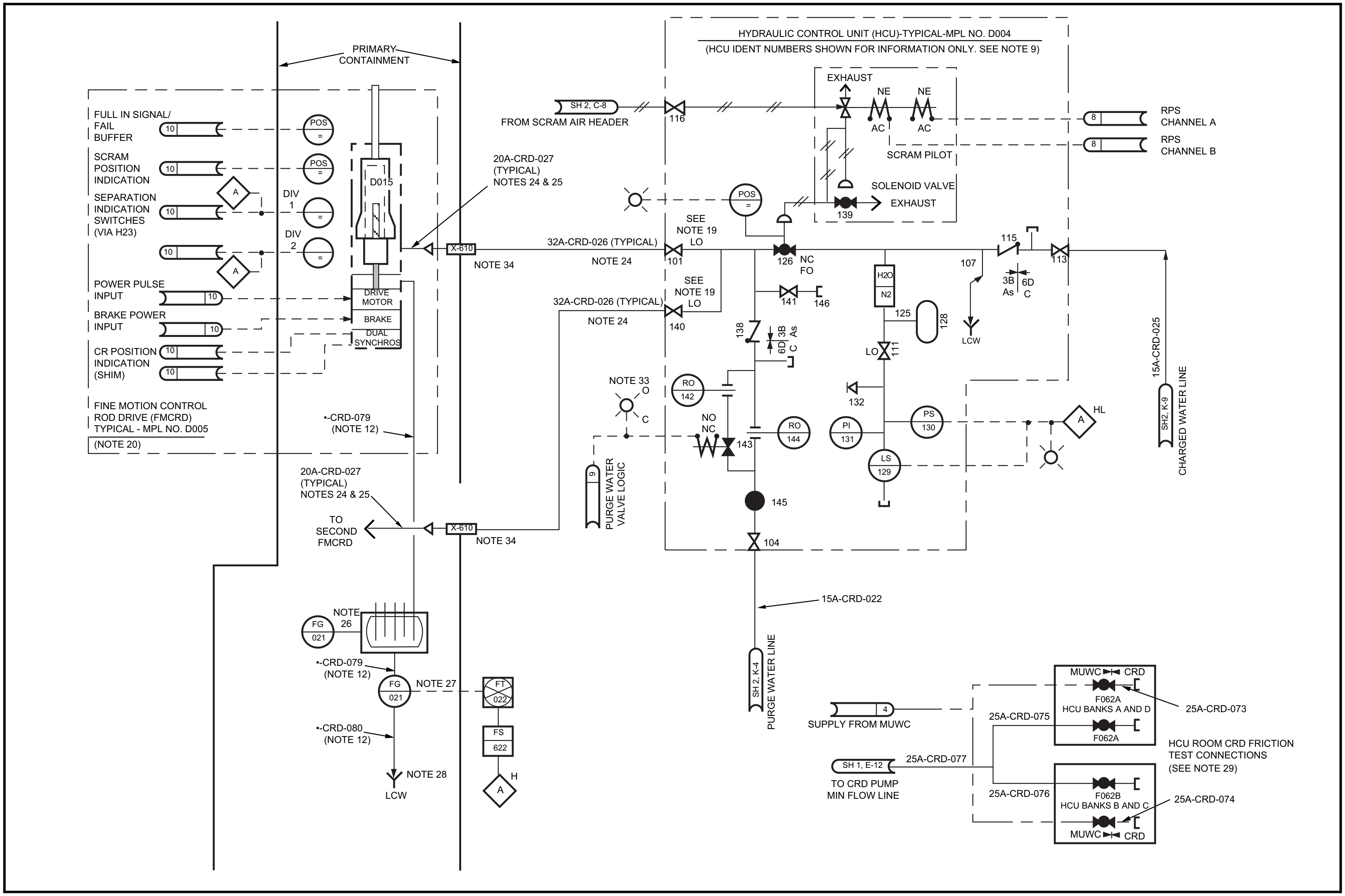

Figure 15B-2 Simplified Hydraulic Control Unit P&ID

The following figure is located in Chapter 21:

