Westinghouse Technology Systems Manual

Section 3.1

Reactor Vessel and Internals

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3.1   REACTOR VESSEL AND INTERNALS

Learning Objectives:

1. State the purposes of the following major reactor vessel and core components:

    a. Internals support ledge
    b. Neutron shield pad assembly
    c. Secondary support assembly
    d. Internals packages
    e. Neutron sources
    f. Burnable poisons
    g. Thimble plug assemblies
    h. Irradiation specimens

2. Describe the flow path of reactor coolant from the inlet nozzles to the outlet nozzles of the reactor vessel.

3. List the core bypass flow paths.

4. Describe the physical arrangement of the following assemblies, including the purposes of the component parts listed:

    a. Fuel assembly

        • fuel rods
        • spring clip grid assembly
        • guide thimbles
        • top and bottom nozzles

    b. Control rod assembly

        • rodlets
        • spider
        • hub
        • drive shaft

    c. Rod drive mechanism

        • magnetic coils
        • gripper latches
        • pressure boundary

5. Describe the reactor vessel head seal arrangement.

6. Describe how the reactor vessel is supported.

3.1.1 Introduction

The reactor vessel and its internals contain the heat source for the nuclear steam supply system in the form of the fuel assemblies in the core area. The cladding of the fuel assemblies provides the first barrier to the release of fission products to the environment. The fuel assemblies are supported and held in alignment by the internals packages within the reactor vessel. Additionally, the internals packages provide flow paths for the coolant to remove the heat from the fuel and distribute it to the coolant loops for circulation.

3.1.2 System Description

A simplified diagram of the reactor vessel and internals is shown in Figure 3.1-1. More detailed cutaway and cross-sectional diagrams can be found in Figures 3.1-2, 3.1-3, and 3.1-4, respectively, and are used for the following descriptions.

The reactor vessel is cylindrical, with a welded hemispherical bottom head and a removable, flanged and gasketed, hemispherical upper head. The vessel contains the reactor core, core support structures, control rods and other components directly associated with the core.

The vessel inlet and outlet nozzles are located in a horizontal plane just below the reactor vessel flange but above the top of the core. Coolant enters the vessel through the inlet nozzles and flows down the core barrel-vessel wall annulus, turns at the bottom and flows up through the core to the outlet nozzles.

The reactor internals are comprised of the upper support structure, the lower core support structure, and the incore instrumentation support structure. They are designed to support, align, and guide the core components, direct the coolant flow to and from the core, and to support and guide the incore instrumentation. The fuel assemblies are arranged in a roughly circular cross-sectional pattern.

The fuel is in the form of slightly enriched uranium dioxide ceramic pellets. The pellets are stacked within zircaloy-4 tubular cladding which is plugged and seal welded at the ends to encapsulate the fuel. The fuel rods are internally pressurized with helium during fabrication. Heat generated by the fuel is removed by demineralized light water which flows upward through the fuel assemblies and acts as both moderator and coolant.

The fuel assembly loading arrangement for an operating cycle is shown in Figure 3.1-5. Refueling is typically accomplished by removing part of the core and replacing it with new fuel. The remaining parts of the core are shuffled. The exact arrangement of the core will depend upon nuclear engineering calculations and vessel embrittlement concerns. For example, to reduce the neutron flux on the vessel, the older fuel can be placed on the outside of the core and the new fuel loaded in the center.

Movable neutron absorbing control rods, designated as Rod Cluster Control Assemblies (RCCAs), are provided to accomplish large rapid reactivity additions for

reactor control or shutdown purposes. Each RCCA is identical and consists of a number of individual absorber rods attached to a common spider and hub assembly. These absorber rods fit within hollow guide thimbles in the fuel assemblies.

As shown in Figure 3.1-1 and 3.1-2, the fuel assemblies are positioned and supported vertically in the core between the upper and lower core plates. These plates are manufactured with pins which fit into holes in the fuel assembly top and bottom nozzles to provide lateral support. The pins maintain the fuel assembly alignment, which ensures free movement of the RCCAs in the fuel assembly without binding or restriction between the rods and their guide surfaces.

