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Design Features Unique to the U.S. EPR Technical Report

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ABSTRACT

The U.S. EPR is an evolutionary Pressurized Water Reactor (PWR) designed by AREVA. It is a four-loop plant with a rated thermal power of 4,590 MWt. The primary system design, loop configuration, and main components are similar to those of currently operating PWRs, thus forming a proven foundation for the design. The EPR is a global product with a basic set of common design features adaptable to the specific regulatory and commercial requirements of each country in which it is offered. The U.S. EPR version shares the basic set of design features such as four redundant trains of emergency core cooling, a containment and shield building, and a core melt retention system for severe accident mitigation, and is adapted to meet applicable U.S. regulatory and commercial requirements.

While the majority of structures, systems, and components of the U.S. EPR will be familiar to NRC personnel, there are some features that are unique. This report describes these unique components and features to provide a greater understanding. Included in this report is a description of the U.S. EPR four safety train concept, the reactor vessel heavy reflector, natural convection cooling of the control rod drive mechanism housing, the PZR pressure control system, the main steam relief train (MSRT), and the approach to mitigation for steam generator tube rupture and small break loss-of-coolant accidents.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
	All	Original Issue

Contents

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Nomenclature

Acronym/Abbreviation	Definition
CCWS	Component Cooling Water System
CHRS	Containment Heat Removal System
CRDM	Control Rod Drive Mechanism
CRDS	Control Rod Drive System
CVCS	Chemical and Volume Control System
DECL	Double Ended Cold Leg
ECCS	Emergency Core Cooling System
EFWS	Emergency Feedwater System
ESWS	Essential Service Water System
FPCS	Fuel Pool Cooling System
FW	Feedwater
IRWST	In-Containment Refueling Water Storage Tank
LHSI	Low-Head Safety Injection
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
MHSI	Medium Head Safety Injection
MSB	Main Steam Bypass
MSIV	Main Steam Isolation Valve
MSRCV	Main Steam Relief Control Valve
MSRIV	Main Steam Relief Isolation Valve
MSRT	Main Steam Relief Train
MSSV	Main Steam Safety Valve
OL-3	Okiluoto-3
PWR	Pressurized Water Reactor
PZR	Pressurizer
RCCA	Rod Cluster Control Assembly
RCPB	Reactor Coolant Pressure Boundary
RCS	Reactor Coolant System
RHRS	Residual Heat Removal System
RPV	Reactor Pressure Vessel
SB	Safeguard Building
SBLOCA	Small Break Loss of Coolant Accident
SG	Steam Generator

SGTR	Steam Generator Tube Rupture
SIS	Safety Injection System
SL	Steam Line
SSS	Startup and Shutdown System

1.0 INTRODUCTION

The U.S. EPR is an “evolutionary” reactor that incorporates several thousand reactor years of light water reactor design and operating experience worldwide. The EPR incorporates experience from the most recent designs: the N4 and KONVOI reactors currently operating in France and Germany, respectively. These designs benefited from the development of pressurized water reactors (PWR) since their introduction in the mid-1950s.

The U.S. EPR design uses as its basis the EPR design for the Okiluoto-3 (OL-3) plant under construction in Finland. The EPR design accounts for the expectations of utilities as stated in the “European Utility Requirements” (EUR) and the “Utility Requirements Document” (URD) issued by the Electric Power Research Institute (EPRI) in the U.S. The EPR complies with the recommendations and positions on major issues established by the French and German safety authorities. In 2004, the French safety authority certified that the EPR safety options comply with the safety enhancement objectives established for the development of new nuclear reactors.

In the process of submitting an application for design certification for the U.S. EPR in accordance with 10CFR52, the design will be modified to incorporate:

- U.S. quality assurance programs
- U.S. codes and standards
- U.S. Nuclear Regulatory Commission (NRC) guidelines and approved methodologies.

While the majority of structures, systems, and components of the U.S. EPR will be familiar to NRC personnel, there are some features that are unique. This report describes these unique components and features to provide a greater understanding. Specifically, these are:

- Four train (N+2) safety concept
- Reactor vessel heavy reflector

- Natural convection cooling of the Control Rod Drive Mechanisms (CRDM)
- PZR pressure control
- Main steam relief train
- Steam Generator Tube Rupture (SGTR) and Small Break Loss of Coolant Accident (SBLOCA) mitigation.

Design features and/or parameters are subject to modest changes up until the time of submittal of the Design Certification Application.

2.0 FOUR TRAIN SAFETY CONCEPT

The four train safety concept for the U.S. EPR is based on an N+2 philosophy. This philosophy provides:

- One train may be out of service for maintenance
- One train may fail to operate (single-failure criteria)
- One train might be removed from service as a consequence of the accident

This leaves one 100-percent capacity train available to mitigate the accident.

2.1 Safeguard Buildings

Each safety train is housed in a separate safeguard building (SB). The four SBs are located around the perimeter of the reactor building (Figure 2-1). SBs 1 and 4 are located on opposite sides of the reactor building. SBs 2 and 3 are located side-by-side, although structurally separated, underneath a common thick concrete cover.

The SBs are physically separated to protect the systems necessary to reach safe shutdown in the event of an external hazard such as an aircraft incident or an explosive pressure wave. The structurally separate buildings also protect the safety trains within each building from internal hazards, such as fire, high-energy line breaks, and/or flooding, within another SB.

Each SB is divided into radiological separate areas to reduce personnel exposure. The mechanical, or “hot,” area houses the systems that contain irradiated fluid. Conversely, the electrical, or “cold,” area houses those systems not expected to become contaminated, as well as the electrical, instrumentation and control equipment for the respective safety train systems. Separate heating, ventilation and air conditioning systems are provided for each of these areas.

2.2 Four Train Systems

Each SB houses one train of each of the following systems (Figure 2-2):

- Safety Injection System/Residual Heat Removal System (SIS/RHRS) which contains:
  - Medium Head Safety Injection (MHSI)
  - Low Head Safety Injection (LHSI)
- Component Cooling Water System (CCWS)
- Essential Service Water System (ESWS)
- Emergency Feed Water System (EFWS)

2.2.1 Safety Injection System/Residual Heat Removal System

The four trains of the SIS/RHRS inject borated water into the reactor coolant system (RCS) to compensate for the loss of RCS inventory or to remove residual (decay) heat from the RCS. The primary components of each train are the MHSI pumps, LHSI pumps, the RHR heat exchanger, an RCS cold and hot leg connection, and a common suction line that connects each pump to the In-containment Refueling Water Storage Tank (IRWST).

In injection mode, the MHSI and LHSI pumps take suction from the IRWST and deliver borated water to the RCS. Typically, this injection goes into the cold legs, but injection can be switched to the hot leg to limit the long-term boron concentration in the core following a loss of coolant accident (LOCA).

The RHRS is used primarily to bring the plant to cold shutdown and refueling conditions. In the event of an accident it is used for post-accident decay heat removal. This is accomplished by aligning suction from the RCS hot leg to the LHSI pump. The LHSI pump delivers fluid to the RHRS heat exchanger where the CCWS removes heat. The water in the RHR train is returned to the RCS via the connected cold leg.

Under normal conditions, all four trains are separate and independent. However, during online preventative maintenance of an LHSI train, valves are open to connect the discharge lines of train one to train two and of train three to train four. In the unlikely event of a large break LOCA coincident with preventative maintenance of an LHSI train and with an assumed single failure of an additional LHSI train, the connections ensure a more even distribution of safety injection to the cold legs.

2.2.2 Component Cooling Water System

The CCWS consists of four safety-related trains consistent with the four train concept. Each train of the CCWS is a basic system designed with a pump, heat exchanger, and associated valves and piping to remove heat from the RHRS and reject heat to the ESWS.

In addition to removing heat from the RHRS, each CCWS train provides the capacity to cool normal operating loads and other safety-related loads. The system is also designed with two dedicated trains that are part of the cooling path for severe accident events.

2.2.3 Essential Service Water System

The ESWS consists of four safety-related trains consistent with the four train concept. Each ESWS train contains a pump, heat exchanger, and associated valves and piping.

The ESWS is designed with four trains that remove the heat from the CCWS and rejects the heat to the ultimate heat sink (UHS) for the site. The ESWS is also designed with two dedicated trains that are part of the cooling path for severe accident events.

2.2.4 Emergency Feed Water System

The EFWS is a safety-related system that is only used during anticipated transient or accident conditions. The U.S. EPR is equipped with a dedicated system, the startup and shutdown system (SSS) that supplies feedwater (FW) to the steam generators (SGs) for SSS operation. The SSS reduces the number of operation cycles of the EFWS and increases the reliability of the entire FW system.

The EFWS has four separate and independent trains, each consisting of a water storage pool, pump, control valves, isolation valves, and interconnecting piping so that water from the storage pools can be pumped into the SGs, one division per SG. The storage pool for each train is a lined concrete structure inside each SB. A supply header connects the individual storage pools to the EFWS pumps. A discharge header is provided that allows any EFWS pump discharge to be aligned with any SG. Normally, the valves between trains are closed and operator action is required to change the flow path.

The EFWS differs slightly from the totally independent four train safety concept. Although the EFWS is capable of adequately supplying FW to the SGs in the event of a single failure of one EFW train with a second train out of service for maintenance, valves on the discharge header can be manipulated to redirect EFW flow from an affected SG to an intact SG. In addition, the valves on the suction piping can be opened to allow access to all EFW storage pools.