Figure 15B-3 Fine Motion Control Rod Drive

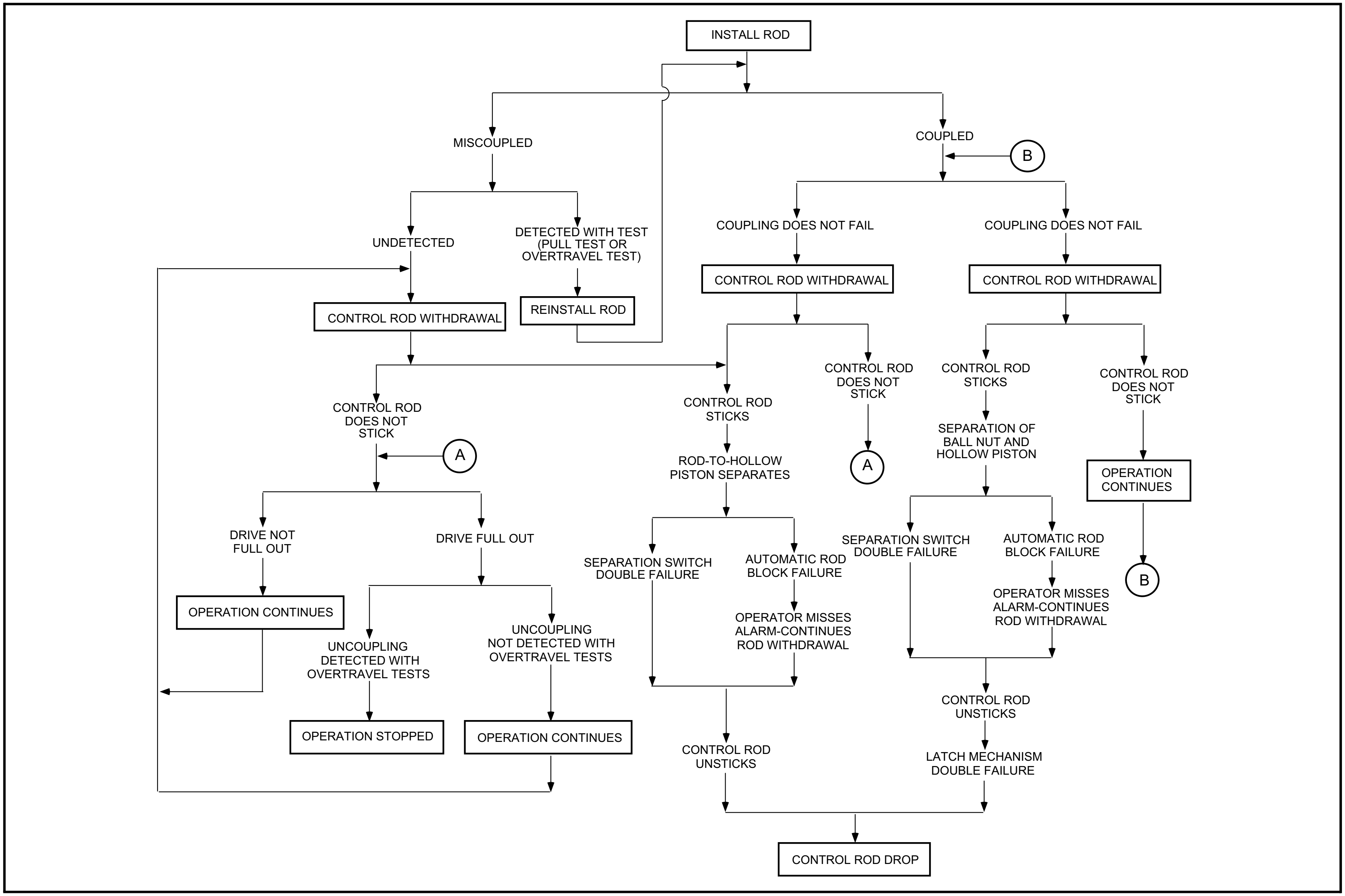

Figure 15B-4 