Overview

The Nuclear Boiler System (NBS) produces steam from the nuclear fission process, and directs this steam to the main turbine. The NBS is comprised of (1) the reactor vessel, which serves as a housing for the nuclear fuel and associated component, (2) the recirculation system, (3) the control rod drive system, (4) the main steam system and (5) the reactor building portion of the feedwater system. Other supporting systems are described in Chapter 5, Auxiliary Systems.

Reactor Vessel and Internals

The reactor vessel houses the reactor core, which is the heat source for steam generation. The vessel contains this heat, produces the steam within its boundaries, and serves as one of the fission product barriers during normal operation. The ABWR reactor assembly is shown in Figure 3-1. For this size reactor, the diameter of the ABWR reactor pressure vessel (RPV) is increased but the height is decreased compared to earlier product lines. The increased diameter has resulted in increased wall thickness. The RPV is approximately 21m in height and 7.4m in diameter.

The most significant differences between the ABWR RPV and earlier product lines are as follows:

- Inward vessel flange design.
- Steam nozzle with flow restrictor.
- Double feedwater nozzle thermal sleeve.

- Conical vessel support skirt.
- Relatively flat bottom head.
- Elimination of nozzles below the core.
- Reactor internal pump penetrations.
- Use of forged shell rings at and below core elevation.

The RPV design is based on proven BWR technology. A noteworthy feature is the lack of any large nozzles below the elevation of the top of the core. This RPV nozzle configuration precludes any large pipe ruptures at or below the elevation of the core. It is a key factor in the ability of ABWR safety systems to keep the core completely and continuously flooded for the entire spectrum of design basis loss-of-coolant accidents (LOCAs).

The vessel contains the core support structure that extends to the top of the core. The presence of a large volume of steam and water results in two very important and beneficial characteristics. It provides a large reserve of water above the core, which translates directly into a much longer period of time being available before core uncovery can occur as a result of feed flow interruption or a LOCA. Consequently, this gives an extended period of time during which automatic systems or plant operators can reestablish reactor inventory control using any normal, non-safety-related system capable of injecting water into the reactor. Timely initiation...
of these systems is designed to preclude initiation of the emergency safety equipment. This easily controlled response to loss of normal feedwater is a significant operational benefit. In addition, the larger RPV volume leads to a reduction in the ABWR pressurization rate that would occur after a rapid isolation of the reactor from the normal heat sink.

The following sections provide further descriptions of the unique features of the ABWR RPV and internals.

Vessel Flange and Closure Head (1)

To minimize the number of main closure bolts, the ABWR RPV has an inside type flange. This is different from the earlier product lines, which had outside type vessel flanges. The inside type vessel flange allows a hemispherical main closure with a radius less than the vessel radius. Also, this helps minimize the weight of the main closure. The vessel closure seal consists of two concentric O-rings which perform without detectable leakage at all operating conditions, including hydrostatic testing.
Steam Nozzle with Flow Restrictor (2)
The ABWR RPV has flow restricting venturi located in the steam outlet nozzles. Besides providing an outlet for steam from the RPV, the steam outlet nozzles will provide for (1) steamline break detection by measuring steam flow to signal a trip for the main steam isolation valves, (2) steam flow measurement for input to the feedwater control system, and (3) a flow-choking device to limit blowdown and associated loads on the RPV and internals in the event of a postulated main steam line break. Calculations show that the pressure drop in the nozzle is within the requirements of the steady-state performance specification.

Feedwater Nozzle Thermal Sleeve (3)
The feedwater nozzles utilize double thermal sleeves welded to the nozzles. The double thermal sleeve protects the vessel nozzle inner blend radius from the effects of high frequency thermal cycling. A schematic of the feedwater nozzle is shown in Figure 3-2.

Vessel Support Skirt (4)
The vessel support skirt has a conical geometry and is attached to the lower vessel cylindrical shell course. The support skirt attachment (knuckle) is an integral part of the vessel shell ring. Locating the conical support skirt on the lower shell ring provides:

- Needed space for the reactor internal pump (RIP) heat exchangers.
- Access for ISI of the bottom head weld.

Reactor Vessel Bottom Head (5)
The bottom head consists of a spherical bottom cap, made from a single forging, extending to encompass the control rod drive (CRD) penetrations and a conical transition section to the toroidal knuckle between the head and vessel cylinder. With a bottom head thickness of approximately 250 mm, the bottom head meets the ASME allowables for the specified design loads. The main advantage of using a single forging for the bottom head is that it eliminates all RPV welds within the CRD pattern, thus reducing future in-service inspection (ISI) requirements.
Use of Forged Shell Rings (7)
The ABWR RPV utilizes low alloy forged shell rings, per ASME SA-508, Class 3, adjacent to and below the core belt line region. The flanges and large nozzles are also per ASME SA-508, Class 3. The shell rings above the core beltline region and the main closure are made from low alloy steel plate per ASME A-533, Type B, Class 1. The required Reference Nil Ductility, \( RT_{NDT} \), of the vessel material is \(-20^\circ C\). Figure 3-4 shows one of the RPV forged shell rings during fabrication.