3.1.3 Component Descriptions

3.1.3.1 Reactor Vessel

The reactor vessel is comprised of (1) a flanged cylinder, made of welded rolled plates or ring forgings, welded to a hemispherical bottom and (2) a removable, flanged and gasketed, hemispherical upper head. The vessel is designed to provide the smallest and most economical volume required to contain the core, core support structures, control rods, and flow directing members of the internals packages. The electromechanical control rod drive mechanisms (CRDMs) and incore temperature instrumentation supports are attached to the reactor vessel head. The bottom of the vessel contains penetrations for the incore nuclear instrumentation. All penetrations are welded to their respective head to minimize coolant leakage.

Inlet and outlet nozzles are located in a horizontal plane below the reactor vessel flange but above the top of the fuel assemblies. Coolant enters the reactor vessel through the inlet nozzles and flows down the annulus between the vessel wall and the core barrel of the core support structure, then turns at the bottom and flows up through the core to the outlet nozzles. All reactor vessel internals are supported from the internals support ledge, which is machined into the reactor vessel flange. Reactor vessel design parameters are listed in Table 3.1-1.

Reactor Vessel Construction

The reactor vessel and head are constructed of manganese-molybdenum alloy steel, with all surfaces in contact with the reactor coolant clad with weld-deposited stainless steel for corrosion resistance. The method of construction is a number of ring forgings and/or rolled plates welded together to form the large reactor vessel, as shown in Figure 3.1-6.

Samples of reactor vessel and weld materials are provided to evaluate the effect of radiation on the fracture toughness of the reactor vessel. The reactor vessel surveillance program uses a number of specimen capsules located in irradiation specimen guides (guide baskets) attached to the outside of the neutron shield pads (Figure 3.1-3). There are two single holders and two double holders. The specimens are positioned at about core midplane height. Dosimeters are also included to evaluate the level of flux experienced by the specimens and vessel wall.

The bottom head of the vessel contains 58 penetration nozzles for connection and entry of the incore nuclear instrumentation. Each nozzle is attached to the inside of the bottom head by a partial penetration weld and extends 12 inches up into the vessel. The nozzles join to the lower internals assembly with a slip fit. Stainless steel conduits are welded to these nozzles below the reactor vessel and are extensions of the Reactor Coolant System (RCS) pressure boundary up to the seal table. At the seal table, a mechanical seal is made to each incore instrument guide thimble, which is inserted inside one of the conduits. The guide thimble is sealed and dry, while the space between the conduit and guide thimble is subjected to reactor vessel pressure. Details of the incore nuclear instrumentation may be found in Section 9.2.

The cylindrical portion of the reactor vessel below the refueling seal ledge and the vessel bottom head are permanently insulated with metallic reflective-type insulation. This insulation consists of inner and outer sheets of stainless steel spaced three (3) inches apart, with the multiple layers of stainless steel and the air between the sheets acting as the insulating agent. Removable panels of this insulation are provided for the reactor vessel flange and head area and also at the vessel inlet and outlet nozzles to facilitate refueling operations and inservice inspections.

Reactor Vessel Flange

The reactor vessel flange is a ring forging that is 32.5 inches wide and contains 54 threaded holes for the studs which hold the vessel head in place. The reactor internals hang from a ledge on the inside surface of the flange. A sealing area is provided on the outside surface of the flange so that a temporary seal may be made between the reactor vessel and the refueling canal liner.

