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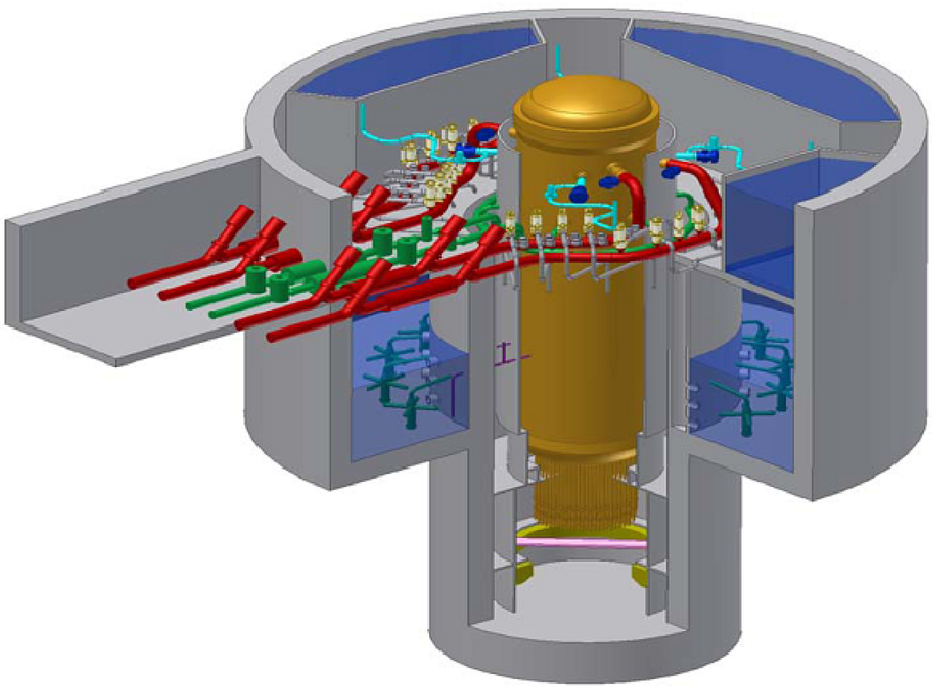

Part II
Introduction to Reactor Technology - BWR

Chapter 2.0, Reactor Vessel System

UNITED STATES

NUCLEAR REGULATORY COMMISSION

HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.
The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.
The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, “First of the Next Generation,” GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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

2.0 REACTOR VESSEL SYSTEM

The purposes of the Reactor Vessel system are to house and support the reactor core, to provide water circulation to the reactor core to remove generated heat, to separate the water and steam produced in the reactor core and deliver dry steam to the Main Steam system, and to provide an internal, refloodable volume to ensure core cooling capability following a loss of coolant accident (LOCA).

The functional classification of the Reactor Vessel system is that of a safety related system. It also contains a component, the control rod drive housing support structure, which is an engineered safety feature.

2.1 System Description

The reactor vessel assembly, shown in Figure 2.0-1, consists of the reactor vessel and its internal components including: the core support structures, core shroud, moisture removal equipment and jet pump assemblies. The various pipes that penetrate the reactor vessel and the vessel internal structure are discussed in later paragraphs of this section.

2.2 Component Description

The major components of the Reactor Vessel system can best be discussed when divided into several different categories:

- the reactor vessel,
- the annulus region components,
- the lower region components,
- the core region components,
- the above core region components and
- the components external to the reactor vessel.

The components associated with each of these categories are discussed in the paragraphs that follow.

2.2.1 Reactor Vessel

The reactor vessel is mounted vertically within the drywell. The vessel consists of a cylindrical center section with a rounded upper and lower head. The lower head of the reactor vessel is an integral part of the main assembly with the upper head being removable to facilitate refueling operations. The vessel assembly is supported by a support skirt which is mounted to the reactor vessel support pedestal.

The reactor vessel, top head and bottom head are fabricated from a low carbon steel alloy. The entire vessel assembly is designed for 1250 psig, 575°F. The inside wall of the cylindrical shell and the bottom head are clad with a stainless steel weld overlay to provide necessary corrosion resistance. The inside of the top head is not clad since it is exposed to the less corrosive steam environment.