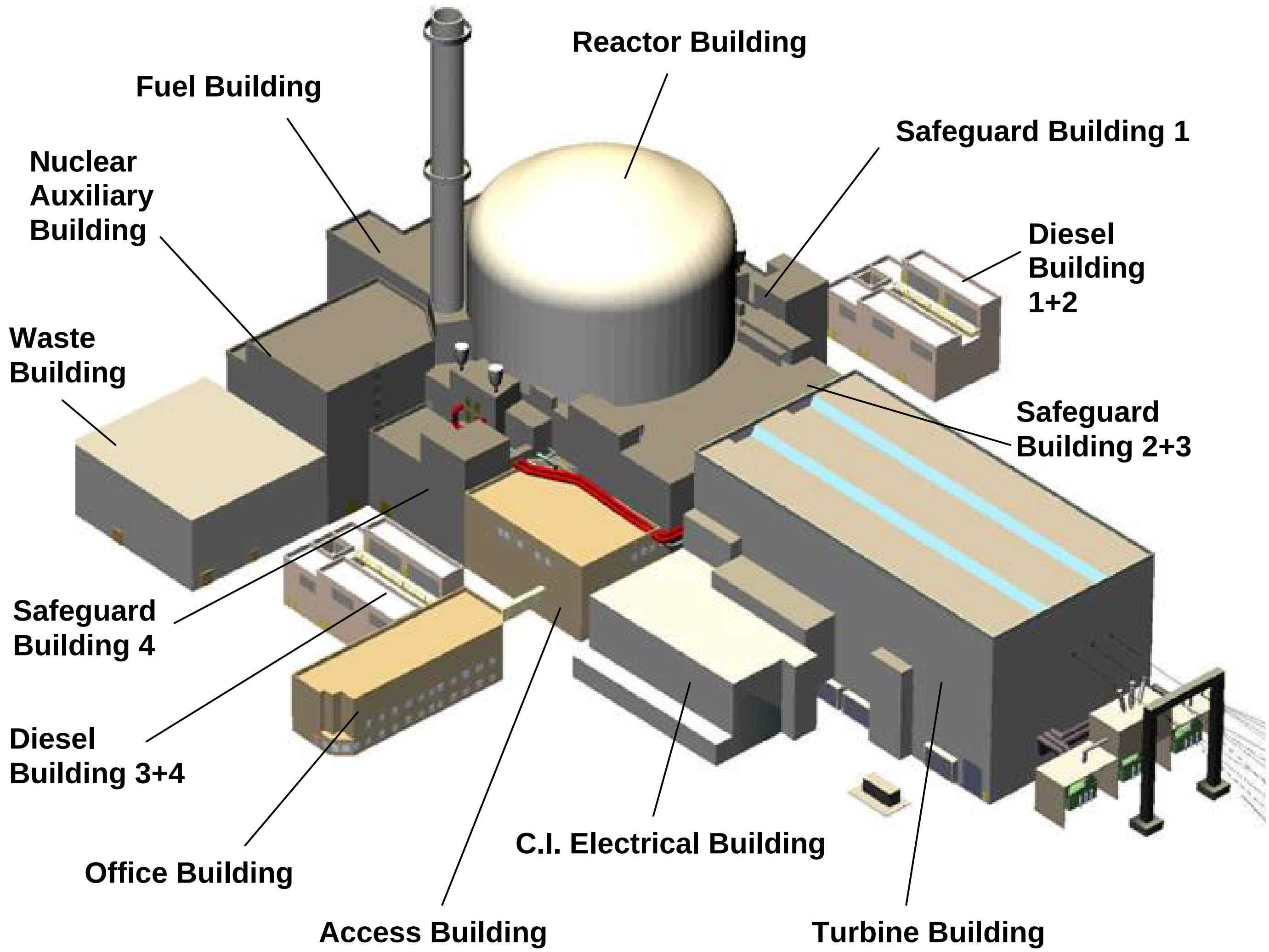

Figure 2-1 General U.S. EPR Layout

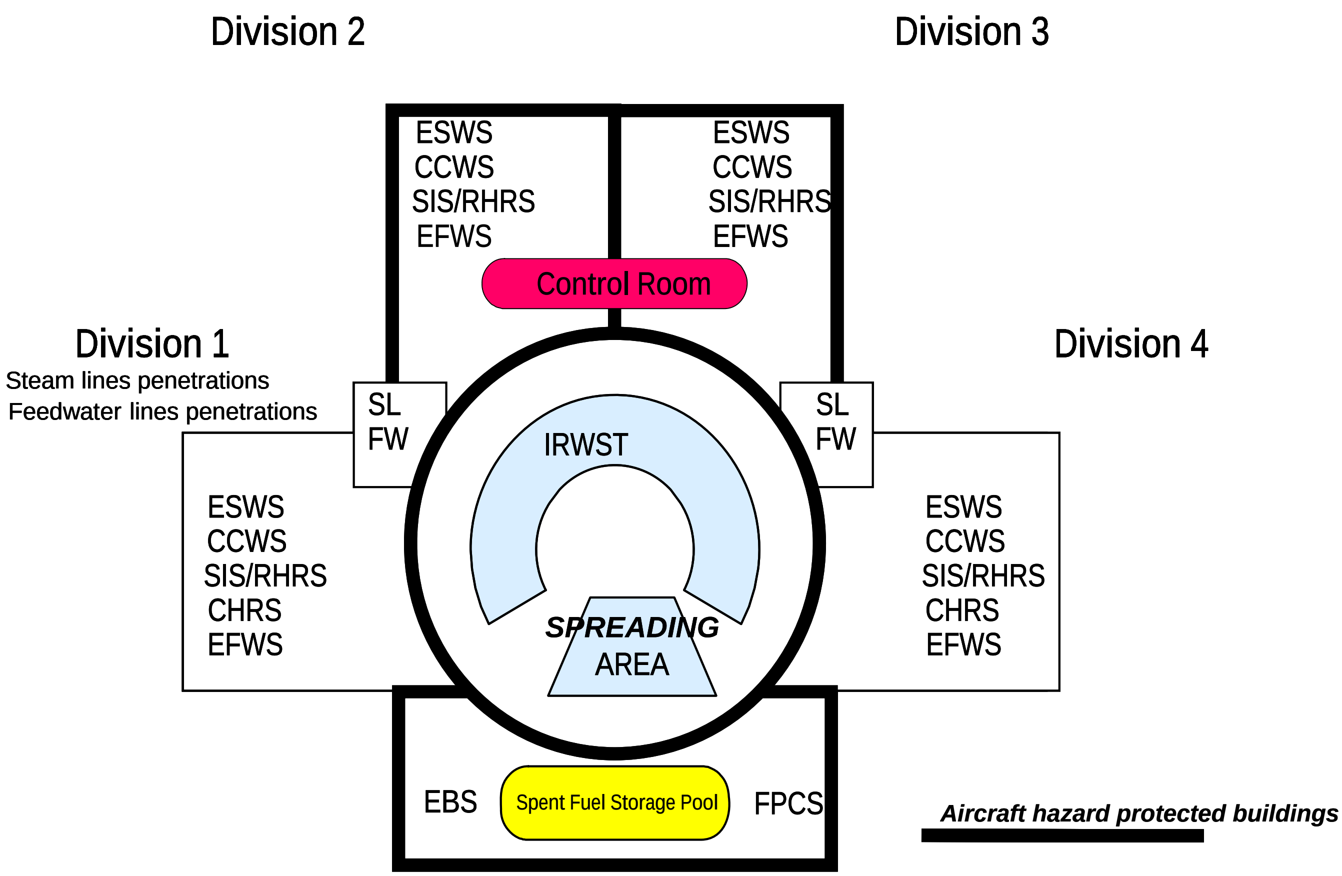

Figure 2-2 Safeguards Building - Divisional Separation

3.0 REACTOR VESSEL HEAVY REFLECTOR

3.1 Reactor Pressure Vessel Internals

The reactor pressure vessel (RPV) internals consist of lower and upper sections. Figure 3-1 shows a cross-sectional view of the RPV and internals. Most components of the internals are made of low carbon chromium-nickel stainless steel. The various connectors (e.g., bolts, pins, tie rods) are made of cold-worked chromium-nickel-molybdenum stainless steel. The various components of the RPV internals are described in the following sections.

3.1.1 Lower Internals

The lower internals consist of the core barrel, the lower core support structure, the heavy reflector, and the flow distribution device. These components are vertically supported by a ledge machined into the flange of the RPV. Their movement is vertically restricted inside the RPV by an annular hold-down spring located between the flanges of the lower and upper internals. This design prevents the lower internals from lifting off the RPV ledge. The lower internals remain in place during refueling, but may be removed for RPV in-service inspections by means of a lifting rig. Figure 3-2 shows a cross-sectional view of the lower internals.

3.1.2 Core Barrel

The core barrel is suspended from the RPV flange support edge and is centered at its upper flange with alignment pins. At the lower section, the lower radial support system restricts rotational and tangential movements, but allows radial thermal growth and axial displacements.

3.1.3 Heavy Reflector

The space between the multi-cornered radial periphery of the reactor core and the cylindrical core barrel is filled with a heavy reflector, which is an all-stainless steel structure. The purpose of this unique feature is to reduce fast neutron leakage, reduce the neutron fluency on the reactor vessel, and flatten the power distribution. The reflector is inside the core barrel above the lower core support plate. To avoid any welded or bolted connections close to the core, the reflector consists of stacked forged slabs that are positioned one above the other with keys (Figure 3-3). The slabs are restrained by tie rods bolted to the lower core support plate (Figure 3-4). The heavy reflector is dimensioned to accommodate expansion of the fuel assembly arrangement. Water cooling is provided by coolant channels (Figure 3-5) inside the heavy reflector to prevent excessive stress and deflections of the rings due to the heat generated inside this steel structure by absorption of gamma radiation.