Reactor Vessel Head

The reactor vessel closure head assembly (Figures 3.1-1 and 3.1-2) is a flanged hemispherical component bolted to the vessel by 54 large threaded studs. The head flange is sealed to the vessel flange by two concentric, self-energizing, metallic O-rings which fit into grooves machined in both flanges (Figure 3.1-7). The O-rings are attached to the head by clips to ensure proper alignment during installation. Seal leakage is detected by means of two leak off connections: one between the inner and outer O-rings (normal alignment), and one outside the outer O-ring (must be manually aligned). Leakage is detected by a leak-off line temperature detector, which alarms in the control room. The leakage is directed to the Reactor Coolant Drain Tank (RCDT) via check valves which require two (2) psid to unseat. The RCDT high pressure setpoint of six (6) psig ensures that the level in the leak-off line does not rise to the point where there could be flow out of the vessel flange.

The reactor vessel closure head studs are loosened and retorqued as required using hydraulic stud tensioners. A stud tensioner (normally three [3] are used simultaneously to torque the head evenly) grips the stud, which is threaded into the reactor vessel flange, and stretches it. Then the nut is tightened and the tension released, producing a correctly torqued stud. The normal procedure is to torque the studs in two stages to eliminate warping. Any time the head is removed, new O-

rings are installed to ensure a good seal. Proper alignment of the head during installation is accomplished by the use of long guide studs threaded into several of the holes in the vessel flange. These guides are then aligned with the proper holes in the closure head flange as the head is lowered into place during reactor assembly. When the studs are tightened, the flanges hold the reactor internals in place.

Reactor vessel head penetrations include:

1. CRDM adapters: These penetrations are attached by partial penetration welds to the underside of the closure head. The upper end of each adapter contains threads for attachment of a control rod drive mechanism housing. The housing and penetration are then sealed by a welded flexible canopy seal. A long closed tube called the rod travel housing is attached to the top of the control rod drive mechanism housing to accept the control rod drive shaft as the control rod is withdrawn. The rod travel housing is, therefore, an extension of the reactor vessel pressure boundary and is filled with high pressure reactor coolant during normal operation. A vent valve is installed at the top of each rod travel housing, but it is not normally used due to possible leakage problems.

2. Reactor vessel head vent: This connection is a 3/4-in. outside diameter inconel tube which passes through the upper head and is increased in size to one (1) inch in diameter. The penetration is secured to the interior surface of the head with a partial penetration weld. This penetration is capped but does provide the tap for the reactor vessel head venting system.

3. Reactor Vessel Head Venting System (RVHVS): This system can be used to remove noncondensible gases or steam from the reactor vessel head under certain conditions when these gases could disrupt natural circulation core cooling (Figure 3.1-8). This system was installed as a result of the accident at Three Mile Island. When the RVHVS is operating, flow from either vent line enters the containment atmosphere. An orifice is installed to limit the flow of hydrogen from the reactor coolant system to permit a reasonable venting period without exceeding containment atmosphere combustible limits. In addition, the orifice is designed to limit flow to within the capacity of one centrifugal charging pump in the event of a ruptured vent line or an inadvertent opening of the vent valves. The solenoid valves in each vent line are powered from redundant vital buses. These valves are normally closed and are energized to open. They fail closed on a loss of electrical power. The RVHVS is operated from the main control board. There are no interlocks associated with this system, and all venting operations require manual operator action. In addition to the solenoid valves, there is a manual globe valve in the common piping upstream of each branch vent line. This valve is open during normal plant operations but may be closed during refueling or system maintenance.

Reactor Vessel Supports

Generally all RCS supports are designed to permit unrestrained thermal growth but to restrain vertical, lateral, and rotational movement resulting from seismic and pipe-

break loadings. The reactor vessel is supported by steel pads integral with four of the coolant nozzles, as shown in Figure 3.1-9.

These pads rest upon steel base plates on a support structure mounted to the concrete foundation wall. Thermal expansion and contraction of the vessel are accommodated by sliding surfaces between the support pads and the base plates. Side stops on these plates keep the vessel centered and resist lateral loads, including all pipe loads. The support shoes and support structure are cooled by the reactor cavity cooling system.

3.1.3.2   Reactor Internals

The reactor internals consist of the lower core support structure, the upper core support structure, and the incore instrumentation support structure. The internals are designed to support, align, and guide the core components; direct coolant flow to and from core components; and guide and support the incore instrumentation.