Control Rod Drop Accident Scenario for FMCRD

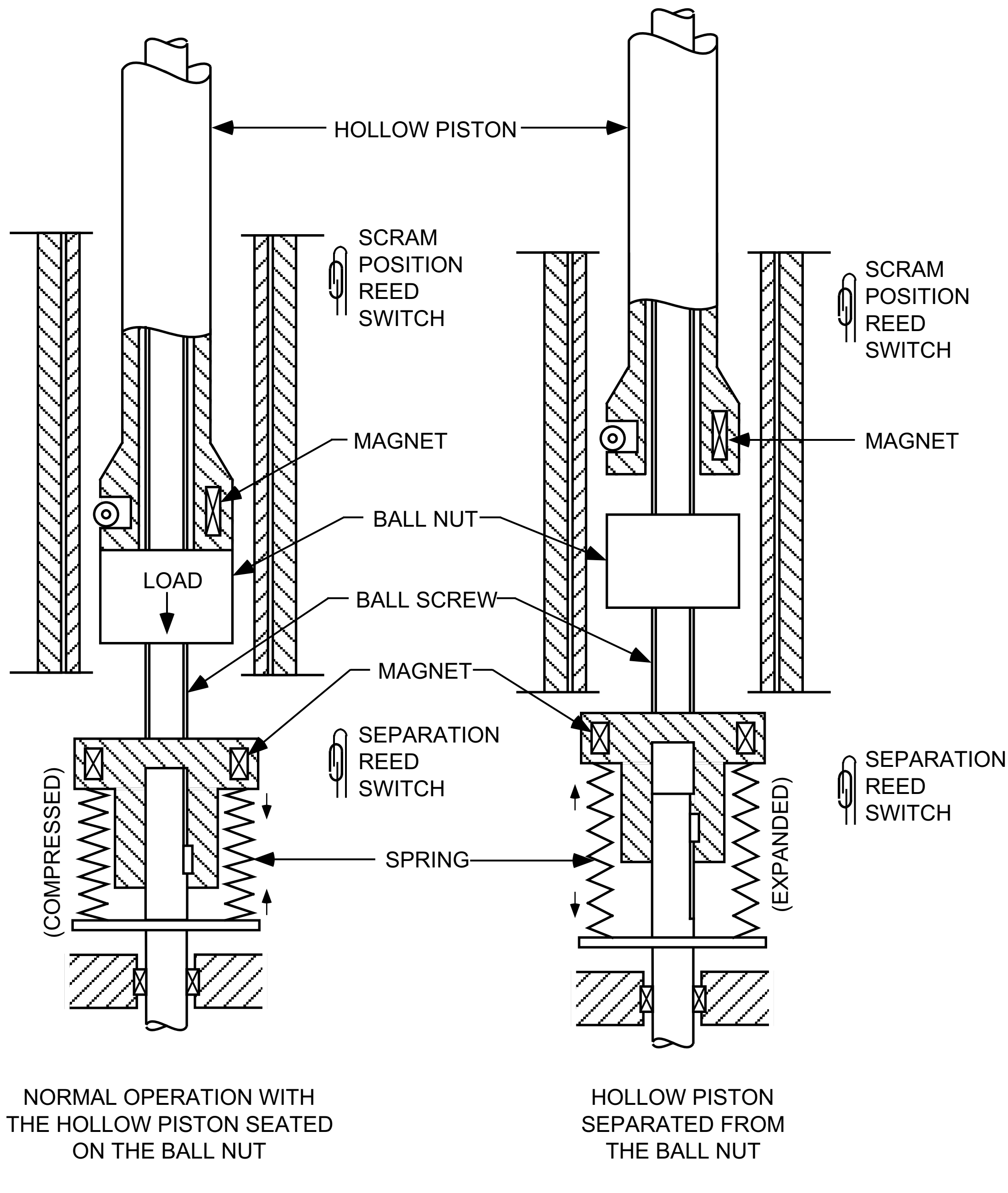

Figure 15B-5 