Shroud (8)
The shroud is a stainless steel cylindrical assembly that provides a partition to separate the upward flow of coolant through the core from the downward recirculation flow. The volume enclosed by the shroud is characterized by upper and lower regions. The upper portion of the shroud surrounds the active fuel and forms the longest section of the shroud. This section is bounded at the bottom by the core plate. The lower shroud, surrounding part of the lower plenum, is welded to the RPV shroud support. The shroud provides lateral support for the core by supporting the core plate and top guide.

Core Plate (9)
The core plate consists of a circular plate with round openings. The core plate provides lateral support and guidance for the control rod guide tubes, in-core flux monitor guide tubes, peripheral fuel supports, and startup neutron sources. The last two items are also supported vertically by the core plate. The entire assembly is bolted to a support ledge in the shroud. The core plate also forms a partition within the shroud, which causes the recirculation flow to pass into the orificed fuel support and through the fuel assemblies.

Top Guide (10)
The top guide consists of a grid that gives lateral support of the top of the fuel assemblies, a cylinder supporting core flooder spargers, and a top flange for attaching the shroud head. Each opening provides lateral support and guidance for four fuel assemblies.
or, in the case of peripheral fuel, one, two or three fuel assemblies. Holes are provided in the bottom of the support intersections to anchor the in-core flux monitors and startup neutron sources. The top guide is bolted to the top of the shroud.

**Fuel Supports (11)**

The fuel supports are of two basic types; namely, peripheral fuel supports and orificed fuel supports. The peripheral fuel supports are located at the outer edge of the active core and are not adjacent to control rods. Each peripheral fuel support sustains one fuel assembly and contains an orifice designed to assure proper coolant flow to the peripheral fuel assembly. Each orificed fuel support sustains four fuel assemblies vertically upward and horizontally and is provided with orifices to assure proper coolant flow distribution to each fuel bundle. The orificed fuel support sits on the top of the control rod guide tube, which carries the weight of the fuel rods down to the bottom of the RPV. The control rods pass through cruciform openings in the center of the orificed fuel support.

**Control Rod Drive Housing (12)**

The control rod drive housing provides extension of the RPV for installation of the control rod drive, and the attachment of the CRD line. It also supports the weight of a control rod, control rod drive, control rod guide tube, orificed fuel support and four fuel assemblies.

**Control Rod Guide Tubes (13)**

The control rod guide tubes extend from the top of the control rod drive housings up through holes in the core plate. Each guide tube is designed as the guide for the lower end of a control rod and as the support for an orificed fuel support. This locates the four fuel assemblies surrounding the control rod drive housing, which, in turn, transmits the weight of the guide tube, fuel support, and fuel assemblies to the reactor vessel bottom head. The control rod guide tube also contains holes, near the top of the control rod guide tube and below the core plate, for coolant flow to the orificed fuel supports. In addition, the guide tube provides a connection to the FMCRD to restrain an hypothetical ejection of the FMCRD.

**In-Core Housing (14)**

The in-core housings provide extensions of the RPV at the bottom head for the installation of various in-core flux monitoring sensor assemblies, which are components of the Neutron Monitoring System. It also supports the weight of an in-core flux monitoring sensor assembly, in-core guide tube and part of the in-core guide tube stabilizer assembly.

**In-Core Guide Tubes and Stabilizers (15)**

The in-core guide tubes extend from the top of the in-core housing to the top of the core plate. They provide the in-core instrumentation with protection from flow of water in the bottom head plenum, and guidance for insertion and withdrawal from the core. The in-core guide tube stabilizers provide lateral support and rigidity to the in-core guide tubes.

**Feedwater Spargers (16)**

The feedwater spargers are attached to brackets on the vessel wall and deliver makeup water to the reactor during plant startup, power generation and plant shutdown modes of operation. Nozzles in the spargers provide uniform distribution of feedwater flow within the downcomer flow passage.
High Pressure Core Flooder Sparger Assembly (17)

The high pressure core flooder (HPCF) spargers inside the cylinder of a top guide are arranged to provide emergency coolant injection over the upper end of the core. The spargers have the function of a standby liquid control solution injection. The HPCF spargers are connected to the HPCF nozzles by means of an HPCF coupling (18).

Low Pressure Flooder Spargers (19)

The two flooding spargers that are attached to the vessel wall deliver flow at low pressure from the RHR System and distribute it in the upper plenum above the shroud head of the reactor. Flow is delivered in either of two modes: (1) for the flooding of the reactor in the event of an abnormal drop in water level, or (2) in the circulation of cooling water to remove residual and core decay heat from the reactor during shutdown.