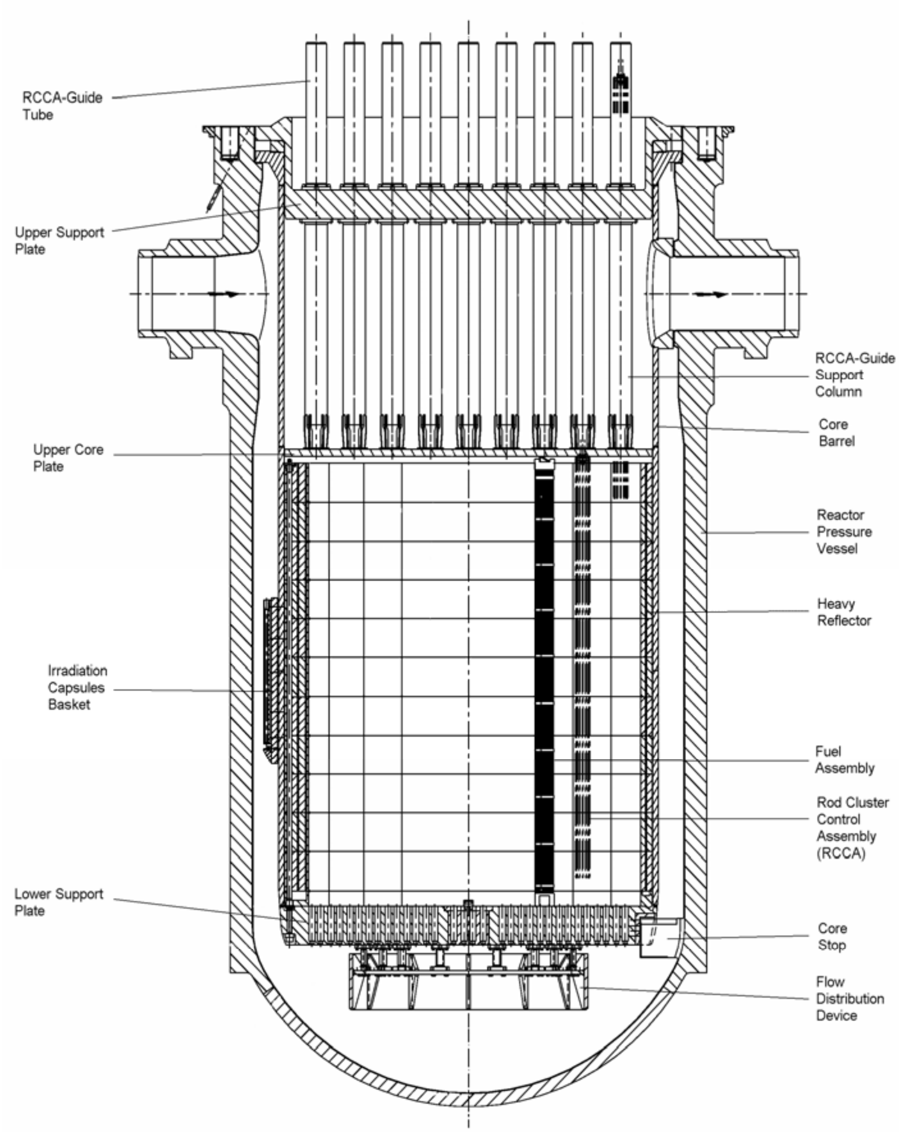

Figure 3-1 Reactor Vessel and Internals

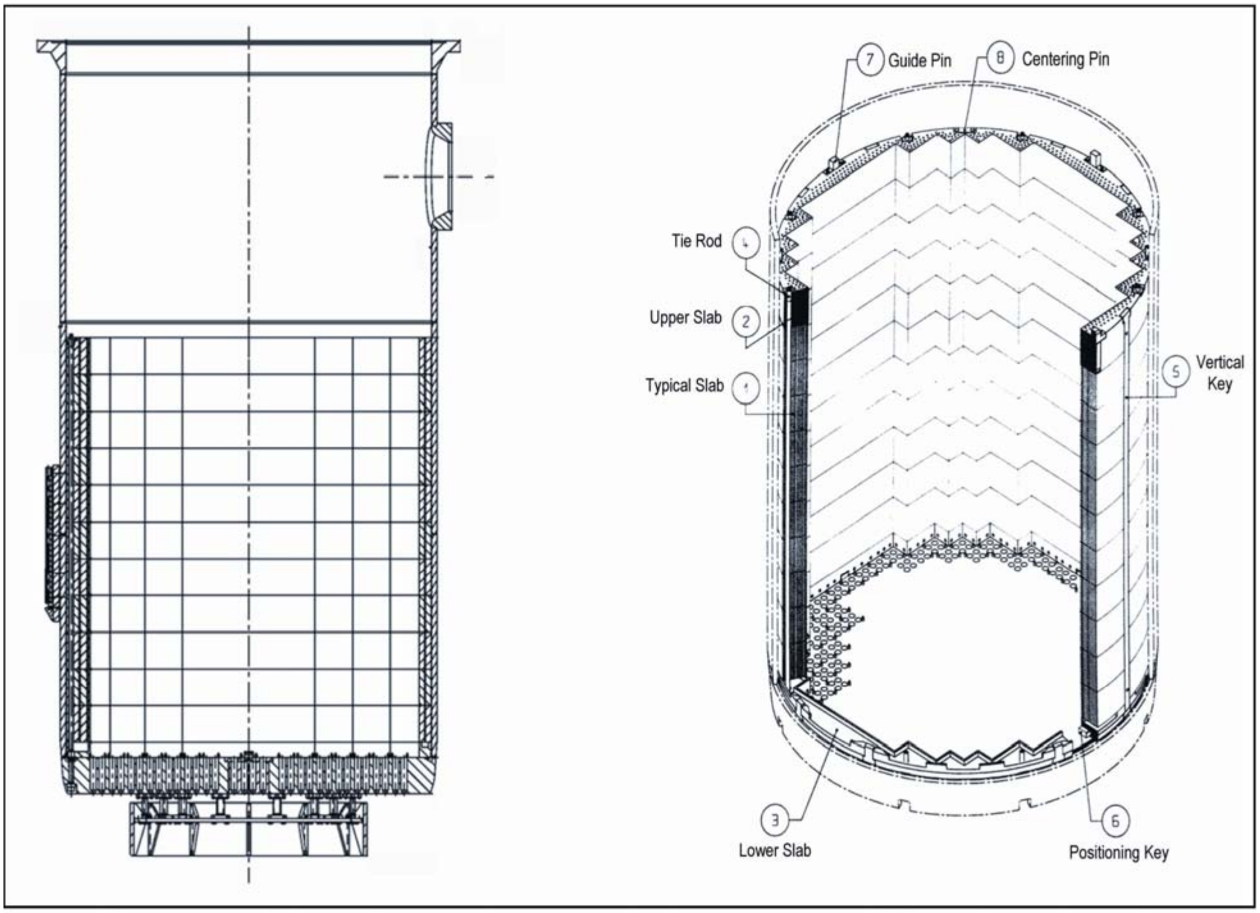

Figure 3-2 Lower Internals

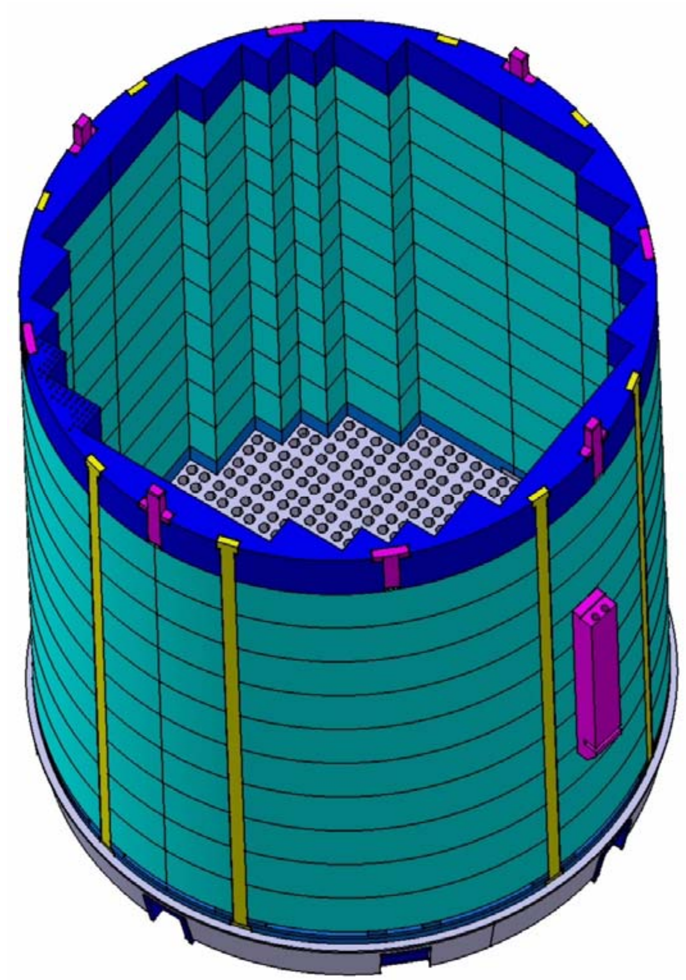

Figure 3-3 Heavy Reflector

- Provide the vertical restraint for the individual slabs
- Restrained at the top and bottom of the heavy reflector
- No threaded connections within the active core region

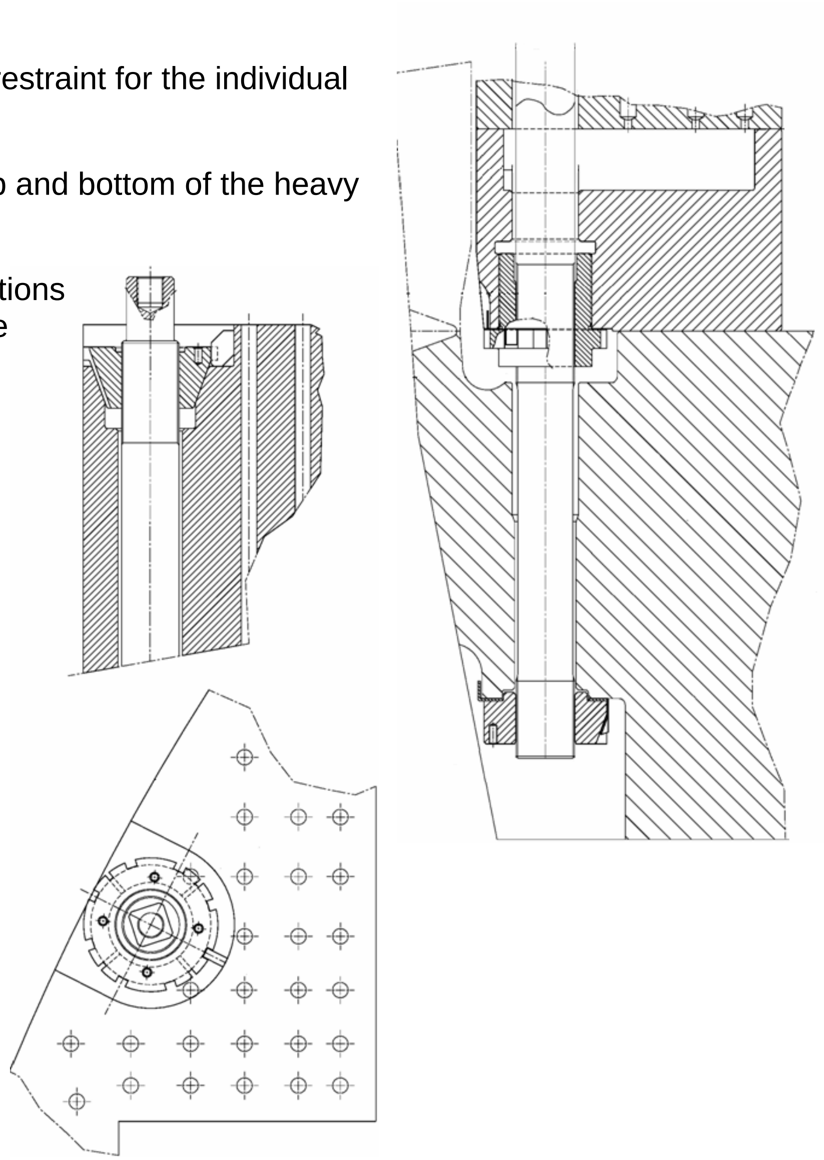

Figure 3-4 Heavy Reflector Tie Rods

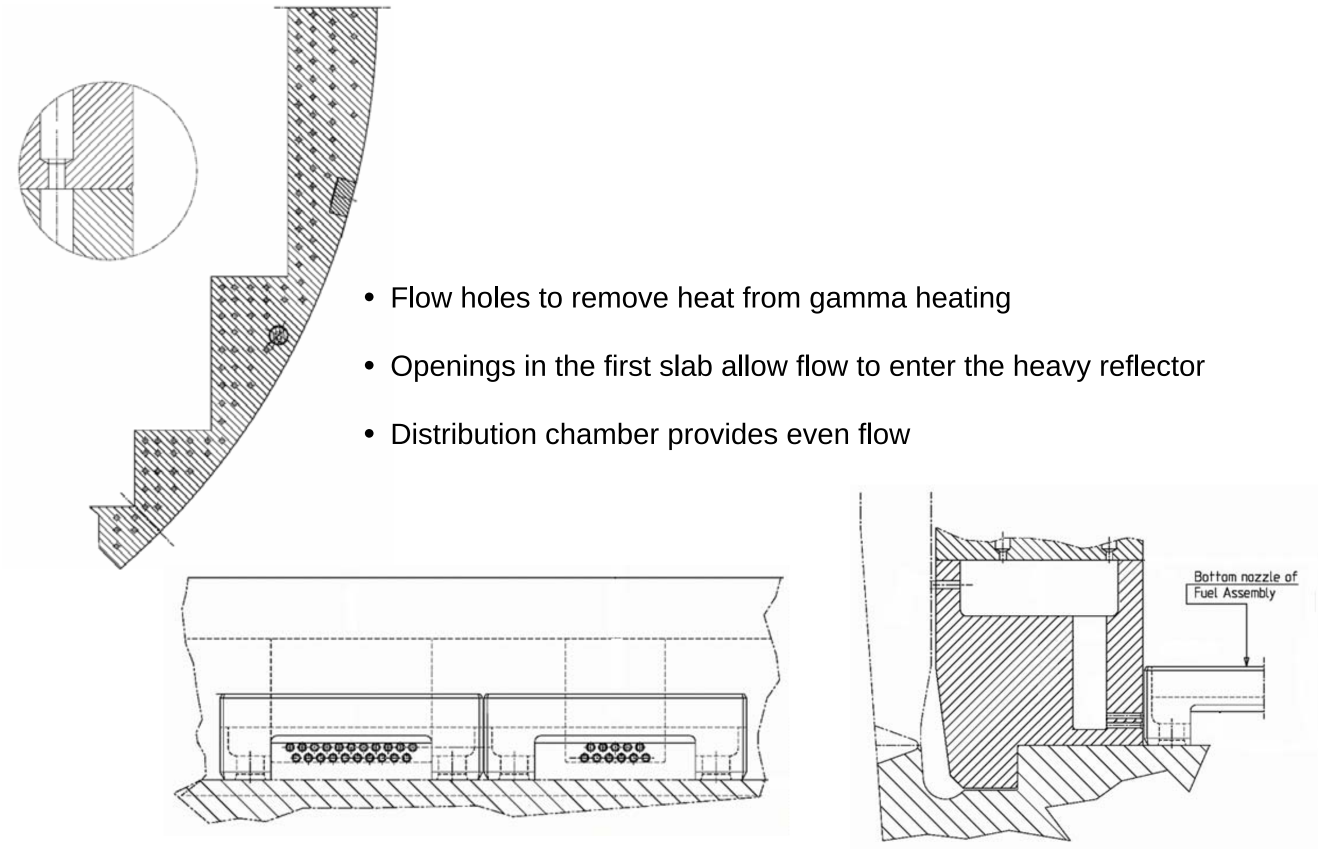

Figure 3-5 Heavy Reflector Cooling

4.0 CONTROL ROD DRIVE MECHANISM HOUSING

The control rod drive system (CRDS) includes the CRDM (Figure 4-1) and extends to the coupling interface with the rod cluster control assembly (RCCA). The CRDMs are mounted on top of the RPV closure head and are used to raise, lower, and maintain the position of the RCCAs. The U.S. EPR utilizes an electromagnetic jack CRDM. The CRDMs for the U.S. EPR employ natural circulation cooling. This unique design feature is described in subsection 4.3.

4.1 CRDM Function

The CRDMs have two main safety functions. First, the CRDMs enable rapid insertion of the drive rod and the attached RCCA by force of gravity when electrical power to the CRDM operating coils is interrupted. Secondly, the CRDM pressure housing forms a portion of the reactor coolant pressure boundary (RCPB) so that RCS inventory is maintained during all modes of operation.

The CRDMs also enable the withdrawal, insertion, and the holding of the RCCAs in a controlled manner during normal phases of plant operation. This controls core power level and power distribution in accordance with core reactivity requirements.

4.2 Major Components of the CRDM

The CRDM consists of four major components. These components are the drive rod, the pressure housing, the latch unit, and the coil housing.

4.2.1 Drive Rod

The drive rod is the connecting link between the latch unit and the RCCA. It consists of a hollow rod that is grooved transversely in the upper section over the required travel length. The drive rod is mechanically coupled to the RCCA.

4.2.2 Pressure Housing

The pressure housing (Figure 4-2) encloses all moving parts of the CRDM. It is attached to the RPV CRDM head adaptor flange via a flanged connection. It is tightened using necked-down bolts and nuts. The connection is sealed using metallic gaskets. The pressure housing forms part of the RCPB.

The pressure housing consists of two main sections; the latch unit and the position indicator. The latch unit section contains the latch unit and the flange that is used to connect the pressure housing to the head adaptor flange of the reactor vessel. The position indicator section is a long capped tubular section that contains the drive rod in the withdrawn position.

4.2.3 Latch Unit

The latch unit (Figure 4-3) is located in the lower section of the pressure housing and is used to control the position of the drive rod. It converts the magnetic forces generated by the coils outside the pressure housing into sequences of motion. The latch unit consists of a central sleeve (i.e., guide tube) as the load-bearing member, latch carriers with latches, stationary poles, and armatures. It employs two sets of latches with three individual latches per set. The latches engage with the drive rod grooves and control its position. The latches are coupled to magnet plungers by links and pins so that movement of the plungers causes the gripper latches to engage or disengage from the grooves in the drive rod. There are three stationary grippers and three moveable grippers in each latch unit. The moveable grippers are used to raise or lower the drive rod in steps equal to the pitch of the grooves in the drive rod. Using a defined energizing sequence of the coils, the drive rod can be raised or lowered, as required.