The upper vessel head is attached to the cylindrical vessel center section (shell) by a stud and nut arrangement. To ensure a water tight seal between the head and shell flanges, two hollow concentric O-rings are mounted in matching grooves in the head flange. The O-rings are self-energized by permitting reactor pressure to act on the inside of the O-rings through slots in the O-rings. Because the O-rings are retained in the upper vessel head by clips, they can be replaced outside the refueling floor reactor cavity area. The double O-ring seal and flange design permits vessel heatup and cooldown without leakage past the second O-ring. The space between the two O-rings is tapped and piped to a pressure and level alarm system. If the inner O-ring should fail to seal, leakage is then detected by the level and/or pressure switches.

2.2.2 Annulus Region Components

The reactor vessel annulus region is the area inside the reactor vessel shell, outside the core shroud and above the baffle plate. The components in this area are discussed in the paragraphs which follow.

2.2.2.1 Feedwater Spargers

The reactor vessel is equipped with six feedwater spargers located in the mixing area above the downcomer annulus region. The feedwater spargers distribute the incoming feedwater to enhance mixing with the hot water returning from the steam separation equipment. Each sparger is fitted to a vessel nozzle penetration and manufactured to conform with the curvature of the vessel wall.

Feedwater entering the vessel through the feedwater nozzles enter through the center of the thermal sleeve. The thermal sleeve directs the feedwater to the distribution header, while preventing the relative cold feedwater from contacting the vessel wall.

The converging discharge nozzles direct feedwater from the distribution header radially upward and inward. The relatively cool feedwater in the downcomer annulus regions, subcools the water flowing to the recirculation pumps and jet pumps to guard against steam formation in the pumps.

2.2.2.2 Recirculation Suction Penetrations

Two recirculation suction lines penetrate the reactor vessel. The suction lines direct annulus region water to the Recirculation system.

2.2.2.3 Recirculation Discharge Penetrations

The ten recirculation inlet penetrations route water from the recirculation pump discharge to the jet pump nozzles.

2.2.2.4 Jet Pump Assemblies

The jet pump assembly, shown in Figure 2.0-2, consists of one inlet riser pipe, two nozzle sections, two mixing sections, two diffuser sections, and the required restraining equipment for support. The jet pumps are arranged in two semicircular groups of ten, with each group being supplied from a separate recirculation pump.

The jet pump nozzles, suction inlets, and throat or mixing sections are joined together with a mechanical slip fit for easy removal during maintenance. The diffuser mates, via a slip fit at the top, with the mixing section and is welded to the baffle plate at the bottom. A firm force, on all the slip fit section, is provided by the hold down bolt assembly.

The design of the jet pumps and arrangement with the shroud permits reflooding the reactor core to at least the height of the jet pump suction following a loss of coolant accident.

2.2.2.5 Baffle Plate

The baffle plate is welded to the reactor vessel wall and supported underneath by column members welded to the vessel bottom head. In addition to supporting the core shroud, the baffle plate provides support for the jet pump assemblies and separation between the annulus region and lower plenum region.

2.2.3 Lower Plenum Region

The lower plenum region is the area inside the reactor vessel lower head, below the baffle plate and core plate. The components in this region are discussed in the paragraphs which follow.

2.2.3.1 Bottom Head Penetrations

The reactor vessel bottom head, which is welded to the vessel shell, contains numerous penetrations which consists of:

- one penetration for the bottom head drain to the Reactor Water Cleanup system,
- one penetration containing two pipes (a pipe within a pipe) for pressure measurement above and below the core plate and SLC poison injection,
- a penetration for each control rod drive mechanism; 137 total,
- a penetration for each local power range monitoring detector string; 31 total,
- a penetration for each intermediate range monitoring detector; 8 total,
- a penetration for each source range monitoring detector; 4 total.

2.2.3.2 Bottom Head Drain

The bottom head drain line penetration directs water to the Reactor Water Cleanup system to aid in the removal of suspended solids, provide a means for monitoring the water temperature in the bottom head area and to minimize cold water stratification at low core flows.

2.2.3.3 Below Core Plate Pressure Line

The below core plate pressure sensing line is used to monitor jet pump performance and provide input to the jet pump flow measurement network. Line also used for SLC injection.

2.2.3.4 Above Core Plate Pressure Line

The above core plate pressure sensing line is used, along with the below core plate pressure measurement, to measure core differential pressure.

2.2.3.5 Control Rod Drive Housing

The Control Rod Drive (CRD) housing are extensions of the reactor vessel bottom head. The CRD housings provide vertical and lateral support for the CRD mechanism. Each housing also transmits the weight of four fuel assemblies, a fuel support piece and a CRD guide tube to the vessel bottom head.