Any operational accident or seismic loads imposed on the fuel assemblies are transmitted to the upper and lower support structures and ultimately to the reactor vessel flange (Figures 3.1-1 and 3.1-2) or to the lower radial support at the bottom of the lower support structure. The internals also provide a form-fitting baffle around the fuel assemblies to direct most of the coolant flow through the fuel assemblies.

During initial assembly and refueling the upper core support structure is removed and installed as a unit. The lower core support structure can also be removed as a unit after all fuel has been removed. The lower core support structure is normally removed only for reactor vessel surveillance.

Lower Core Support Structure

The major support assembly of the reactor internals is the lower core support structure, shown in Figures 3.1-10 and 3.1-11. This support structure consists of the core barrel, the core baffles, the lower core plate and support columns, the neutron shield pads, the specimen holders, and the lower core support plate.

The core barrel supports and contains the fuel assemblies and directs the coolant flow. The core barrel is a cylindrical shell 147.25 inches in diameter and 330.75 inches long. The barrel hangs from a ledge on the reactor vessel flange and is aligned by four flat sided pins which are press fitted into the barrel at 90-degree intervals. Four main coolant outlet nozzles penetrate the shell in the upper region. The lower end of the core barrel is restrained from transverse movement by a radial support system. The radial support system consists of six (6) equally spaced key and keyway joints around the reactor vessel inner wall. At each point an Inconel clevis block is welded to the reactor vessel. An Inconel insert block is bolted to each clevis block, forming the keyway. Welded to the lower end of the core barrel are six (6) keys. These keys engage the keyways when the core barrel is lowered into the reactor vessel. Radial and axial expansions of the core barrel are accommodated, but transverse movement of the core barrel is restricted.

Located on the barrel flange are sixteen reactor vessel head cooling flow nozzles that direct 0.13% of the reactor coolant flow upward to cool the head. The flow passes down minor holes in the control rod guide tubes and into the main outlet flow stream.

An internals hold-down spring is positioned in a groove in the core barrel main flange beneath the upper internals main support flange. The spring separates the upper internals and lower internals flanges and maintains a force to resist any uplift of the lower internals.

There are four (4) neutron shield pads attached to the core barrel. The neutron shield pads attenuate fast neutrons that would otherwise excessively irradiate and embrittle the vessel walls. In addition, gamma radiation is attenuated by the shield pads to alleviate thermal stresses due to uneven gamma heating of the vessel. The four pads are 147 in. high, 48 in. wide and 2.7 to 2.8 in. thick. The pads are made of 304 stainless steel and are attached to the core barrel by spacer blocks. The spacer blocks allow cooling flow between the pads and the reactor vessel.

The reactor vessel specimen holders are attached to the outside surfaces of the neutron shield pads. The specimens are used to evaluate the irradiation effects on the vessel. One sample is evaluated after the first refueling, and subsequent samples are checked at 10-, 20-, and 30-year intervals.

The lower core support plate is 18 in. thick and is welded to the bottom of the core barrel. The support plate carries the weight of the fuel assemblies and distributes the coolant flow to the fuel assemblies. The secondary support structure, tie plates, instrument guide columns, and support columns hang below the lower core support plate (Figure 3.1-11).

The secondary support structure is in place in the event of a postulated downward vertical displacement of the lower internals (or portion thereof) and the reactor core. As the secondary support base falls against the vessel bottom head, the energy absorption features stretch and, by strain energy dissipation, limit the force applied against the vessel head to an acceptable fraction of the yield strength of the pressure vessel. The support structure also ensures that downward displacement of the lower internals is limited, so that the upper core plate remains in engagement with the fuel assemblies. This prevents a misalignment and thus ensures that the controls rods remain capable of inserting.

The secondary core support has four (4) energy absorbing columns that extend up to the lower core support plate and are connected at the bottom by a sole plate. The sole plate is contoured to the shape of the lower head. A 1/2-in. clearance is maintained when the RCS is hot. The energy absorbing devices allow a 3/4-in. displacement, for a total displacement of 1-1/4 in.