Shutdown Cooling Nozzles (20)

Suction for the RHR System in the shutdown cooling mode is provided by three shutdown cooling nozzles.

Shroud Head and Steam Separator Assembly (21)

The steam separator assembly consists of a slightly domed base on top of which is welded an array of standpipes with a three-stage steam separator located at the top of each standpipe. The steam separator assembly rests on the top flange of the core shroud and forms the cover of the core discharge plenum region. The seal between the separator assembly and core shroud flanges is metal-to-metal contact and does not require a gasket or other replacement sealing devices. The separator assembly is bolted to the core shroud flange, by long holddown bolts which, for ease of removal, extend above the separators. During installation, the separator base is aligned on the core shroud flange with guide rods and finally positioned with locating pins. The objective of the long-bolt design is to provide direct access to the bolts during reactor refueling operations with minimum-depth underwater tool manipulation during the removal and installation of the assemblies. It is not necessary to engage threads in mating up the shroud head. A tee-bolt engages in the top guide and its nut is tightened to only nominal torque. Final loading is established through differential expansion of the bolt and compression sleeve. The fixed axial flow type steam separators have no moving parts and are made of stainless steel. In each separator, the steam-water mixture rising through the standpipe impinges on vanes which give the mixture a spin to establish a vortex wherein the centrifugal forces separate the water from the steam in each of three stages. Steam leaves the separator at the top and passes into the wet steam plenum below the dryer (Figure 3-5). The separated water exits from the lower end of each stage of the separator and enters the pool that surrounds the standpipes to join the downcomer annulus flow.

Steam Dryer Assembly (22)

The steam dryer assembly consists of multiple banks of dryer units mounted on a common structure which is removable from the RPV as an integral unit. The assembly includes the dryer banks, dryer supply and discharge ducting, drain collecting trough, drain ducts, and a skirt which forms a water seal extending below the separator reference zero elevation. Steam from the separators flows upward and outward through the drying vanes (Figure 3-6). These vanes are attached to a top and bottom supporting member forming a rigid, integral unit. Moisture is removed and carried by a system of troughs and drains to the pool surrounding the separators and then into the recirculation downcomer annulus between the core shroud and reactor vessel wall. Upward and radial movement of the dryer assembly under the action of
The functions of the Reactor Recirculation System (RCIR) are to:

- Provide forced circulation of reactor coolant for energy transfer from fuel to the cooling fluid and, as a result, generate a larger amount of steam.
- Control the reactor power by changing the recirculation flow; the flow is controlled by the use of adjustable speed pumps.

The assembly is arranged for removal from the vessel as an integral unit on a routine basis.
The RCIR System provides forced circulation of reactor water through the core, removing the heat produced by the fuel. The reactor water is made up of water removed from the two-phase reactor coolant (core flow) in the moisture separators and steam dryers and the incoming feedwater flow. The RCIR System uses an arrangement of ten reactor internal pumps (RIPs). The pumps are mounted internally in the reactor vessel to provide the motive force for core flow. The RIPs function collectively to force the reactor coolant through the lower plenum of the reactor and upward through openings in the fuel support castings, through the fuel bundles, steam separators, and down the annulus to be mixed with feedwater and recirculated through the core. Figure 3-7 shows the RIPs and the pumped flow path.

Recirculation flow rate is variable over a range from natural circulation flow of 20% to above the rated flow required to achieve rated core power. In fact, the RCIR design can produce rated core flow rate at 100% reactor power with nine of its ten pumps operating. The flow control range allows automatic regulation of reactor power output between ~70 to 100% without control rod movement. Core flow (RCIR pumping capacity) is regulated by the Recirculation Flow Control System (RFC). The RFC System provides conditioned control and logic signals, which regulate the RIP speed, which, in turn, regulates the pump flow. Because the core flow affects reactor power and fuel thermal margins, the RCIR System is also used to mitigate the effects of transient, upset and emergency modes of reactor operation.

Three RCIR subsystems are used in conjunction with the reactor internal pumps:

- Recirculation Motor Cooling Subsystem (RMC Subsystem).
- Recirculation Motor Purge Subsystem (RMP Subsystem).
- Recirculation Motor Inflatable Shaft Seal Subsystem (RMISS).
Recirculation Motor Cooling Subsystem (RMC)

Each RIP has its own external heat exchanger (Figure 3-8). Each RIP motor casing and the RIP heat exchanger is connected via stainless steel piping. The heat exchanger is a typical shell-tube type with U-tubes supported by baffles. The hot water coming from the motor enters from the upper end of the heat exchanger shell side and leaves from the lower end of the shell side and returns back to the motor. The connecting piping is welded to the RIP motor casing and also to the heat exchanger shell to prevent any leakage during the plant operation.