2.2.3.6 Control Rod Guide Tubes

The control rod guide tubes, located inside the vessel, extend from the top of the control rod drive housings through the core plate. Each tube is designed to provide lateral support for a control rod and vertical support for a four-lobed fuel support piece. The bottom of the guide tube is supported by the control rod drive housing; which, in turn, transmits the weight of the guide tube, fuel support piece, and fuel assemblies to the reactor vessel bottom head.

2.2.3.7 Incore Housings and Guide Tubes

The incore housings provide for mounting of the incore nuclear instrumentation assemblies. The guide tubes are welded to the top of the incore housings and extend up to the core plate. The guide tubes and housings prevent jet pump flow (core flow) impingement on the nuclear instrumentation assemblies in the below core plate area, thereby eliminating possible vibration damage to these assemblies.

Each guide tube is perforated at the lower end by four holes to provide a cooling water path for the nuclear instrumentation assemblies. These nuclear instrumentation assemblies are loaded into the guide tubes from the top of the vessel with the assemblies extending upward from the guide tubes into the bottom of the top guide.

2.2.4 Core Region Components

The shroud region is the area bounded at the bottom by the core plate, at the top by the shroud head and circumferentially by the core shroud. The components of this region are discussed in the paragraphs that follow.

2.2.4.1 Core Shroud

The core shroud is a two inch thick, cylindrical stainless steel assembly which surrounds the core. The shroud provides the following:

- a floodable volume following a loss of coolant accident (LOCA)
- a barrier to separate or divide the upward core flow from the downward flow in the downcomer or annulus region
- a vertical and lateral support for the core plate, top guide and shroud head
- a mounting surface for the core spray spargers
- aids in forming the core discharge plenum

2.2.4.2 Core Plate

The core plate consists of a circular, horizontal stainless steel plate with vertical stiffener plate members mounted on the underside of the horizontal plate. The core plate acts as a partition to force the majority of the core flow into the control rod guide tubes where it will be directed to the fuel assemblies. The core plate also provides vertical and lateral support for 12 peripheral fuel assemblies via their fuel support pieces.

2.2.4.3 Top Guide

The top guide is a lattice assembly formed by a series of stainless steel plates joined at right angles to form square openings for control cells. Along the periphery are smaller openings which accommodate the peripheral fuel assemblies. Cutouts are provided on the bottom edge of the top guide, at the junction of the cross plates, to accommodate the spring loaded upper ends of the neutron instrument assemblies and source holder.

Support for the top guide is provided by a rim near the top end of the shroud and is held in place by a nut and bolting arrangement.

2.2.4.4 Fuel Support Pieces

The fuel support pieces are of two basic types, peripheral and four-lobed. The peripheral fuel support pieces, which are welded to the core plate, are located at the outer edge of the active core and are not adjacent to control rods. Each peripheral fuel support piece will support one fuel assembly and contains a replaceable orifice assembly designed to ensure proper coolant flow to the fuel assembly. The four-lobed fuel support pieces support four fuel assemblies each and are provided with orifice plates to ensure proper coolant flow distribution to each fuel assembly. The four-lobed fuel support pieces rest in the top of the control rod guide tubes and are supported laterally by the core plate. The control rods pass through slots in the center of the four-lobed fuel support pieces. A control rod and the four fuel assemblies which immediately surround it represent a control cell.

2.2.4.5 Core Spray Spargers

Two core spray pipes penetrate the reactor vessel 180° apart. Once inside the vessel, the pipes divide and are routed 90° in each direction from the point of vessel entry. The pipes are directed down and then inward to penetrate the upper core shroud just below the shroud head flange. After penetrating the shroud, the lines are again divided and proceed around the inside of the upper shroud in two semicircular headers. Spray nozzles connected to these headers are adjusted to provide the correct spray distribution to the fuel assemblies.

2.2.4.6 Shroud Head

The shroud head is rounded in shape and an integral part of the steam separator assembly. The top of the shroud head contains an array of penetrations used to channel the steam/water mixture exiting the core to the steam separator standpipes which are welded to the penetrations. The shroud head is attached to the shroud, with a special bolting arrangement, to form the core discharge plenum.

2.2.5 Above Core Region Components

Moisture or steam separation is accomplished internal to the reactor vessel via a steam separator and steam dryer. The steam separating components are discussed in the paragraphs which follow.