4.2.4 Operating Coil Assembly

The operating coil assembly (Figure 4-4) consists of a stationary gripper coil, a moveable gripper coil, and a lifting coil. It is combined with the position indicator coils and a sheet steel casing to form a single assembly that can be easily pulled off the pressure housing. The sheet steel casing is arranged around the position indicator coils so that natural air convection is generated via a chimney effect. This feature is addressed in Section 4.3 of this report.

Movement of the drive rod and the RCCA is controlled by the energizing sequence of the operating coils. The stationary and moveable grippers are engaged with the grooves on the drive rod when the corresponding operating coils are opened. During normal operation, the drive rod is held in place by the stationary grippers.

4.3 Natural Air Convection Cooling

4.3.1 Martensitic Material Pressure Housing

The CRDMs for the U.S. EPR employ natural air convection cooling. Natural air convection cooling is possible because of the design of the CRDM pressure housing. As noted in Section 4.2.2, the pressure housing consists of two main sections; the latch unit and the position indicator. The material used in the latch unit section of the pressure housing is martensitic stainless steel. Martensitic stainless steels are ferromagnetic, so permanent magnetic properties are exhibited. The martensitic stainless steel is used to reduce the magnetic resistance of the magnetic circuit. The field produced outside of the pressure housing in the working coils moves the armatures of the latch unit inside the pressure housing. The reduction of the magnetic resistance makes it possible to significantly reduce the necessary coil current without significant loss of magnetic forces between the armature and its adjacent pole. Therefore, the temperature of the CRDM pressure housing is reduced and natural air convection cooling is possible.

The temperature of the CRDM depends on the operating status of the plant and the CRDM itself (e.g., number of steps, reactor trip, and steady state). Forced cooling would be required if the coil temperature approaches 662°F steady-state or 842°F during rod motion. During normal operation, the wall temperature of the pressure housing is less than 482°F. After rod drop, the wall temperature of the pressure housing can rise to 536°F, which is well below the CRDM pressure housing design temperature of 662°F. Therefore, forced air cooling is not required for the U.S. EPR CRDMs. Subsection 4.3.3 describes operating experience with CRDM natural cooling.

4.3.2 Air Flow Path

For convection air cooling to be effective, the proper air flow path must be available. The cooling air flow path from the CRDMs through the reactor vessel closure head equipment is shown in Figure 4-5. The reactor vessel closure head equipment is a key component of the natural air cooling of the CRDMs. Ejection locking crosses, placed above the CRDMs, form missile protection after a CRDM pressure housing break. The open structure of the grating at the ejection locking crosses provides large openings that allow the up-streaming cooling air to pass without interference. Thermocouples are used to check exhaust air to ensure temperatures are maintained from 140°F to 158°F.

4.3.3 History of Natural Convection Cooling

The U.S. EPR CRDMs are the same design as the last CRDM series from the KONVOI plants. The only difference between the U.S. EPR CRDMs and the KONVOI CRDMs is the length of the pressure housing due to the increased RCCA length in the U.S. EPR. There are three German KONVOI operating plants, which employ a CRDM design that is similar to the U.S. EPR. Each KONVOI unit employs 61 CRDMs that have been operating for over 17 years. In addition, other German plants have employed natural convection cooled CRDMs in their plants for up to 35 years without failures.