Recirculation Motor Purge Subsystem (RMP)

The RMP Subsystem provides a source of clean control rod drive (CRD) water that flows up the annulus between the stretch tube and the shaft and prevents the intrusion of reactor water with its associated contamination into the motor. The purge system normally operates continuously even when the RIPs are tripped or the reactor is shutdown for the refueling and/or maintenance.

Recirculation Motor Inflatable Shaft Seal Subsystem (RMISS)

During normal operation, the purpose of this system is to prevent any leakage of reactor water (escaping from the primary seal) during plant outages and to assist in maintenance or inspection of motors. During the maintenance of the RIPs, a portable pump is used to pressurize the seal using water from the Makeup Water System (MUW). The seal is made of elastomeric material and seals tightly between the pump shaft and the pump motor casing. The pump pressurizes the seal and maintains it at shutoff head conditions.

Reactor Internal Pumps

The vessel-mounted RIPs simplify the RPV by eliminating all large nozzles below the core, significantly reducing piping in-service inspection (ISI) and personnel exposure, and allowing for a compact containment design due to elimination of the external recirculation system piping. Use of the RIP feature allows for the optimization of the Emergency Core Cooling System (ECCS) and assures no core uncovery for postulated pipe breaks. One of the goals for the ABWR is to reduce calculated core damage frequency by an order of magnitude relative to GE’s previously designed BWR operating plants. One of the most important design features contributing to this goal was the adoption of RIPs in place of externally pumped reactor recirculation system/pumps.

The internal pumps are an improved version of a European designed RIP that is in operation in many European nuclear power plants. About 9 million pump hours of successful operating experience has been accumulated, with some pumps having been in service since the mid-1970’s.

The general design details of the RIP, motor, and heat exchanger are shown in Table 3-1:

<table>
<thead>
<tr>
<th>Number of Pumps:</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Pump:</td>
<td>Vertical shaft, single stage, mixed flow</td>
</tr>
<tr>
<td>Rated Flow:</td>
<td>7700 m³/hr/ pump</td>
</tr>
<tr>
<td>Rated Head:</td>
<td>40m</td>
</tr>
<tr>
<td>Rated Pump Speed:</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Overall Height (Impeller &amp; Motor):</td>
<td>3m</td>
</tr>
<tr>
<td>Overall Weight:</td>
<td>5000 kg</td>
</tr>
<tr>
<td>Motor Type:</td>
<td>3-Phase, Wet Induction Motor</td>
</tr>
<tr>
<td>Rated Output Power:</td>
<td>830 kW</td>
</tr>
<tr>
<td>Rated Voltage:</td>
<td>~3300V</td>
</tr>
<tr>
<td>Heat Exchanger Type:</td>
<td>Shell &amp; Tubes</td>
</tr>
<tr>
<td>Hx Cooling Capacity:</td>
<td>1.15 kcal/hr</td>
</tr>
</tbody>
</table>

Table 3-1. Key RIP Parameters
Reactor Internal Pump Component Description

There are 10 RIPs arranged circumferentially between the shroud and the RPV near the RPV bottom head. Figure 3-9 shows a cross-section of the RIP used in the ABWR, and key components are described below.

**Diffuser:** The RIP has the impeller and diffuser inside the RPV. The diffuser is installed in the pump deck and sealed by a piston ring arrangement. The RIP diffuser is removable. The diffuser is retained on the RPV nozzle by the stretch tube.

**Stretch Tube:** The stretch tube is essentially a long hollow bolt which passes through the RPV nozzle penetration from the diffuser to the top of the RIP motor casing where it is held in tension by a large nut. The stretch tube is preloaded by use of a stud tensioner similar to that used for the main closure studs of the RPV. The pump shaft passes through the center of the stretch tube and motor rotor. The pump shaft key fits in a slot in the motor rotor tube.

**Impeller and Pump Shaft:** The impeller and the pump shaft are connected by the impeller bolt. The pump shaft passes through the stretch tube, rotor and is connected to the thrust bearing disk at its lower end. The motor rotor keyway slot fits with the key on the pump shaft and transmits motor torque.
Radial Bearings: The motor upper radial bearing is below the secondary seal. This bearing design has been tested and proven to eliminate bearing instability due to half-speed rotation.

The lower radial bearing is located below the motor rotor and the stator. The lower radial bearing is similar to the upper radial bearing.

Thrust Bearing: The thrust bearing is of an offset tilting pad configuration. The rotating portion of the thrust bearing is integral with the cooling water auxiliary impeller, which circulates water through the motor and bearing to provide cooling and cleaning via the RMP Subsystem.

Anti-Reverse Rotation Device: Below the cooling water auxiliary impeller is the Anti-Reverse Rotation Device (ARD). This is a cam clutch arrangement that prevents the RIP from rotating in the reverse direction when one RIP is tripped while the others are running (which can result in backflow through the tripped RIP). The purpose of the ARD is to prevent reverse rotation of the pump shaft and minimize the backflow through an idle/tripped RIP.