2.2.5.1 Steam Separator Assembly

The steam separator assembly consists of individual stainless steel axial flow cyclone separators welded to the top of standpipes. Within each separator, the steam water mixture passes swirl vanes which impart a spin to establish a vortex separating the water from the steam. The steam exits the top of the separator with a steam quality between 90 to 95%. The separated water exits from under the separator cap and flows out between the standpipes, draining into the downcomer annulus region, joining the feedwater.

2.2.5.2 Steam Dryer Assembly

The steam dryer assembly dries the wet steam leaving the steam separators to greater than 99.9% quality. The dryer assembly also provides a seal between the wet steam area and the dry steam flowing to the steam lines. The seal is formed by the steam dryer assembly seal skirt extending below the normal water level.

The individual dryer sections force the steam to be directed horizontally through the dryer panels. The steam is forced to make a series of rapid changes in direction while traversing the panels. During these direction changes, the heavier drops of entrained moisture are forced to the outer walls where moisture collection hooks catch and drain the liquid to collection troughs. From the collection troughs the liquid is directed to the annulus area via drain tubes.

2.2.5.3 Main Steam Outlet Penetrations

Four, twenty-four inch diameter steam line nozzles are installed to direct the steam out of the reactor vessel.

2.2.5.4 Vessel Head Penetrations

The reactor vessel head contains three penetrations of which only two are normally used after completion of the initial startup testing program. The first penetration closest to center is commonly called the head vent. It provides the dual function of venting noncondensible gases from the reactor vessel head area and providing a sensing line for shutdown level indication. During operation at temperatures less than the boiling temperature, the noncondensible gases are vented to the drywell equipment drain sump through two motor operated valves. The second penetration, which is approximately 30 inches radially off center, is used by the Residual Heat Removal system for head spray.

2.2.6 Components External To Reactor Vessel

Components external to the reactor vessel are discussed in the paragraphs which follow.

2.2.6.1 Reactor Vessel Support Skirt

The support skirt is welded at the top to the reactor vessel bottom head. The support skirt is anchored at the bottom to the vessel support pedestal via a ring girder and anchoring bolts. The support skirt provides vertical support for the reactor vessel, its internal components, the fuel, control rods and the moderator in the vessel.

2.2.6.2 Reactor Vessel Pedestal

The concrete and steel reactor pedestal is constructed as an integral part of the reactor building foundation. Steel anchor bolts, set in the concrete, extend through a bearing plate and secure the flange of the reactor vessel support skirt to the bearing plate and thus to the support pedestal. The reactor pedestal also supports the biological shield.

2.2.6.3 Biological Shield

The biological shield is a cylindrical structure of high density concrete between interior and exterior steel liners. The base of the shield wall attaches to the reactor pedestal, while the top of the shield wall is free. The biological shield surrounds the reactor vessel to provide shielding for personnel and equipment during normal power operation and shutdown conditions. In addition, the shield wall provides structural support for vessel insulation, access platforms in the area of the reactor vessel and other equipment supports. Openings are provided in the shield to permit passage of required vessel piping.

2.2.6.4 Reactor Vessel Insulation

Heat losses to the drywell atmosphere are minimized by insulation panels provided for the reactor vessel shell, top and bottom heads, and vessel nozzles. The insulation panels for the cylindrical vessel shell sections are held in place by insulation supports attached to the biological shield. Sections of the insulation are removable to permit access for vessel inspection.

2.2.6.5 CRD Housing Support Structure

Located below the reactor vessel is a control rod drive housing support structure, shown in Figure 2.0-1, which prevents the ejection of a control rod in the unlikely event of a control rod drive housing failure with the reactor pressurized. This network consists of support beams on the inside of the reactor pedestal with hanger rods and spring washers suspended from the beams. Grid clamps, grid plates, and support bars are bolted to the hanger rack to vertically support the bottom end of each housing and drive.

2.3 System Features and Interrelations

A short discussion of the system features and interrelations this system has with other plant systems is given in the paragraphs that follow.

2.3.1 Normal Operation

During normal operation, the recirculation pumps and jet pumps provide forced flow of coolant through the core. Approximately 90% of this flow enters the fuel assemblies while a designed 10% bypasses the fuel to cool other incore components. The water absorbs the heat energy of the fuel which increases the water temperature to saturation and boils a portion of the total core flow.