Control Rod Separation Detection

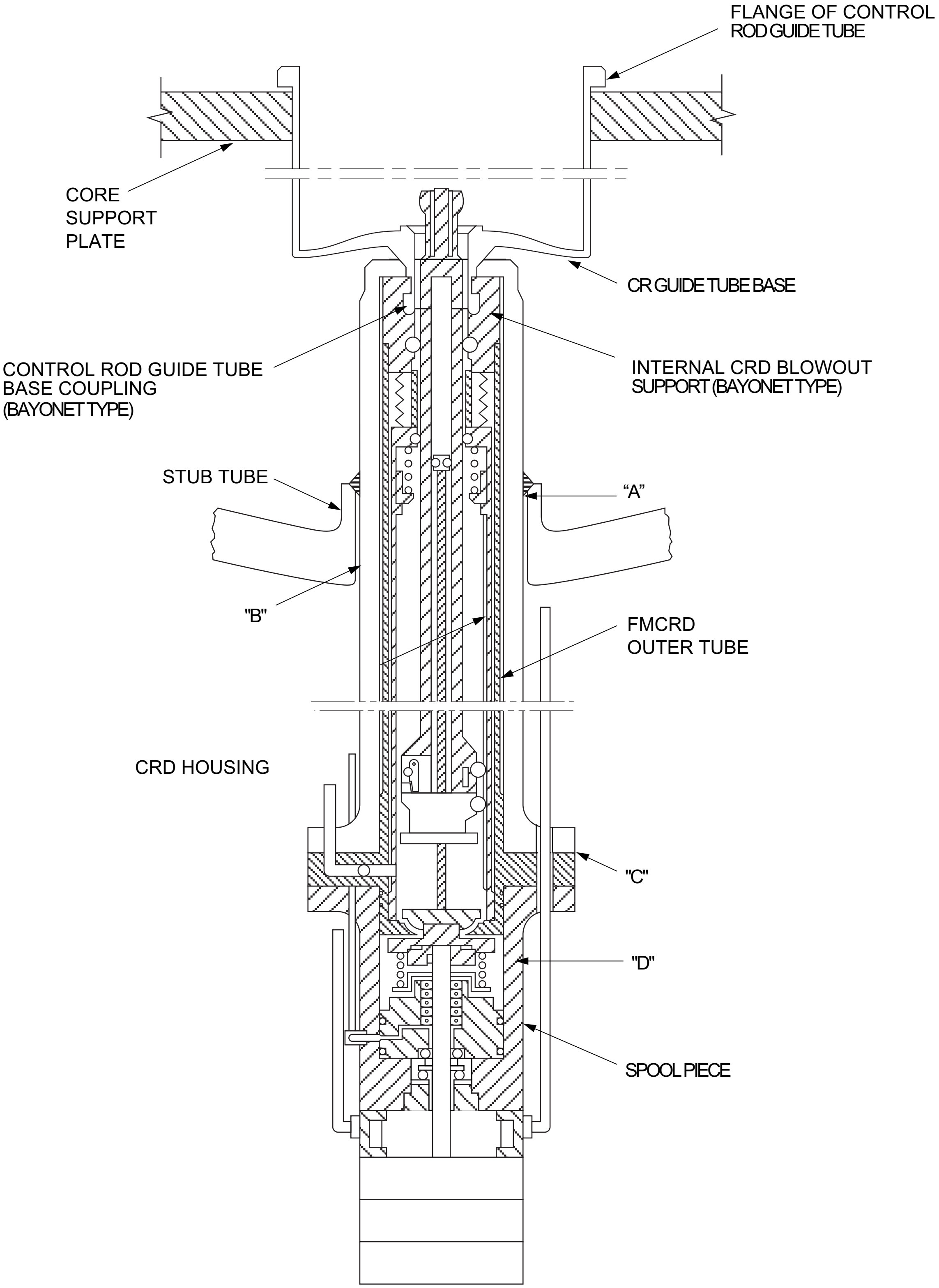

Figure 15B-6 Internal CRD