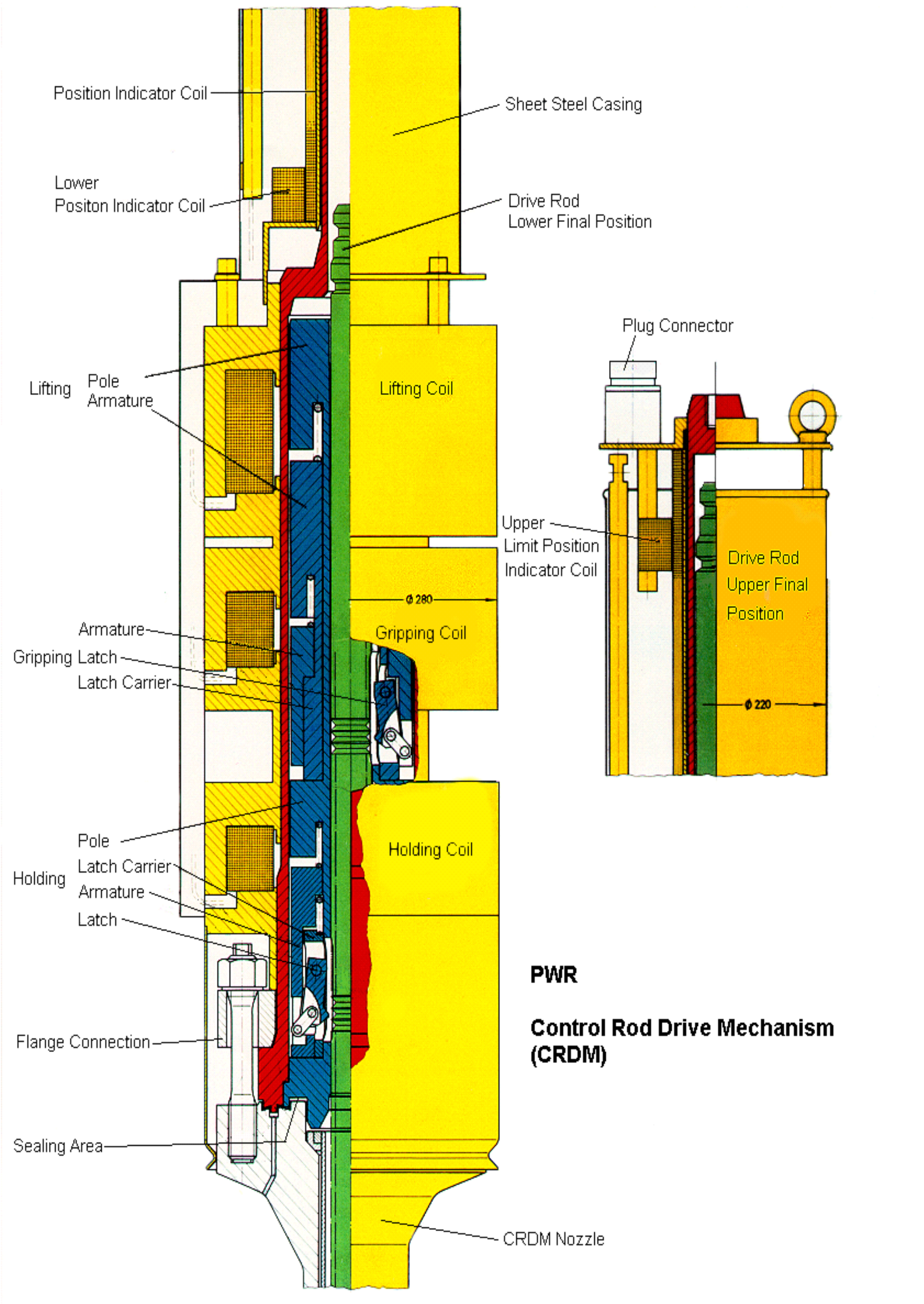

Figure 4-1 Control Rod Drive Mechanism

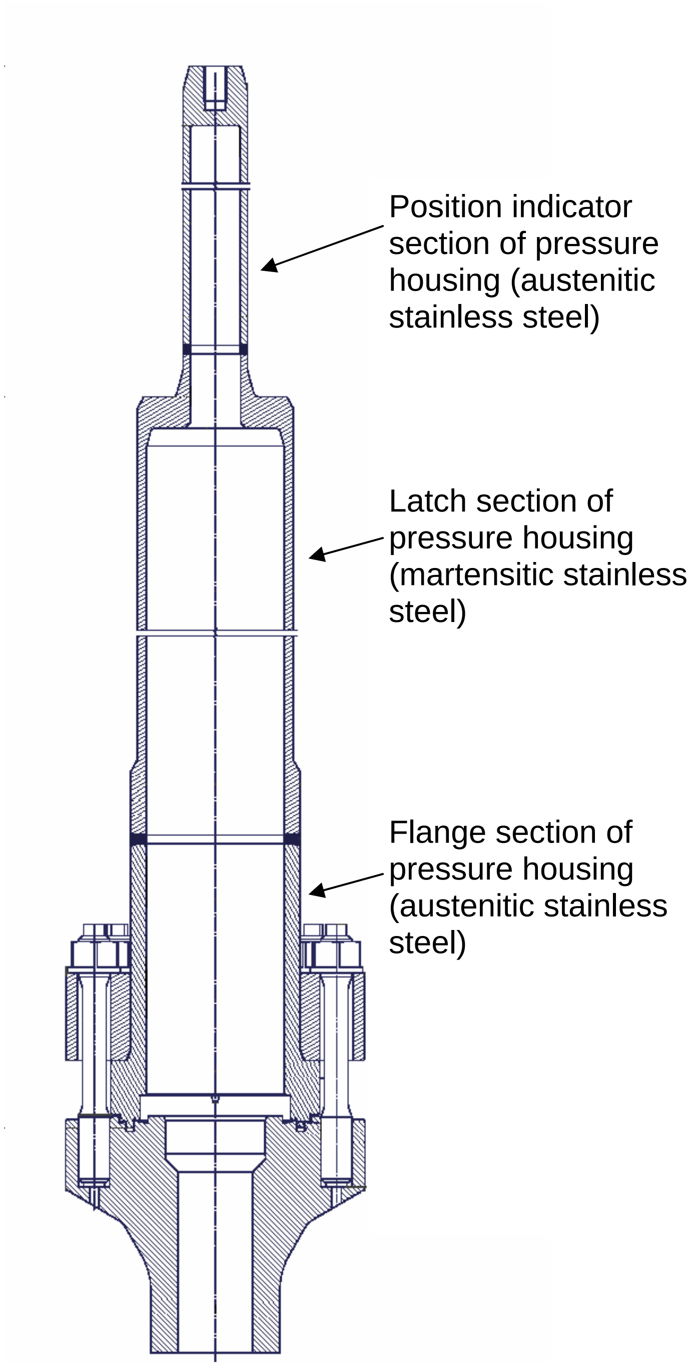

Figure 4-2   Pressure Housing

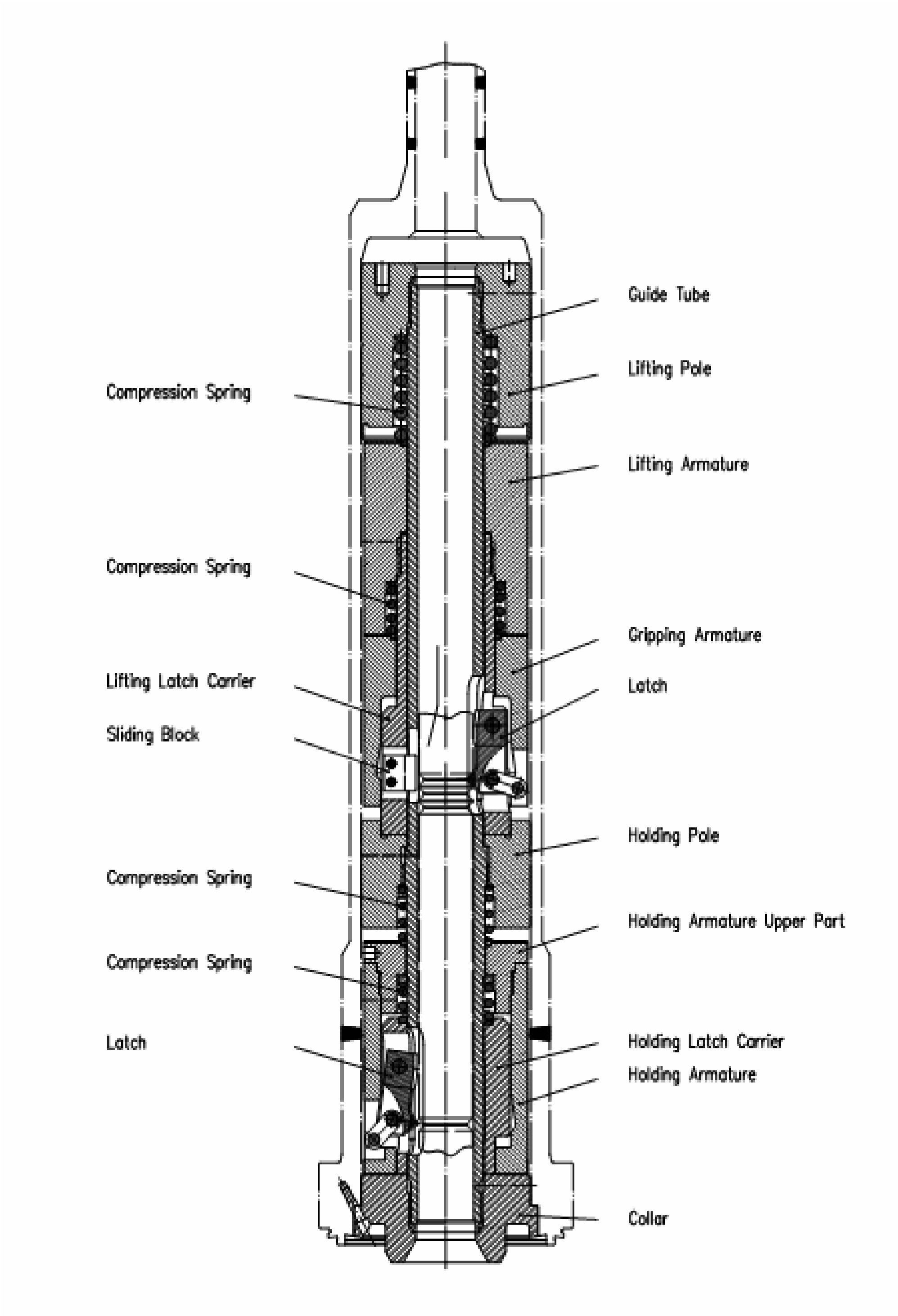

Figure 4-3 Latch Unit

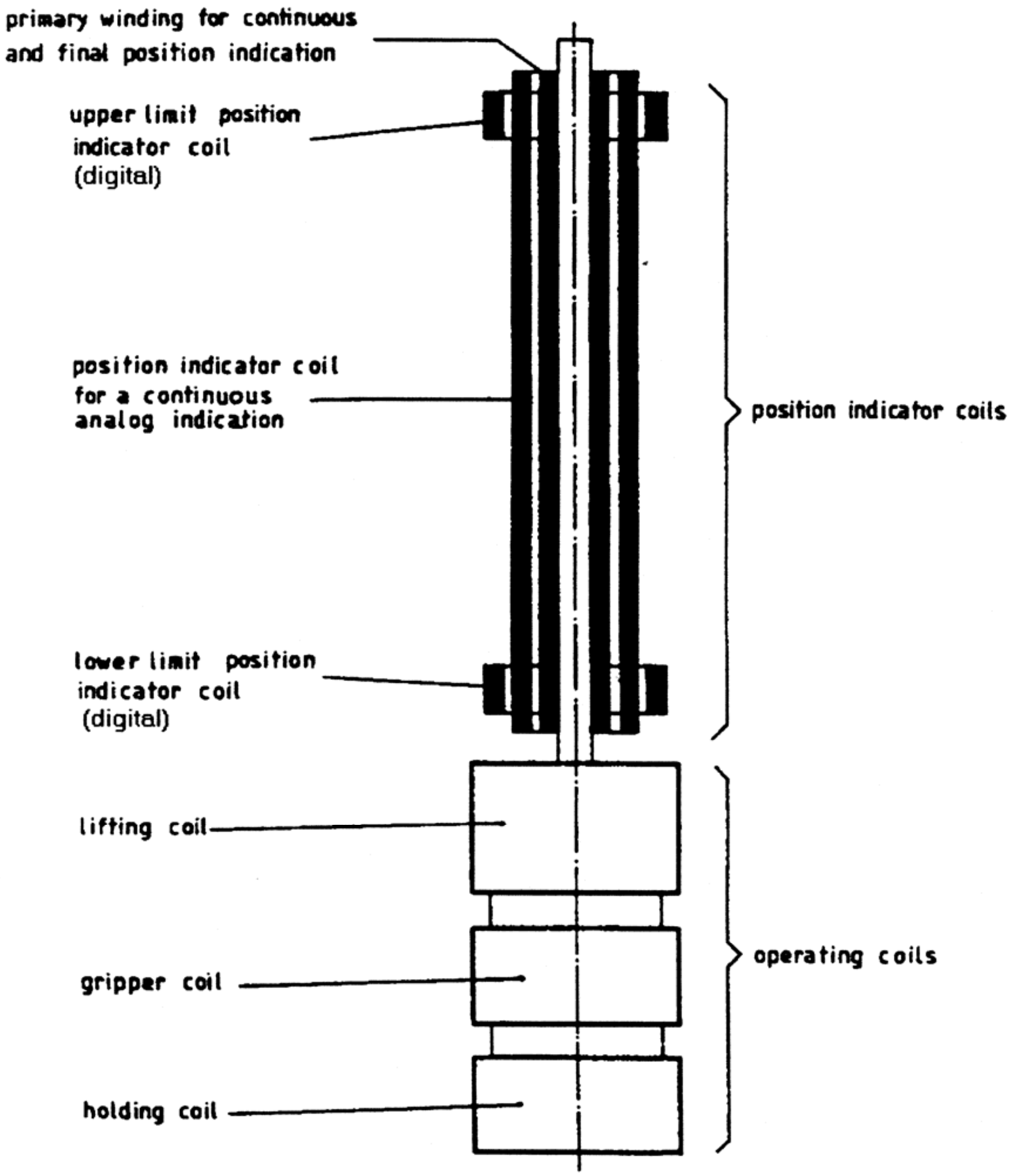

Figure 4-4 Operating Coil Assembly

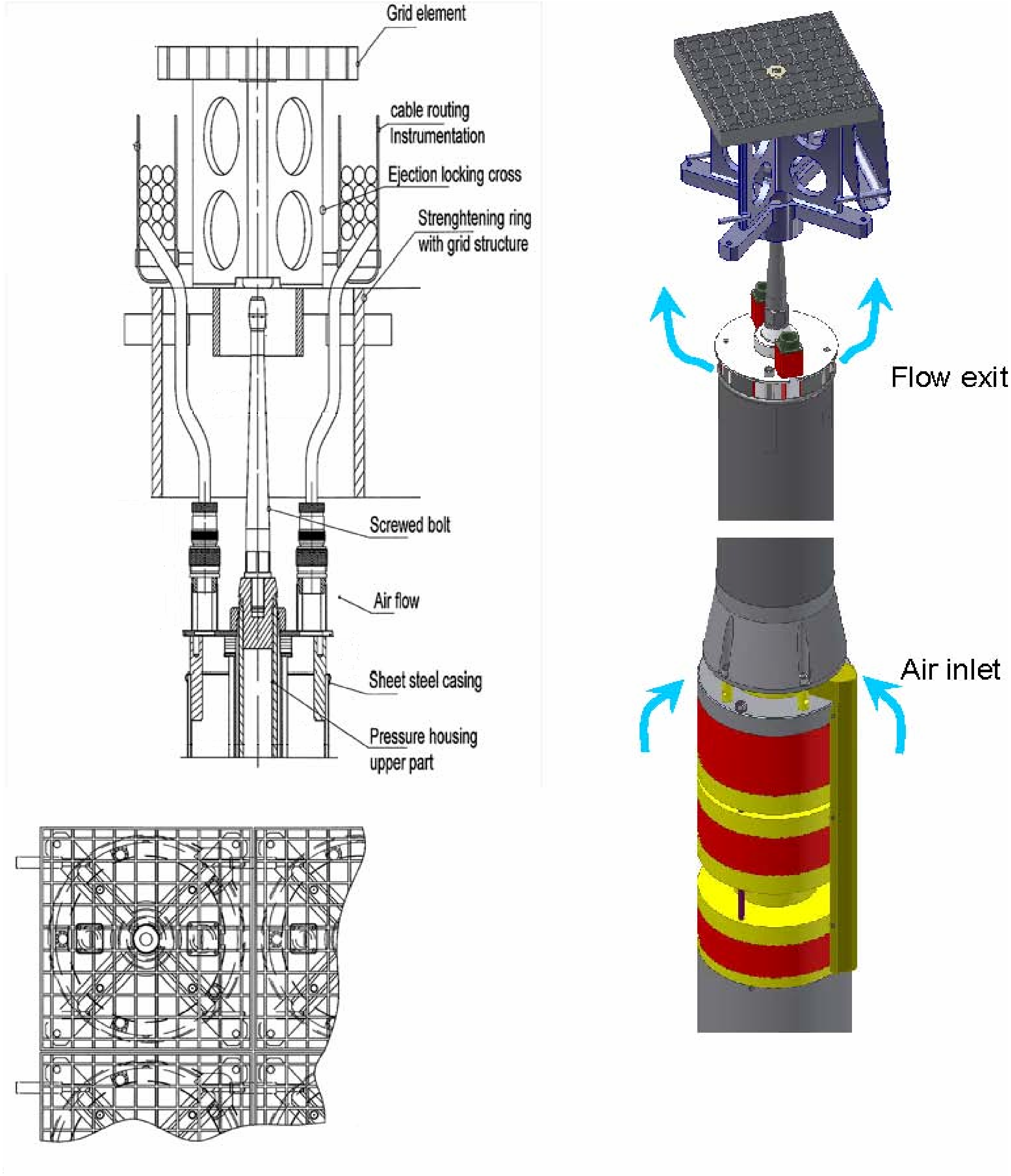

Figure 4-5 Natural Convection Air Flow Path

5.0 PRESSURIZER PRESSURE CONTROL

The pressure control within the pressurizer (Figure 5-1), specifically pressure reduction, has two unique aspects. These aspects consist of the pressurizer spray design and the pressurizer safety valves.

5.1 Pressurizer Sprays

The RCS pressure is controlled by the pressurizer. The pressurizer is equipped with heaters and sprays to control pressure. The U.S. EPR design provides a total of three pressurizer sprays; two are normal sprays and one is an auxiliary spray.

5.1.1 Normal Sprays

The two normal spray lines transport water from cold legs 2 and 3 of the RCS to the pressurizer. These lines are connected, respectively, to two lances that pass laterally through the spray nozzles that are mounted on the upper part of the cylindrical shell of the pressurizer. Each lance acts as a thermal sleeve within the spray nozzles and may be replaced from the outside of the pressurizer. Water is delivered into the steam bubble through the spray heads that are connected to the end of the lances.

Each spray line has a control valve to adjust the flowrate to reduce PZR pressure, as required. Each spray line also has a small bypass line with a manual valve to bypass the control valve. The bypass flow is designed to balance the boron concentration of the pressurizer fluid from the RCS. The continuous flow through the bypass line thermally stabilizes the spray lines.

5.1.2 Auxiliary Spray

The auxiliary spray line connects the pressurizer to the chemical volume and control system (CVCS). The auxiliary spray line is connected to a single lance that also passes laterally through a spray nozzle that is mounted on the upper cylindrical shell of the pressurizer.

The auxiliary spray is used primarily to cool and depressurize the pressurizer when the reactor coolant pumps (RCPs) are not in operation, which results in the unavailability of the normal sprays. However, the auxiliary spray is continuously available and may be used along with the normal sprays or in the event of a normal spray failure. The auxiliary spray line is not equipped with a bypass line. The line and nozzles are designed for the thermal transient that occurs when the auxiliary spray control valve is actuated.

5.2 Pressurizer Safety Relief Valves

The RCS of the U.S. EPR is protected from overpressure transients by three pressurizer safety relief valves (Figure 5-2). The pressurizer safety relief valves are connected to the relief valve nozzles and discharge to the pressurizer relief tank. A scoop is welded to the pressurizer wall that allows a seal to form upstream of each relief valve. This seal prevents hydrogen or other gases within the pressurizer from escaping to the relief tank.

Each pressurizer safety relief valve contains:

- One main safety relief valve
- A linear position indicator on top of the main valve
- Two spring-loaded pilot valves mounted in parallel
- One double solenoid valve equivalent to two solenoid valves mounted in series
- One connection block with isolation valves.

Table 5-1 provides design data for the pressurizer safety relief valves. One of the two spring pilot valves is used as a backup. All isolation valves for this pilot valve are closed. Each pilot valve requires one impulse line from the pressurizer as well as an exhaust and a drain line. The solenoid pilot valves also require a discharge line. The isolation and test valves are mounted on the main valve body.

5.2.1 Main Valve

The main valve is a controlled safety valve that operates on the relief principle. The system pressure is applied to the relief disc. As the system pressure increases, the closing force on the valve seat increases (Figure 5-3).