The steam and water mixture exiting the core is forced to pass through the two stages of moisture removal in the steam separator and dryers. The water removed in moisture separation flows back to the annulus area where it mixes with the incoming feedwater. The dry steam exits the reactor vessel through the four main steam lines. Incoming feedwater enters the reactor vessel at six different penetrations and is distributed via feedwater spargers.

2.3.2 Core Floodability

The Emergency Core Cooling Systems (ECCS) and the reactor vessel design are compatible to ensure that core can be adequately cooled following a Loss Of Coolant Accident (LOCA).

The worse case LOCA, with respect to core cooling, is a recirculation line break with the reactor at full power. In this case, the reactor vessel water level rapidly decreases uncovering the core. However, several systems automatically provide makeup water to the reactor core within the shroud. Water level increases until it reaches the level of the top of the jet pump mixing sections. Water then spills out of the jet pump suction into the annulus area and out through the broken recirculation line. The jet pump suction elevation is approximately at 2/3 of the height of the core.

If flooding of the reactor vessel is accomplished within a specified time frame, and if level is maintained at the 2/3 core coverage point, the core will be adequately cooled and the integrity of the fuel cladding will be maintained. The lower 2/3 of the core will be cooled because it is flooded with water and the upper 1/3 of the core will be cooled by a mixture of steam and water flowing upward because of the boiling in the lower 2/3 of the core.