Motor (Stator and Rotor): The RIP motor is a 3-phase, 4-pole wet induction motor. The cooling water flows upward through the windings of the stator and the rotor. The motor stator is attached to the motor cover.

Terminal Box: The electrical terminal box is bolted to the motor cover. The motor winding cable penetrations pass through the motor cover coolant pressure boundary and are connected to the power supply leads at this location. Each motor is driven by its own variable frequency power supply known as the Adjustable Speed Drive (ASD).

Speed and Vibration Sensors: Two-pump speed sensors and two-motor casing vibration sensors are on each RIP motor casing. There is an additional sensor on each RIP to detect rubbing of internal parts of the pump.
RIP Operation

Whenever the RIP motor is started, it is controlled to reach its minimum speed. Similarly, one by one, the other nine RIPS are started and brought to the minimum speed level. From this condition, the speed of all 10 RIPS can be increased individually when in the individual speed control mode, or as a group when in the automatic ganged mode of operation, with the ganged mode being the normally preferred mode after all 10 RIPS have been started. The RFC System controls the speed of the RIPS, as described earlier in this section. A change in RIP speed conditions will vary the core flow in the reactor, which, in turn, will change the reactor power during normal power range operation.

The RFC operational modes also include the core flow control mode and the automatic load-following mode. The core flow mode controls the speed of the RIPS selected for gang speed operation to maintain the steady-state core flow equal to the core flow demand signal. For the automatic load-following mode, the RFC System controls the speed of those RIPS selected for gang speed operation to reduce the load demand error signal (from the turbine control system) to zero.

Individual RIP speed control operation mode and the ganged speed mode of operation provide significant flexibility during normal plant operation. If, for any reason, one RIP develops a problem, then either speed can be reduced to eliminate the problem or that RIP can be tripped, if necessary, without affecting the continued operation of other RIPS.

During normal plant rated power operation (in either the core flow control mode or the automatic load-following mode), if one RIP is lowered in speed or tripped, then the speed of the remaining nine RIPS is increased by the control system to maintain the demanded core flow; thus, steady-state plant output power remains unaffected.

RIP Power Supply

The RIP motor is driven by a solid-state variable-frequency power supply known as the Adjustable Speed Drive (ASD). The ASD is a proven product with wide industrial applications as well as experience in the European nuclear plants. The ABWR application uses ~3000V for the output voltage rating. The ASD power supply provides extremely low maintenance, high reliability, and excellent RIP speed maneuverability.

Each RIP is driven by its dedicated ASD. Six RIP ASDs receive power from constant speed Motor-Generator (M-G) sets and the other four directly from medium voltage buses. A representative simplified power distribution one-line diagram is shown in Figure 3-10. Each M-G set provides power to three associated RIP ASDs. The other four RIP ASDs are divided into two sets receiving power directly from two separate main buses.

The assignment of the power distribution to individual RIP ASDs is chosen to balance the azimuthal distribution within the vessel (e.g., when a M-G set trips or one medium voltage bus is lost). The M-G sets have inertial flywheels to provide continued operation of the associated RIPS during either the momentary or complete loss of incoming power. After complete loss of the main bus power, continued operation of these RIPS for at least 3 seconds is provided via the M-G sets.

Control Rod Drive System

The Control Rod Drive (CRD) System controls changes in core reactivity during power operation by movement and positioning of the neutron absorbing control rods within the core in fine increments in
response to control signals from the Rod Control and Information System (RCIS). The CRD System provides rapid control rod insertion in response to manual or automatic signals from the Reactor Protection System (RPS). Figure 3-11 shows the basic system configuration and scope.

When scram is initiated by the RPS, the CRD System inserts the negative reactivity necessary to shut down the reactor. Each control rod is normally controlled by an electric motor unit. When a scram signal is received, high-pressure water stored in nitrogen charged accumulators forces the control rods into the core. Thus, the hydraulic scram action is backed up by an electrically energized insertion of the control rods.

The CRD System consists of three major elements:

- Electro-hydraulic fine motion control rod drive (FMCRD) mechanisms.
- Hydraulic control unit (HCU) assemblies.
- Control Rod Drive Hydraulic System (CRDHS).

The FMCRDs provide electric-motor-driven positioning for normal insertion and withdrawal of the control rods and hydraulic-powered rapid control rod insertion for abnormal operating conditions. Simultaneous with scram, the FMCRDs also provide electric-motor-driven run-in of control rods as a path to rod insertion that is diverse from the hydraulic-powered. The hydraulic power required for scram is provided by high pressure water stored in the individual HCUs. An HCU can scram two FMCRDs. It also provides the flow path for purge water to the associated drives during normal operation. The CRDHS supplies pressurized water for charging the HCU scram accumulators and purging to the FMCRDs.