Blowout Support Schematic

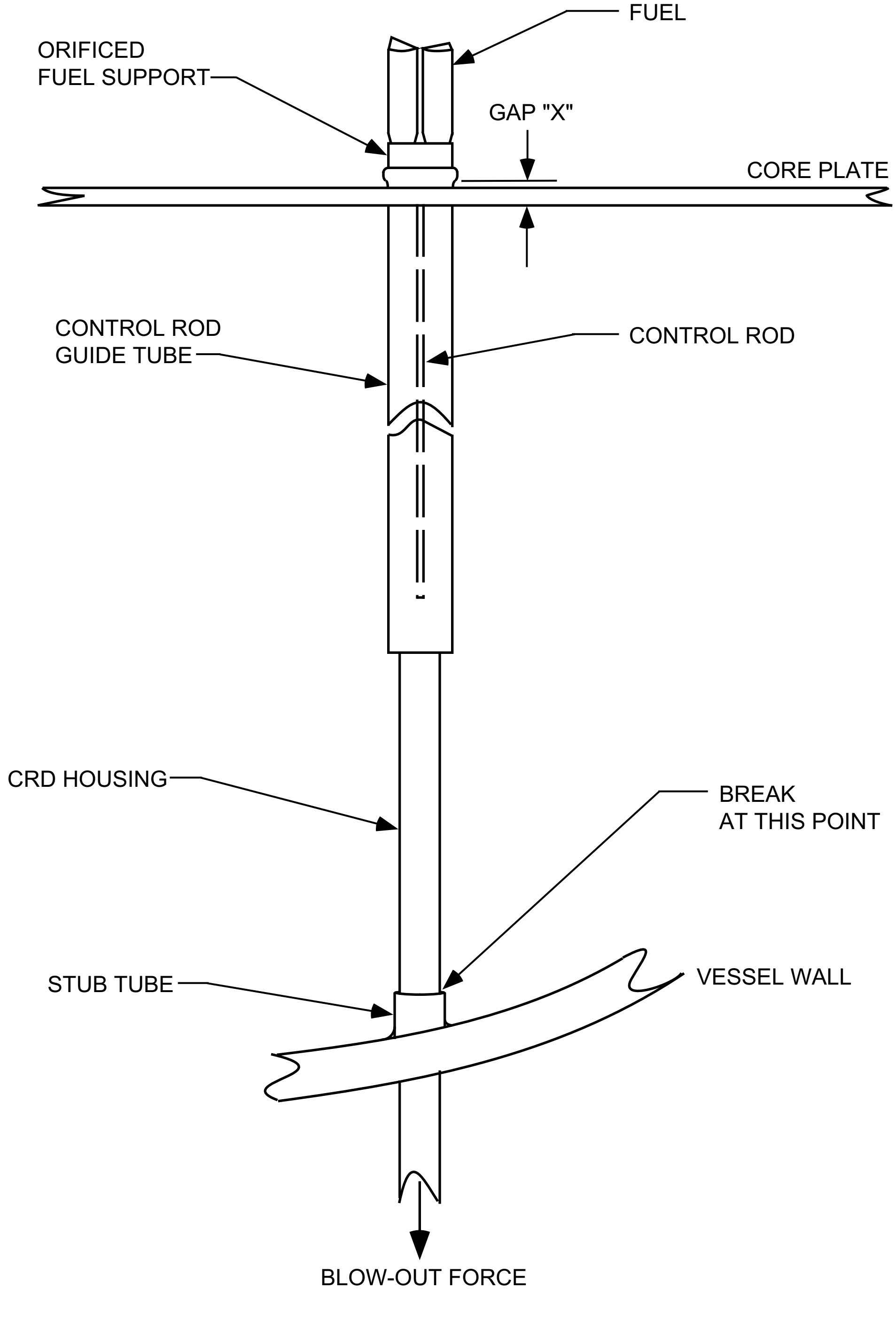

Figure 15B-7 FMCRD Internal Support