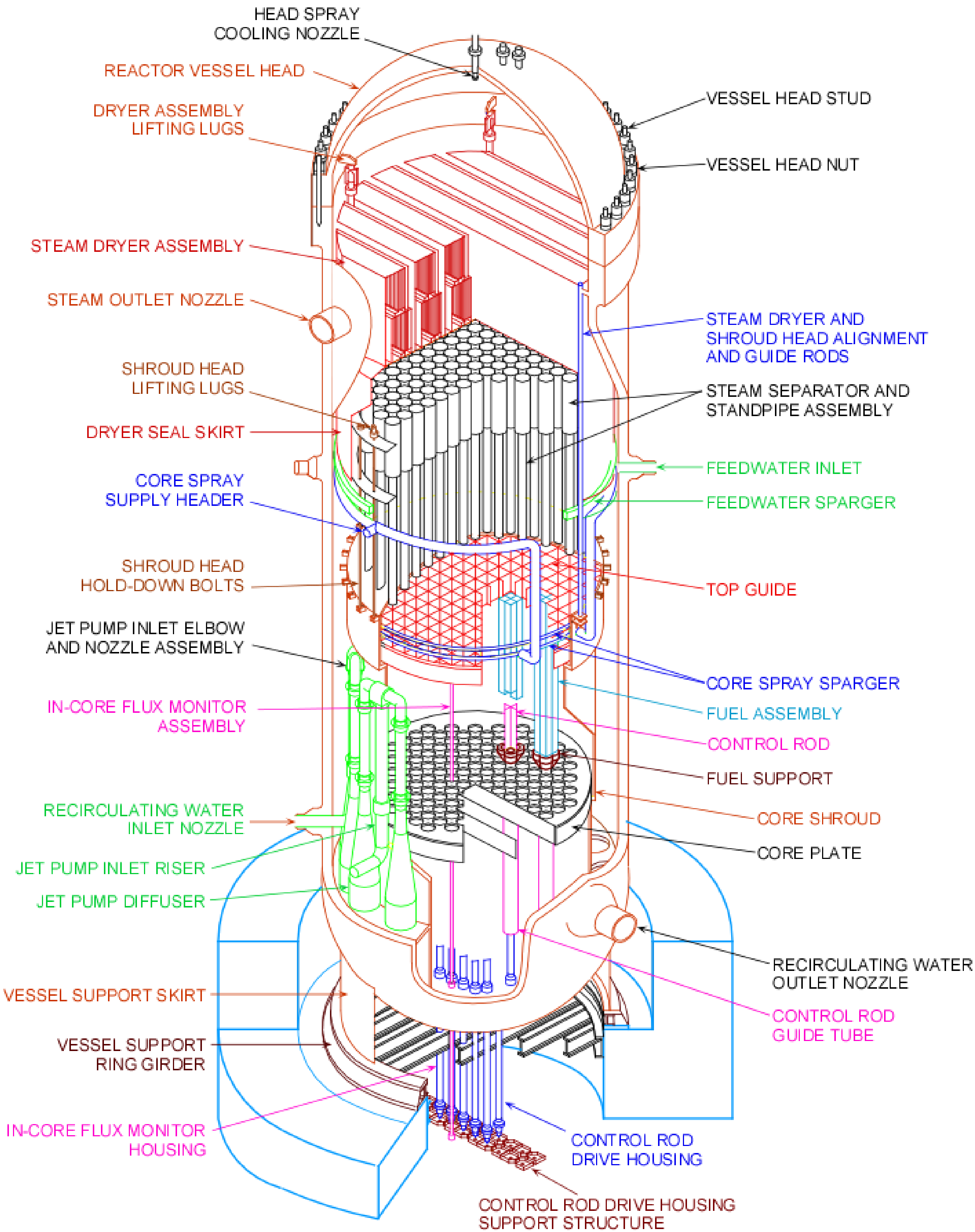

Figure 2.0-1, Reactor Vessel

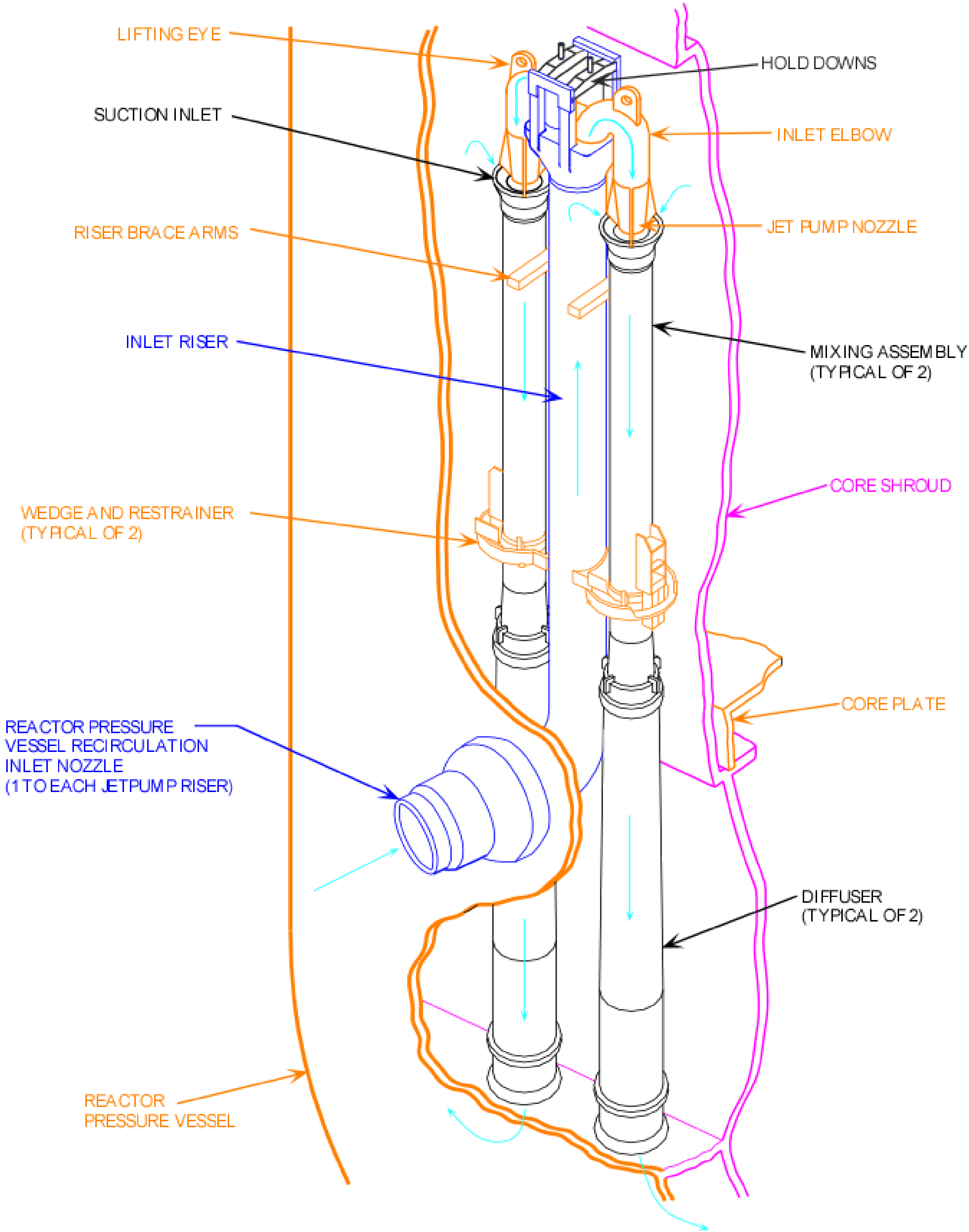