**Fine Motion Control Rod Drives**

The ABWR FMCRDs are distinguished from the locking piston CRDs, which are in operation in all current GE plants, in that the control blades are moved electrically during normal operation. This feature permits small power changes, improved startup time, and improved power maneuvering. The FMCRD, as with current drives, is inserted into the core hydraulically during emergency shutdown. Because the FMCRD has the additional electrical motor, it drives the control blade into the core even if the primary hydraulic system fails to do so, thus providing an additional level of protection against ATWS events. The FMCRD design is an improved version...
of similar drives that have been in operation in European BWRs since 1972.

Figure 3-12 shows a cross-section of the FMCRD as used in the ABWR. The FMCRD consists of four major subassemblies: the drive, spool piece, brake and motor/synchros. The spool piece and motor may be removed without disturbing the drive, allowing maintenance with low personnel exposure.

The drive consists of the outer tube, hollow piston, guide tube, buffer, labyrinth seal, ball check valve, spindle adaptor and splined spindle adaptor back seat.

The coupling is a bayonet-type configuration which, when coupled with the mating coupling on the control rod blade, precludes separation of the blade and the hollow piston.

The hollow piston is a long hollow tube with a piston head at the lower end. The hollow piston is driven into the reactor during scram by the pressure differential that is produced by the high scram flow. The labyrinth seal, which is contained inside the buffer, at the top end of the outer tube restricts the flow from the drive to the reactor, thereby maximizing the pressure drop which enhances scram performance. Additionally, it allows the purge flow during normal operation to preclude entrance of reactor water and associated crud into the drive. The piston head contains latches that latch into notches in the drive guide tube after scram. The scram buffering action is provided by an assembly of belleville washers in the buffer and is supplemented by hydraulic damping as the buffer assembly parts come together.

The outer tube performs several functions, one of which is to absorb the scram pressure, preventing its application to the CRD housing, which is part of the reactor core pressure boundary (RCPB). The outer tube top end is a bayonet connection similar to that employed on the hollow piston which couples with a similar bayonet connection on the control rod guide tube, sandwiching the CRD housing end cap between the two. The outer tube lower end is a flange which bolts to the CRD housing flange. The bolts allow the drive to remain in place when the motor and spool piece are removed. The combination of the positive coupling of the control rod guide tube and the drive and the flange on the lower end of the outer tube form a positive means of preventing ejection of the FMCRD/control rod for any postulated housing break. Protection against the postulated failure of the housing to stub tube weld is provided by the same features, with the shootout load being transferred to the core plate by the flange at the top end of the control rod.
guide tube. These internal CRD blowout support features allow the elimination of the external support structure of beams, hanger rods, grids and support bars used to prevent rod ejection as in previous GE BWR product lines.

The latches are designed so that with only one being engaged it is sufficient to hold the control rod in place under all loading, including the ejection load caused by a scram line break.

In normal operation, the hollow piston rests on the ball nut and is raised and lowered by translation of the ball nut along the ball screw resulting from rotation of the ball spindle. The latches are held in a retracted position by the ball nut. During scram, the hollow piston is lifted off the ball nut by the hydraulic pressure.

The spindle adaptor and splined spindle adaptor back seat provide a back seat type anti-withdrawal latch feature, which consists of a gear that automatically engages whenever the spool piece is lowered. This prevents the ball spindle from rotating and withdrawing the rod.

The spool piece contains a redundant packing type shaft seal to preclude leakage from the drive. The spool piece also contains radial and thrust bearings for the stub shaft that is also part of the spool piece. The stub shaft transmits torque from the motor to the ball screw via a slip coupling. The spool piece also contains the weighing platform.

The weighing device is a spring-loaded platform with two magnets located on it. In normal service, weight of the hollow piston and control rod is transferred to the weighing device. If, during withdrawal, the weight of the rod or hollow piston is removed from the device, then the device will move upwards and trigger two external reed switches. The two external reed switches are called separation switches and, if either is opened, withdrawal motion is inhibited. There are two separation switch probes which are directly opposite each other. Each probe contains one switch.
The spool piece is bolted to the CRD housing by bolts which pass through the outer tube flange. As mentioned above, the outer tube is also bolted to the CRD housing. The double bolting arrangement, combined with the back seat type lock feature discussed above, allows spool piece servicing without disturbing the drive.

The motor bolts to the spool piece through a motor bracket. The motor is a stepping motor similar to that used in robotic and precision positioning applications. The use of the stepping motor is the major change from the configuration used in Europe. The European drives used a gear motor and, because of this, had less precise positioning capability than the ABWR FMCRD. In addition, the gear motor required increased maintenance compared to the stepping motor. The stepping motor design is based on motors that have had successful experience in industrial applications.

There are two synchro-type position indicators located below the stepping motor. The synchros provide a continuous readout of the rod position during normal operation and are driven by gears from the motor shaft.