The lower core plate is a two (2) in. thick plate located above the lower core support plate through which flow distribution holes for each fuel assembly are machined (four holes per assembly). Additional holes are machined in the plate to allow for passage of the incore instruments and to allow for cooling of the core baffles and formers. Fuel assembly locating pins (two per assembly) are also attached to this

plate. The lower core plate is supported by a circumferential ring that is welded to the core barrel. Support columns are also installed between the lower core plate and the lower core support plate of the core barrel in order to provide stiffness and to transmit the load to the lower core support plate.

The boundary of the fuel region of the core is established by the core baffle assembly. This assembly extends from just above the lower core plate to above the fuel assemblies; it guides the coolant flow through the core. Since the fuel assemblies are square and the core barrel is round, without the baffle gaps would exist around the periphery of the core and a large portion of the cooling water flow would bypass the core. This baffle assembly consists of a number of vertical plates (baffles) and horizontal stiffeners (formers). The formers are bolted to circular grooves in the core barrel, and the baffle plates are bolted to the formers to provide alignment and structural rigidity. Small flow holes are drilled in the formers to allow flow mixing to eliminate stagnant areas. This small amount of flow bypasses the fuel region and is considered as a core bypass flow path in the design.

The lower core support structure serves to provide support for the core and guide the flow of reactor coolant. Reactor coolant flow from the vessel inlet nozzles proceeds down the annulus between the core barrel and the vessel wall, flows on both sides of the neutron shield pads, and then flows into a plenum at the bottom of the vessel. It then turns and flows up through the lower core support plate and passes through the lower core plate. The flow holes in the lower core plate are arranged to provide a uniform entrance flow distribution to the core. After passing through the core, the coolant enters the area of the upper support structure and then flows radially to the core barrel outlet nozzles and through the reactor vessel outlet nozzles.

The upper core barrel contains nozzles to direct the outlet flow from the fuel assemblies out of the upper core support structure. These nozzles have a close but noncontacting fit with the reactor vessel outlet nozzles. Since there is no positive seal at this point, a small amount of coolant inlet flow bypasses the core and internals and goes directly to the vessel outlets. This flow is considered a core bypass flow in the design.

Upper Core Support Structure (Upper Internals)

The upper core support structure and its components are shown in Figures 3.1-12, 3.1-13, and 3.1-14. The upper core support structure provides structural support for the fuel assemblies, RCCAs, and incore instrumentation. The structure consists of an upper support assembly, upper support columns, RCCA guide columns, thermocouple columns, and the upper core plate.

The upper core support plate is five (5) in. thick and 172 in. in diameter. The support plate rests on the lower internals hold-down spring and transmits the weight of the upper internals assembly to the hold-down spring, and ultimately to the reactor vessel flange ledge. Holes machined in the upper support plate accommodate the RCCAs, the five (5) thermocouple columns, and some covered spare penetrations.

The 48 upper support columns establish the spacing between the upper support assembly and the upper core plate and are fastened at top and bottom to these plates. These support columns serve to transmit the weight of the upper core plate and the spring force of the fuel assembly top nozzles to the upper core support plate.

The upper core plate is the lowest major component of the upper internals assembly. The 147.25 in. diameter, three (3) in. thick plate serves to align and locate the fuel assemblies. The plate transmits the uplift forces of core flow and spring forces of fuel assembly top nozzles to the support columns and thus to the upper core support plate. The upper core plate also has machined holes to accommodate the same equipment as the upper support plate.

Control rod guide tube assemblies (Figures 3.1-12 and 3.1-13) shield, guide, and support the RCCAs. They are fastened to the upper support plate and the upper core plate for proper orientation and support. Additional vertical support for the absorber rods is provided by the control rod guide tube extensions which are attached to the upper support plate.