Figure 2.0-2, Jet Pump Assembly

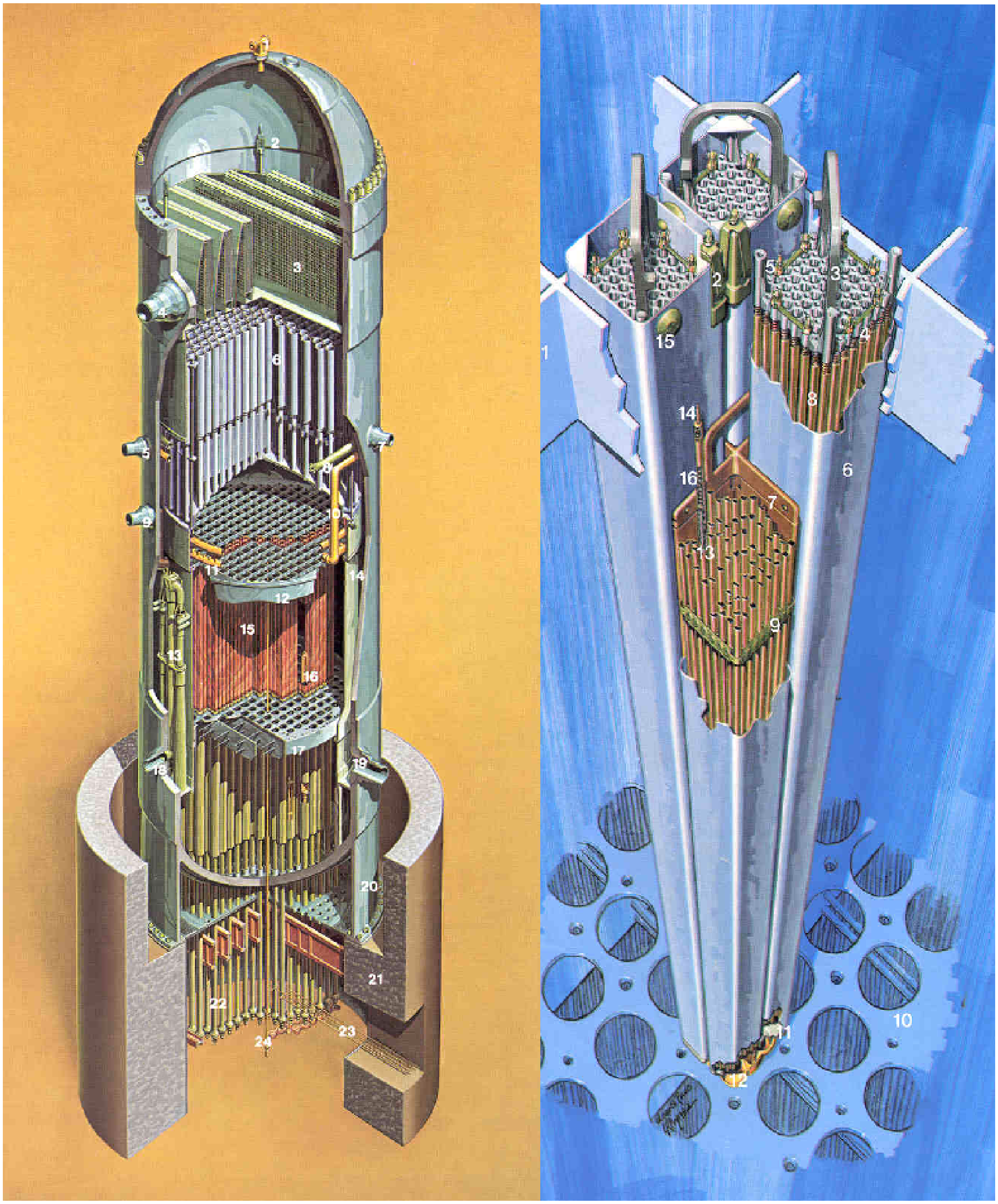

Figure 2.0-3, Control Cell