The brake is mounted between the motor and the synchros. The brake serves to restrain the rod against withdrawal in the unlikely event that the scram line breaks. The brake is redundant with the ball check valve in mitigating the scram line break. It should be noted at this point that the check valve on the FMCRD has no function other than to mitigate the scram line break and to limit leakage during drive replacement. Table 3-2 provides some key FMCRD parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FMCRD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step Size</td>
<td>18.3 mm</td>
</tr>
<tr>
<td>Movement Speed</td>
<td>30 mm/sec</td>
</tr>
<tr>
<td>Scram time 60%</td>
<td>1.7 sec</td>
</tr>
</tbody>
</table>

Table 3-2. Key FMCRD Parameters

The balance of the FMCRD System includes the scram position probes which are mounted on the outside of the CRD housing. The scram probe provides a position signal at 10%, 40% and 60% insertion, as well as continuous full-in. The continuous full-in signal prevents the loss of position indication that would otherwise occur while the hollow piston is held by the scram latches at the top latched position.

The probes use reed switches similar to the Locking Piston Control Rod Drive (LPCRD), as do the separation switch probes that are mounted on the side of the spool piece. The separation probes and associated circuits and equipment are considered important to safety and are therefore categorized as Class 1E.

In addition to the FMCRD and probes, other items in the system include the power supply to motor (also known as the inverter controller), the Hydraulic Control Unit (HCU), scram piping, wiring and the CRD pump and its associated equipment.

Power to the FMCRD is provided by a solid state, thyristor-driven power supply. The power supply is based on proven products with successful experience in industrial applications. The power supply is a variable voltage and frequency device which starts the motor at low speed, accelerates it to the normal run speed and then slows it when approaching the specified position. The power supply interfaces with the Rod Control and Information System (RCIS). The power
supply includes the capability to move the individual drive, while the RCIS provides the logic and control for overall control rod motion.

The DC power for the brake, which is an energize-to-release model, is supplied by an inverter which is integrated with the motor power supply cabinets.

Hydraulic Control Units

The HCU consists of a gas bottle and accumulator which are mounted on a frame. The HCU also includes the scram and scram pilot valves. In an ABWR, there is one HCU for every two FMCRDs, rather than the one HCU per CRD as in past GE plants. The use of the paired arrangement allows savings in space and maintenance without sacrificing reliability or safety. The two FMCRDs on a given HCU are widely separated in the core so that there is no additional loss of shutdown margin if an HCU fails.

Control Rod Drive Hydraulic System

The ABWR Control Rod Drive Hydraulic System (CRDHS) supplies clean, demineralized water, which is regulated and distributed to provide charging of the HCU scram accumulators and purge water flow to the FMCRDs. The CRDHS is also the source of pressurized water for purging the RIP and the Reactor Water Cleanup (RWCU) System pump.

The CRD pump is basically the same as that used in BWR/6 plants (i.e., a multi-stage centrifugal pump). The filtration system is basically also the same as that used on BWR/6.

Main Steam System

The purpose of the Main Steam System (MS) is to direct steam flow from the RPV steam outlet nozzles to the main turbine. A main steamline flow restrictor is provided in each steam outlet nozzle. It is designed to limit the flow rate in the event of a postulated steamline break. The system also incorporates provisions for relief of over-pressure conditions in the RPV.

In the ABWR design, four 28-inch steamlines transport steam from the steam outlet nozzles on the RPV through Reinforced Concrete Containment Vessel (RCCV) penetrations and then through the steam tunnel to the turbine. Main steam isolation valves (MSIVs) are installed in each steamline inboard and outboard of the RCCV penetrations. Eighteen safety/relief valves (SRVs) are installed on horizontal steamline headers, and the discharge from each SRV is routed through the associated SRV discharge line to quenchers located in the suppression pool. Of the 18 SRVs, 8 provide the Automatic Depressurization System (ADS) function during an accident condition. Figure 3-13 is a simplified piping diagram of the MS, and Figure 3-14 illustrates the three-dimensional configuration of the piping, MSIVs and SRVs.

The MS is composed of several components and subsystems in addition to the above, which are necessary for proper operation of the reactor under various operating, shutdown and accident conditions. Some of these subsystems include: main steam bypass/drain subsystem, SRV and ADS, reactor head vent subsystem, and system instrumentation.

Main Steam Isolation Valves

Two MSIVs are welded in a horizontal run of each of the four main steam pipes. The MSIVs are designed to isolate primary containment upon receiving an automatic or manual closure signal, thus limiting the loss of coolant and the release of radioactive materials from the nuclear system.
Each MSIV is a Y-pattern, globe valve and is powered by both pneumatic pressure and compressed spring force (Figure 3-15). The main disk assembly is attached to the lower end of the stem. Normal steam flow tends to close the valve and the pressure is over the disk. The bottom end of the valve stem or a stem disk attached to the stem closes a small pressure balancing hole in the main disk assembly. When the hole is open, it acts as an opening to relieve differential pressure forces on the main disk assembly. Valve stem travel is sufficient to provide flow areas past the wide open main disk assembly greater than the seat port area. The main disk assembly travels approximately 90% of the valve stem travel to close the main seat port area; approximately the last 10% of the valve stem travel closes the pilot seat. The air cylinder actuator can open the main disk assembly with a maximum differential pressure of 1.38 MPaG (200 psig) across the isolation valve in a direction that tends to hold the valve close. The Y-pattern valve permits the inlet and outlet passages to be streamlined; this minimizes pressure drop during normal steam flow and helps prevent debris buildup on the valve seat.