The main valve responds only to the response of either the spring pilot valves or the actuation of both solenoid pilot valves. The spring pilot valves are designed to open when there is an increase in system pressure above a preset limit and to close when the system pressure drops below this limit. Manual operation is required for the solenoid pilot valves.

5.2.2 Spring Loaded Pilot Valves

The spring loaded pilot valves consist of three subassemblies within a common body. These subassemblies are the converter, pilot, and actuator.

The converter subassembly converts system pressure to linear motion. System pressure is applied via a sensing line to the interior of the converter bellows. At the bottom of the converter, a spring disk assembly exerts a force that balances the force generated by the system pressure on the cross-sectional area of the converter bellows.

The pilot subassembly consists of a pressurizing piston with a seat for the relieving disk. The bottom of the pressurizing piston has latches that engage matching latches on the converter. The converter rod is guided inside the pressurizing piston and acts on the relieving disk. The annular space around the rod provides an exhaust path for venting the chamber to an area of lower pressure.

The actuator subassembly consists of a spring-loaded plug with a seat and backseat. As the plug lifts off the seat, a path forms to relieve the pressure from the main valve control chamber.

During normal operation, the spring pilot and the main valve are in the closed position. The spring connected to the bottom of the converter subassembly provides the force that keeps the converter resting on its bottom support. During this time, the pressurizing piston and the relieving disk of the pilot subassembly are at their lower limits. As a result, the control chamber above the plug in the actuator subassembly is exposed to system pressure. This pressure keeps the plug against the seat, and the main valve remains closed.

If the system pressure increases, the hydraulic force inside the converter bellows also increases. This pressure compresses the disk spring, which causes the converter to move upward. If the pressure increase is sufficient, the converter rod travels enough to completely unseat the relieving disk. This depressurizes the chamber above the actuator subassembly, which allows the plug to travel to the backseat. This relieves the pressure on the main valve and allows it to open.

As flow passes through the relief valve, the system pressure begins to decrease. This allows the converter bellows to contract and the spring to pull the converter disk and rod downward. The relieving disk, which is then only subjected to the force of its spring, reseats. This pressurizes the chamber above the actuator subassembly, which causes the plug to move back to its seat. Pressure is restored to the main valve control chamber, which causes the valve to close.

5.2.3 Solenoid Pilot Valves

The solenoid pilot valves are one double solenoid valve mounted onto the main valve body. The double valve is controlled as two separate valves in series to prevent a spurious failure of one valve from opening the main valve. To provide single failure protection in the event that a solenoid valve fails to open, each pressurizer safety relief valve is equipped with solenoid pilot valves.

Solenoid pilots act directly on the control chamber of the main valve. When both solenoid valves are opened, pressure is relieved from the main valve disk, causing it to open. If either solenoid valve closes, pressure is restored to the main valve control chamber, and the main relief valve closes.

The solenoid pilot valves allow the pressurizer safety valves to be manually operated to depressurize the RCS in the event that pressurizer sprays are unavailable. The solenoid pilot valves also allow the pressurizer safety valves to be automatically opened by the protection system to prevent RCS overpressurization during low-temperature operation. Because the solenoid pilot valves are in series, a single-failure of one solenoid pilot valve would prevent the safety valve from operating as desired. Consequently, two pressurizer safety valves are normally used to provide low-temperature overpressure protection.

Table 5-1 Pressurizer Safety Relief Valve Design Data

Parameter	Value
Quantity of Valves	3
Design Pressure	2790 psig
Design Temperature	734°F
Pressure Setpoint (Valves 1/2/3)	2450 / 2525 / 2600 psig
Relief Capacity	661,400 lbm/hr @ 2535 psig

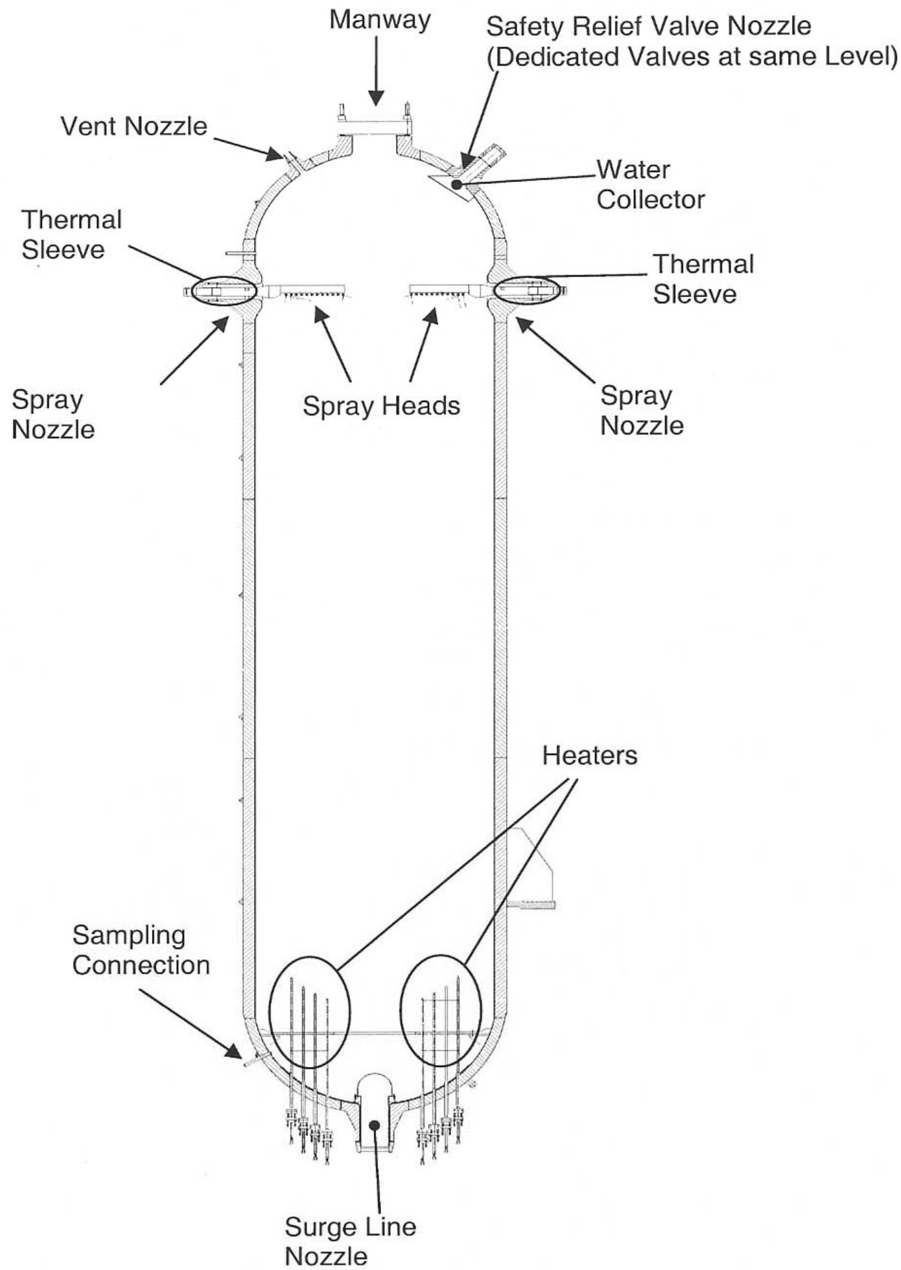

Figure 5-1   Pressurizer

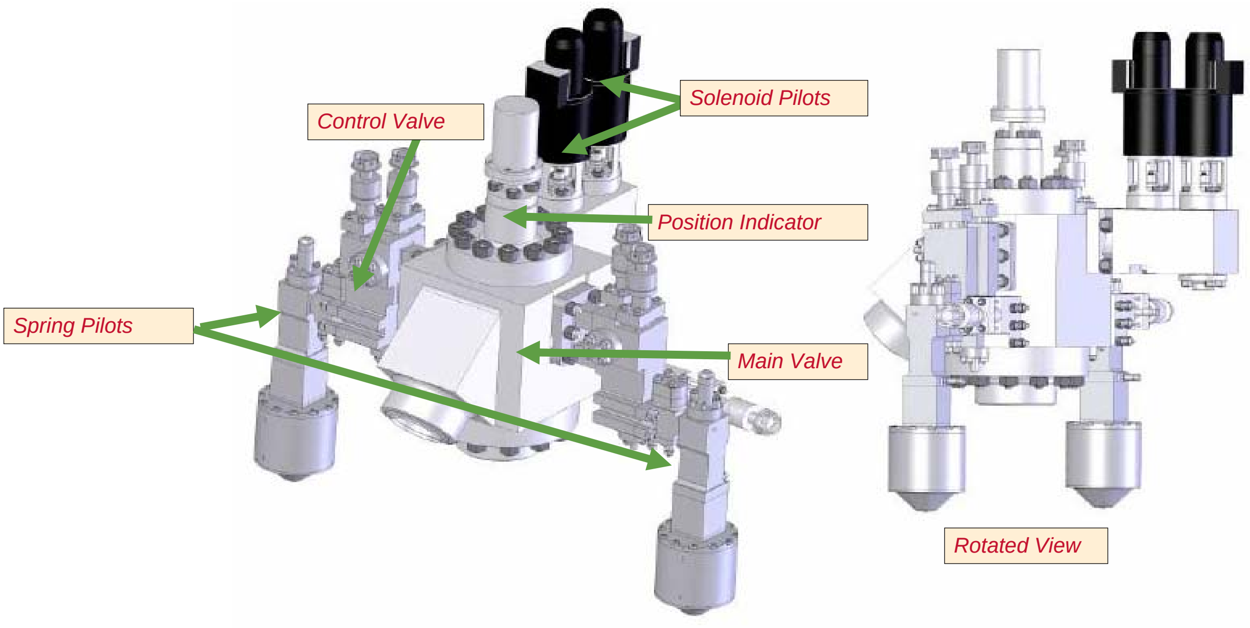

Figure 5-2 Pressurizer Safety Relief Valve Arrangements

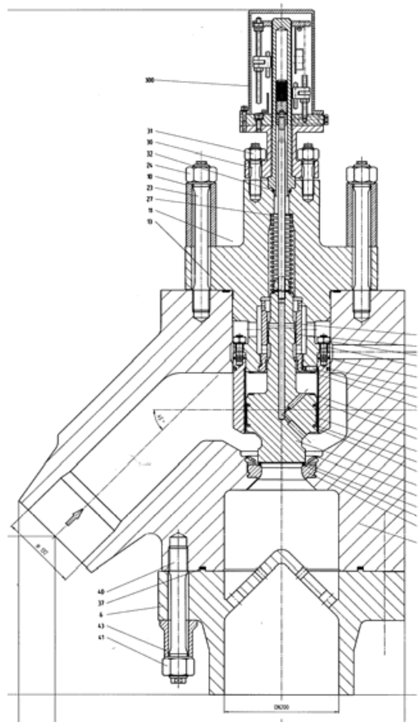

Figure 5-3 Main Valve Arrangement

6.0 MAIN STEAM RELIEF TRAIN

The main steam line (SL) from each SG is provided with one Main Steam Relief Train (MSRT) located outside of containment and upstream of its Main Steam Isolation Valve (MSIV) and Main Steam Safety Valves (MSSVs) as shown in Figure 6-1.

6.1 MSRT Function

The function of the MSRTs is to provide overpressure protection for the SG secondary side pressure boundary and attached piping, RHR capability, and isolation/containment of the SG secondary side, when required.

6.1.1 Overpressure Protection

The MSRTs are considered a part of the SG secondary side overpressure protection. The MSRT, in conjunction with the two MSSVs, provides sufficient relief capacity during anticipated transients to prevent system pressure from exceeding 110 percent of the design pressure. The minimum relief capacity of each MSRT is 50 percent of the normal operating full load steam flow and each of the MSSVs is capable of relieving a minimum of 25 percent of the normal operating full load steam flow.

The MSRT setpoint is established at 1370 psig to minimize challenges to the MSSVs. The capacity and setpoints of the MSRT and MSSVs are established so that once reactor trip occurs, either the MSSVs or the MSRT acting alone prevents system pressure from rising above 110 percent of design pressure upon full loss of load.

6.1.2 Residual Heat Removal

During shutdown and accident conditions the MSRTs remove residual heat from the RCS by venting steam into the atmosphere. In the event that the Main Steam Bypass (MSB) system is unavailable during shutdown, the MSRTs are capable of removing residual heat via controlled steam release to the atmosphere from hot shutdown conditions until the RHRS entry conditions are reached. The MSRT capacity enables two of the four trains to provide sufficient heat removal to cool the primary side to the RHRS entry conditions within 36 hours.