Attached to the upper end of the stem is an air cylinder that opens and closes the valve and a hydraulic dashpot that controls its speed. The speed is adjusted by hydraulic control valves in the hydraulic return lines bypassing the dashpot piston.

The valve is designed to close quickly when nitrogen or air is admitted to the upper piston compartment to isolate the MS in the event of a LOCA, or other events requiring containment or system isolation to limit the release of reactor coolant. The MSIVs can be test
Figure 3-14. Main Steam System Schematic

- **Main steam**
- **SRV**
- **Feedwater**
closed one at a time at a slow closing speed by admitting nitrogen or air to both the upper and lower piston compartments. This is to ensure that the slow valve closure does not produce a transient disturbance large enough to cause a reactor scram.

When all the MSIVs are closed, the combined leakage through the MSIVs for all four steamlines is monitored to within the offsite radiation dose release limit.

Nitrogen is used for the inboard MSIV operation because of the inerted drywell environment where the inboard MSIVs are located. Instrument air is used for the outboard MSIV operation.

A separate pneumatic accumulator is provided and located close to each MSIV and supplies pressure as backup operating gas to assist in valve closure in the event of a failure of pneumatic supply pressure to the valve actuator.

**Safety/Relief Valves**

The SRV is a dual function, direct-acting valve and is classified as safety-related (Figure 3-16). The SRV is considered as part of the RCPB because the inlet side of the valve is connected to the steamline prior to the inboard MSIV. The SRV logic and solenoids are also classified and qualified as Class 1E per the IEEE Standards. This classification is also applied to the ADS function and other associated systems.

The SRV capacity is sized to maintain primary system pressure below the ASME Code design limits. Figure 3-17 illustrates the SRV and MSIV configuration.

The SRVs are located on the main steamlines between the RPV and the inboard MSIV. These valves provide three main protection functions:

- **Overpressure Safety Operation**: The valves function as spring-loaded safety valves and open to prevent RCPB overpressurization. The valves are self-actuated by inlet steam pressure.
- **Overpressure Relief Operation**: The valves are opened using a pneumatic actuator upon receipt of an automatic or manually initiated signal at the solenoid valve located on the pneumatic actuator assembly. This action pulls the lifting mechanism of the main disk, thereby opening the valve to allow inlet steam to discharge through the SRV. The SRV
The pneumatic operator is so arranged that, if it malfunctions, it does not prevent the SRV from opening when steam inlet pressure reaches the spring lift setpoint.

Eight of the 18 SRVs are designated for the ADS function, and are equipped with three separate solenoid valves powered by 125 VDC. The other non-ADS SRVs are each equipped with one solenoid valve powered by 125 VDC.

The SRVs are divided into five setpoint groups to relieve the RPV pressure in accordance with the RPV overpressure protection evaluation.

A separate pneumatic accumulator is provided for each SRV function and is located close to each SRV to supply pressure for the purpose of valve actuation. SRVs that are designated for ADS function are provided with one additional accumulator for each valve.

The SRVs can be operated individually in the power-actuated mode by remote manual switches located in the main control room. They are provided with position sensors which provide positive indication of SRV disk/stem position.

Each SRV has its own discharge line with two vacuum breakers. The SRV discharge lines are sized so that the critical flow conditions occur through the valve. This prevents the conditions in the discharge lines of waterhammer and pressure instability. The SRV discharge lines terminate at the quenchers located below the surface of the suppression pool (SP).

**Figure 3-16. Safety/Relief Valve**

- **Automatic Depressurization System (ADS) Operation:** The ADS valves open automatically or manually in the power actuated mode when required during a LOCA. The ADS designated SRVs open automatically as part of the Emergency Core Cooling System (ECCS) as required to mitigate a LOCA when it becomes necessary to reduce RCPB pressure to admit low pressure ECCS coolant flow to the reactor.
Feedwater System
(Nuclear Island)

Two 22-inch feedwater lines transport feedwater from the feedwater pipes in the steam tunnel through RCCV penetrations to horizontal headers in the upper drywell which have three 12-inch riser lines that connect to nozzles on the RPV (Figure 3-18). Isolation check valves are installed upstream and downstream of the RCCV penetrations, and manual maintenance gate valve are installed in the 22-inch lines upstream of the horizontal headers. Also shown in the figure are the interconnections from the RCIC, RHR and RWCU Systems.