The MSRTs also provide RHR in response to small, intermediate break LOCAs, which include SGTR. Although it is preferred to transfer steam to the condenser, especially for SGTR mitigation, the MSRTs provide safety-related equipment to cool and depressurize the primary system down to the MHSI pressure (which is termed partial cooldown).

6.1.3 Isolation / Containment during Steam Generator Tube Rupture Event

As discussed in 6.1.2, the MSRTs enable a partial cooldown of the primary side to the MHSI pressure. In the event of an SGTR, the MSRT setpoint for the affected SG, as detected by a high radiation signal in the associated main SL, is increased to just below system design pressure, which is 1435 psig. This process follows the completion of the partial cooldown to minimize steam release, and thus radioactivity, from the affected SG. The MSRTs of the unaffected SGs remain available for continued heat removal down to the RHRS entry conditions.

6.2 MSRT Design Requirements

The MSRT components up to and including the main steam relief control valve (MSRCV), are designed to Quality Group B (ASME Class 2) requirements. Although the piping and silencer equipment downstream of the MSRCV are not required to achieve the functions discussed in Section 6.1, the equipment is designed to Quality Group C (ASME Class 3) requirements to ensure the functions are not affected by failures within this equipment.

Portions of the MSRT required to perform the safety functions are located within a Seismic Category I structure (i.e., main steam valve room within each SB) to provide protection of the equipment from natural phenomena and external hazards. The MSRT equipment is designed to accommodate the effects of, and to be compatible with, the environmental conditions in these structures associated with normal operation, maintenance, testing, and postulated accidents. The location of the MSRT within these structures separates each MSRT from the remaining three trains.

The MSRT components are powered from the Class 1E Emergency Power Supply system. The MSRT components are also powered from the station batteries to ensure initial availability of two hours during the loss of both onsite and offsite power with Divisions 1 and 4. These two divisions are also capable of being supplied with power from the station blackout diesels for long term conditions.

6.3 MSRT Components

Each MSRT includes a normally closed Main Steam Relief Isolation Valve (MSRIV) in series with an MSRCV and discharges through a silencer.

6.4 Main Steam Relief Isolation Valve

The MSRIV is a self-medium operated angle globe valve (Figure 6-2). The valve is solenoid actuated and pilot operated for quick response and rapid opening in performance of its overpressure protection function as a power operated relief valve.

During normal operation, the valve is kept closed by a spring located above the actuator piston with balanced steam pressure (i.e., at operating line pressure) above and below the actuator piston. The valve opening is controlled by depressurization of the control volume above the actuator piston. The actuator is provided with one set of four solenoid-driven pilot valves arranged with two pilots in series within each of the two redundant control lines (manifolds). These lines are connected to the control volume above the actuator piston. Upon receipt of an actuation signal, the solenoids are opened to admit steam into the pilot valves. This causes the pilots to open, venting the steam from the upper chamber of the actuator piston into the atmosphere. The steam pressure below the actuator piston results in an applied force greater than the force applied over the valve disc and the spring above the piston, resulting in the valve opening.

When the valve actuation signal clears, the solenoids are closed. This removes the steam pressure from the pilot valves, which causes the pilots to close, repressurizing the control volume above the actuator piston. With the pressure above and below the actuator piston balanced and aided by the force applied by the spring above the actuator piston, the valve is forced closed.

For overpressure protection, the MSRIV is set to open at a set pressure of 1370 psig. This is based on signal from four redundant pressure transmitters located on the main SL upstream of the MSRT. The setpoint is established at a pressure lower than that of the MSSVs to minimize challenges to the MSSVs during mild pressure transients. The valve opening time is limited to a maximum of 1.8 seconds, which includes an allowance for 1.5 seconds of deadtime.

The MSRIV controls are configured to preclude opening due to a single failure. The MSRIV is sized to limit maximum flow to 110 percent of the minimum certified flow to minimize potential overcooling of the primary side in the event of spurious valve opening. In addition, the MSRIV is designed to fail closed when there is a loss of electrical power or steam pressure.

6.5 Main Steam Relief Control Valve

The MSRCV is a motor operated angle globe type control valve. During normal operation, this valve is maintained open (either partially or fully, depending on power level), in “stand-by” position. As long as the MSRIV is closed and no other protection system actuation signals are present, the position of the MSRCV is maintained as follows:

- For power levels between 0 percent and 20 percent normal power, the valve is positioned at 40 percent open.
- For power levels from 20 percent to 50 percent normal power, the valve positioned is varied linearly from 40 percent to 100 percent open.
- For power levels above 50 percent normal power, the valve is positioned fully open.

These valve positions are selected to minimize overcooling of the RCS in the event of spurious opening of the MSRIV while ensuring sufficient relief capacity for overpressure events. The valve positions are maintained for the MSRT to meet overpressure protection requirements. The MSRCV controls for maintaining the valve position ensure that the valve remains open during all operating conditions for which overpressure protection of the SG secondary side and main steam system is required.

Upon receipt of an actuation signal from the protection system, the MSRCV is automatically switched to “SG pressure control” mode. In this mode, the MSRCV modulates to control the SG pressure at the specified setpoint pressure. This setpoint is adjusted by the protection system to produce a controlled cooldown and depressurization of the RCS to below MHSI dead-head. The MSRT can be used to cool to RHRS entry conditions.

In the event of spurious opening of the MSRIV, the MSRCV can be manually closed from the control room to provide a backup for isolation of the SG secondary side. The valve is specified to close from the full-open position within 40 seconds.

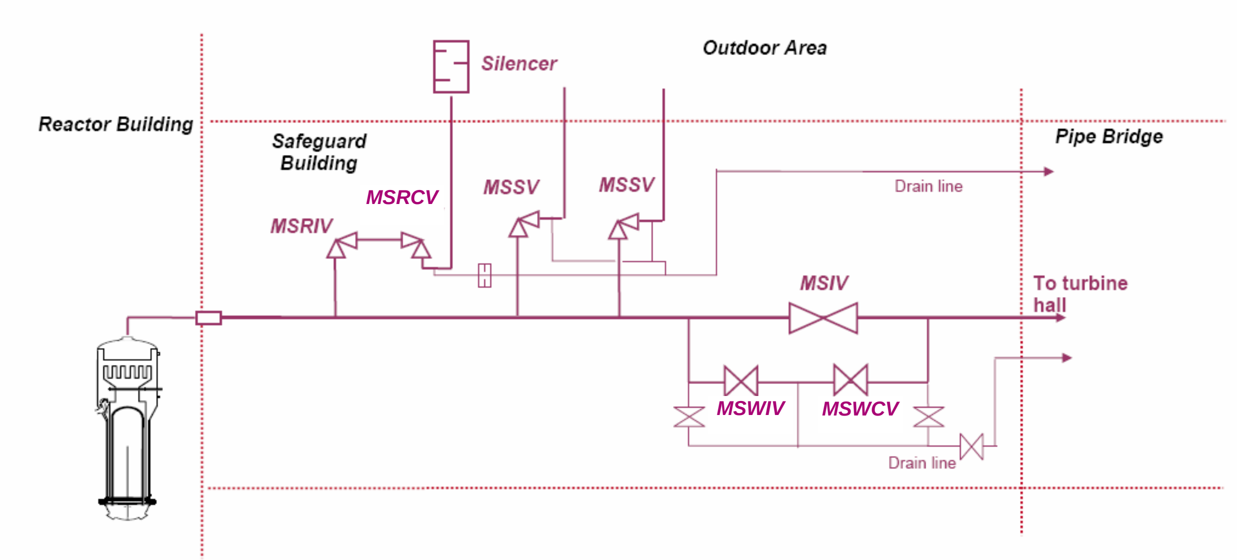

Figure 6-1 Main Steam Relief Train

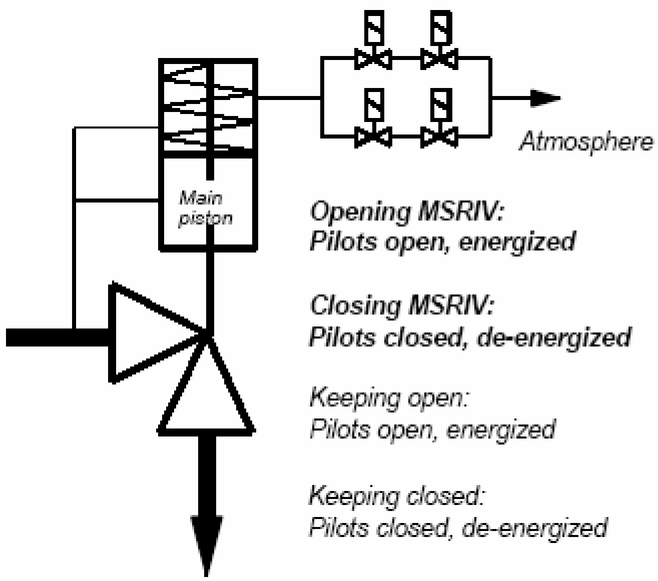

Figure 6-2 Main Steam Relief Isolation Valve

7.0 STEAM GENERATOR TUBE RUPTURE AND SMALL BREAK LOSS OF COOLANT ACCIDENT MITIGATION

The U.S. EPR employs a number of features to mitigate postulated SGTRs and SBLOCAs. Although the mitigation strategies are the same as current PWR, the combination of features, including system automation, are unique to the U.S. EPR.

7.1 Design Basis Requirements

The design basis requirements imposed on the U.S. EPR for mitigating SGTR events are:

- Radiation doses to personnel in the main control room and to the public at the exclusion area boundary are within applicable regulatory limits
- Overfill of the affected steam generator is precluded to prevent introduction of liquid into the SLs
- No operator action is required to mitigate the event prior to 30 minutes.

The design basis requirements imposed on the U.S. EPR for mitigating SBLOCA events are:

- Meet acceptance criteria specified in 10CFR50.46
- Radiation doses to personnel in the main control room and to the public at the exclusion area boundary are within applicable regulatory limits
- No operator action is required to mitigate the event prior to 30 minutes.

7.2 Mitigation Strategies

The mitigation strategy for an SGTR is similar to existing PWRs:

- Add liquid to the RCS to make up for the leakage through the ruptured tube
- Cool and depressurize the RCS to reduce the leak rate
- Isolate the affected SG to terminate any release of radiation and maintain doses to the public and main control room personnel within limits

- Prevent liquid discharge through main steam safety valves on the affected SG to ensure that the affected SG remains isolated from the environment.

To preclude the possibility of liquid discharge through the main steam safety valves on the affected SG, which could lead to significant release of fission products to the atmosphere, the shutoff head of the MHSI pumps is set to a value less than the lift setpoint of the MSSV. This means that operator action is not required to throttle MHSI flow to prevent SG overfill or MSSV lift.

Furthermore, isolation of the affected SG is automated as part of the protection system. After the RCS is cooled and depressurized (see discussion of partial cooldown function, below), the affected SG is identified based on high-high secondary liquid level or high N-16 radiation trip is automatically isolated by the protection system.

The LOCA mitigation strategy for the U.S. EPR is similar to the existing fleet of PWRs. A combination of safety injection, passive accumulators and LHSI are used to ensure core cooling during a postulated LOCA.

However, the selection of MHSI for mitigation of SGTR has an affect on the ability to mitigate certain SBLOCAs. For certain break sizes, the energy removal through the break is insufficient to automatically depressurize the RCS. In these cases, heat is transferred to the SG. The primary system pressure equilibrates to a value near SG secondary pressure. If the SG pressure setpoint is greater than the shutoff head of the MHSI pumps, no MHSI liquid enters the RCS (Figure 7-1).

Consequently, the U.S. EPR employs automatic depressurization of the SGs to ensure adequate MHSI flow into the RCS. Specifically, upon a low-low pressurizer low pressure signal (used to actuate SI), the SGs are depressurized to 870 psia at a controlled rate using the MSRT. The depressurization rate is controlled by changing the secondary pressure setpoint of the MSRT linearly from the post-trip setpoint (approximately 1385 psia) to 870 psia in approximately 20 minutes, which is equivalent to a reduction in secondary saturation temperature of about 180ºF/hr.

This automatic depressurization function is called partial cooldown. All components necessary to perform partial cooldown are safety-related, including the instrumentation, power supplies, and MSRT valves. Reducing the steam pressure to 870 psia is sufficient to decrease primary system pressure will decrease so that adequate MHSI flow is supplied for the full spectrum of SBLOCAs (Figure 7-2). Because partial cooldown is automatic, operator action prior to 30 minutes is not required.

7.2.1 Small Break Loss of Coolant Accident Scenario

The limiting SBLOCA scenario focuses on an approximate 2-inch diameter break, which, without a partial cooldown, would not cause the RCS to depressurize below the MHSI design pressure. The limiting break location is in a cold leg pump discharge piping. The event is depicted in Figure 7-3.

For this scenario, the reactor trips on low PZR pressure. SI is actuated on low-low PZR pressure. The SI signal automatically starts the MHSI and LHSI pumps and initiates a partial cooldown of the secondary system. The partial cooldown cools the primary system and lowers the RCS pressure.

During the partial cooldown, the RCS pressure decreases sufficiently to allow MHSI injection into the cold legs. The partial cooldown is performed by depressurizing all SGs via the MSRT, by automatically decreasing the respective MSRT setpoints at a constant cooldown rate to a fixed secondary pressure value. This results in an RCS pressure low enough to permit the needed MHSI injection and limits overcooling to prevent core recriticality.

After the partial cooldown, the RCS pressure remains constant because the energy transfers through the break and to the SGs match decay heat. As long as the break flow is composed of liquid, the MHSI flow is insufficient to match the break flow and RCS inventory continues to decrease. Voiding in the RCS increases, until the loop seal in the cold leg pump suction piping voids sufficiently, to allow steam to reach the break site. At this time, the mass flow rate of the MHSI is sufficient to compensate for the leakage, and RCS inventory begins to increase. The core does not uncover for this break.

7.2.2 Steam Generator Tube Rupture Scenario

The SGTR leads to a loss of primary coolant to the secondary side of the affected SG. The break causes a decrease of the primary pressure and a contamination of the secondary system. Reactor trip occurs on low PZR pressure, if no credit is taken for proper operation of the chemical and volume control system. The turbine trips on reactor trip and the SGs pressurize. Assuming a loss of offsite power coincident with reactor and turbine trip, the condenser is unavailable and SG pressures are controlled via the MSRT on each SL. Primary pressure continues to decrease and an SI signal is automatically actuated on low-low PZR pressure. Upon the SI signal, MHSI is actuated and the partial cooldown is automatically initiated in all four SGs. During the partial cooldown, the RCS pressure decreases to a value below the shutoff head of the MHSI pumps and MHSI flow into the RCS compensates for the leakage from the ruptured steam generator tube. Leakage to the affected SG continues because the affected SG pressure is less than RCS pressure.

The affected SG is automatically isolated by the protection system when:

- Partial cooldown is complete
- High-high steam generator level is exceeded or high steam line N16 radiation is exceeded.

Isolation of the affected SG is performed by the protection system by:

- Closing the main steam isolation valve
- Closing emergency FW isolation valve
- Raising MSRT pressure setpoint to the nominal value (approximately 1385 psia).

Following isolation, the affected SG pressure equalizes with the RCS pressure and leakage through the ruptured tube will cease. This effectively terminates the event from a radiological standpoint. RCS depressurization and isolation of the affected SG are performed automatically without operator intervention.

For scenarios where the leak rate is less than that expected for a double-ended rupture of a SG tube, or the proper function of the chemical and volume control system is credited, the primary system pressure equilibrates above the low PZR pressure reactor trip setpoint. In this case the plant will continue to operate and the operator has significant time to take any actions necessary to shutdown the plant, isolate the affected SG, and terminate the primary-to-secondary leakage.

7.3 Summary

The MHSI pump shutoff head is less than the MSSV lift setpoints to ensure that it is not possible to discharge radioactive liquid through the MSSVs of the affected SG during an SGTR. To ensure adequate MHSI flow into the RCS during certain SBLOCA scenarios, the U.S. EPR protection system automatically depressurizes the steam generators following indication of an SBLOCA. Equipment necessary to perform this partial cooldown function are safety-related. The combination of MHSI and safety-related partial cooldown ensure that applicable acceptance criteria are satisfied during SGTR and SBLOCA.

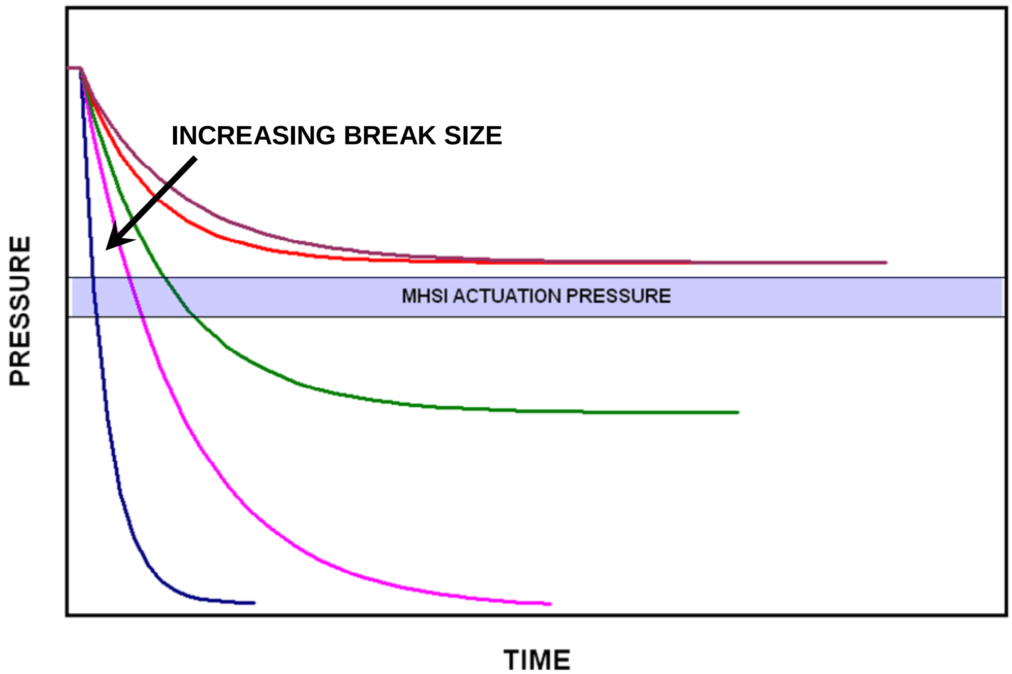

Figure 7-1 RCS Pressure for Postulated LOCAs

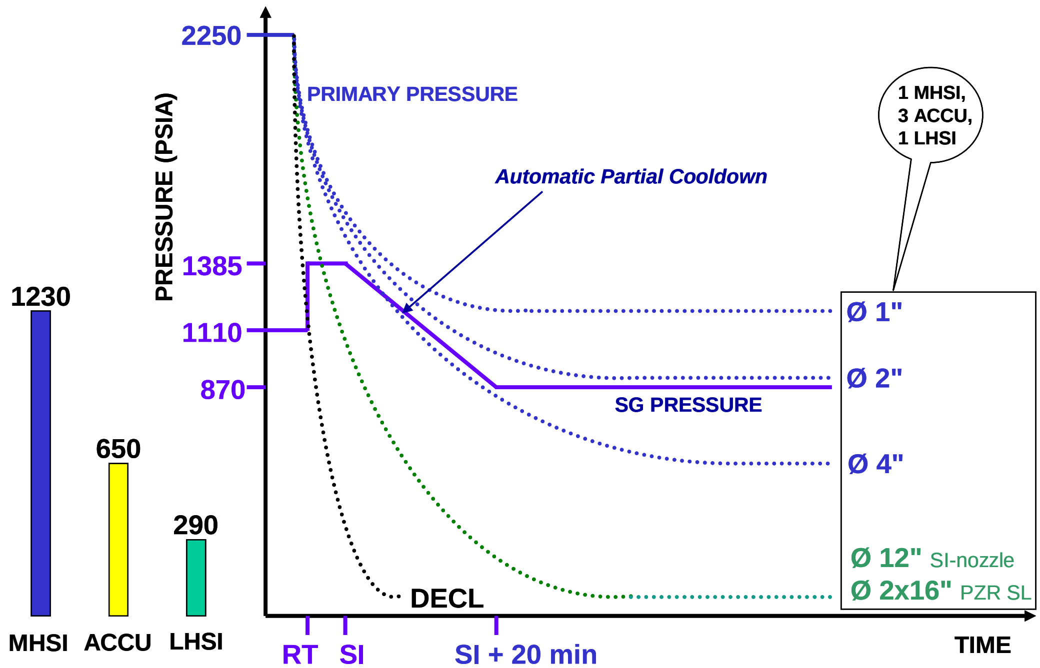

Figure 7-2 Effect of Partial Cooldown on LOCA Response

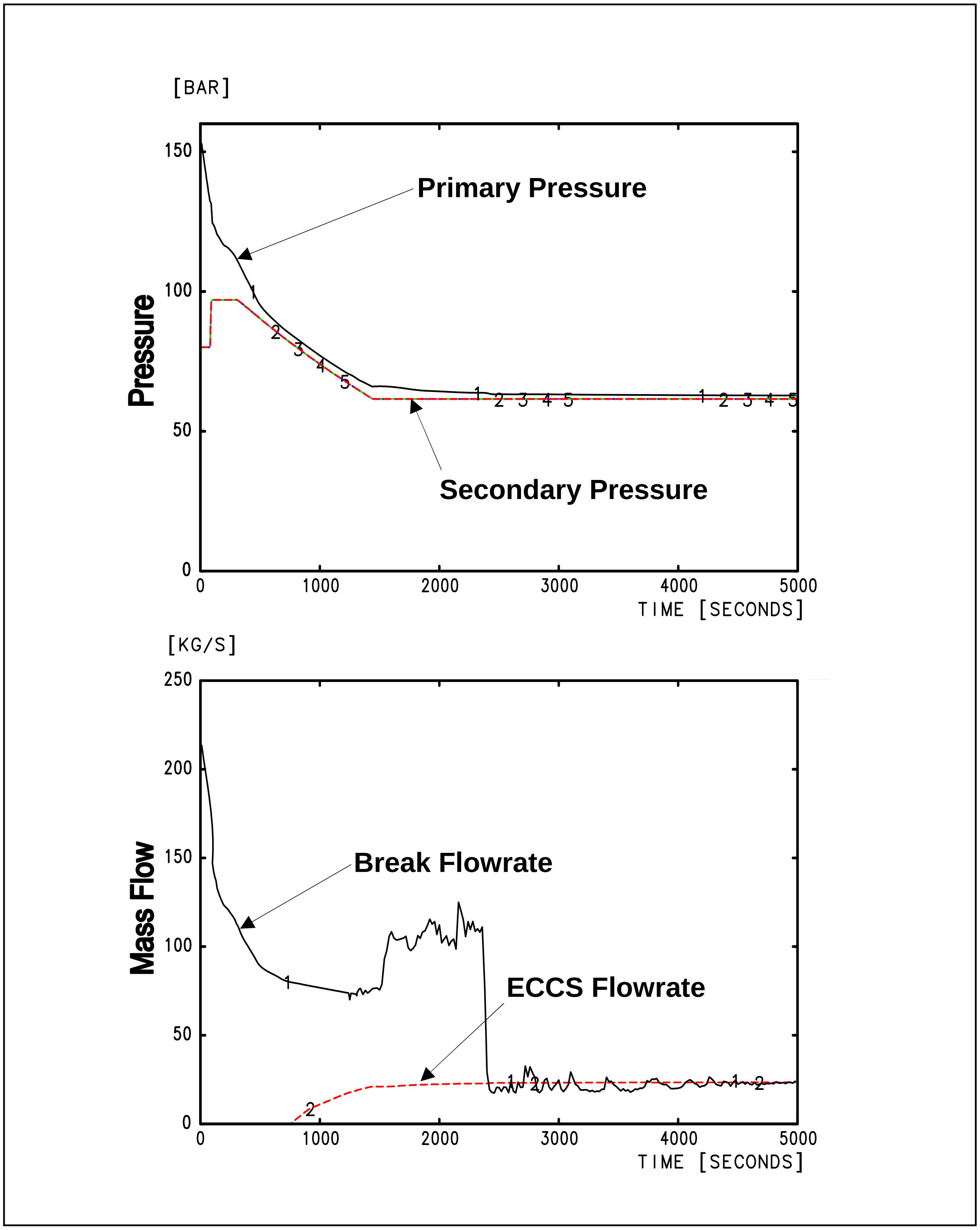

Figure 7-3 Response to 2-Inch Diameter SBLOCA with Partial Cooldown

8.0 CONCLUSION

This document discusses the features of the U.S. EPR that are unique compared to plants currently operating in the U.S. While these design features may be unique, they are based on proven technology and use the insights gained from the design of OL-3 and incorporate world wide operating experience. These features, combined with improvements in materials, control systems, personnel radiological protection, and operating and maintenance procedures based on thousands of reactor years of both design and operating experience make the U.S. EPR an “evolutionary” power plant.