The upper core support structure, which is removed as a unit during refueling operation, is oriented properly with respect to the lower core support structure by the slots in the upper core plate (Figure 3.1-14) which engage flat sided upper core plate alignment pins welded into the core barrel. At an elevation in the core barrel where the upper core plate is positioned, the flat-sided pins are located at angular positions of $90°$ from each other. As the upper core support structure is lowered into the lower internals, the slots in the plate engage the flat-sided pins. Lateral displacement of the plate and of the upper support assembly is restricted by this design.

As in the lower core plate, fuel assembly locating pins protrude from the bottom of the upper core plate and engage the fuel assemblies as the upper core support structure is lowered into place. Proper alignment of the lower core support structure, the upper core support structure, the fuel assemblies, and control rods are thereby assured by this system of locating pins.

Vertical loads from weight, earthquake acceleration, hydraulic loads and fuel assembly pre-load are transmitted through the upper core plate via the support columns to the upper support plate and then to the reactor vessel flange. Transverse loads from coolant cross flow, earthquake acceleration, and possible vibrations are distributed by the support columns to the upper support and upper core plate. The upper support plate is particularly stiff to minimize deflection.

Incore Instrumentation Support Structure

The incore instrumentation support structure (Figure 3.1-15), consists of an upper system to convey and support incore temperature monitors (thermocouples) penetrating the vessel through the head and a lower system to convey and support incore nuclear instrumentation flux thimbles penetrating the vessel through the bottom.

There are 65 thermocouples attached to the upper core plate at selected fuel assembly outlets. The leads from these thermocouples are enclosed in sealed stainless steel tubes called thermocouple conduits. The conduits are routed along and supported by the support columns of the upper support structure. The thermocouple conduits are grouped and routed inside five (5) instrumentation port columns which penetrate the reactor vessel head.

A mechanical sealing device is provided at each head penetration to prevent leakage during operation, while allowing disconnection of the thermocouple leads when the head must be removed for refueling. Details of the incore temperature monitoring system are found in Section 9.2.

The lower system is provided to align and support the guide thimbles for the incore nuclear instrumentation system. These guide thimbles are dry, sealed, stainless steel tubes which are inserted into 58 fuel assemblies. A movable miniature fission chamber can be inserted into each dry thimble during reactor power operations for the monitoring of core power distribution.

To each of the 58 penetrations in the reactor vessel bottom head is welded a stainless steel conduit of larger diameter than the incore guide thimble. These conduits extend from the bottom of the reactor vessel, through a concrete shield area (this opening is also used for access under the reactor vessel when shutdown) to a seal table located above the height of the core.

Each closed, dry guide thimble is then inserted through a conduit and extended into a fuel assembly instrumentation thimble (Figure 3.1-17). The dry guide thimbles are closed at the fuel assembly end and serve as a pressure boundary during operation. Since the conduits welded to the reactor vessel are open to vessel pressure, the spaces between the guide thimbles and conduits are subjected to full reactor vessel pressure. Mechanical seals between the guide thimbles and the conduits are installed at the seal table.

During normal operation, the dry guide thimbles are fixed inside the conduits, and the movable detectors are moved in and out of the core through the dry guide thimbles. For refueling operations, the mechanical seals are broken, and the dry guide thimbles are mechanically withdrawn from the fuel assembly instrumentation thimbles to allow fuel movement. This can produce high radiation levels under the reactor vessel during refueling, since these dry guide thimbles, which have been in the fuel during operation, are now in the conduit outside the reactor vessel. Since these dry guide thimbles are of small diameter and flexible, and have little structural strength, they must be supported and aligned constantly from the penetrations to their entrances into the fuel assemblies.

Figures 3.1-2 and 3.1-10 show components called instrumentation thimble guides. Either a thimble guide or a hollow lower core support column slips over each vessel penetration and encloses the guide thimble to protect it from flow induced vibration. The instrumentation thimble guides are tubes with cross-shaped (cruciform) blades. They are inserted through flow holes in the lower core support and thus provide alignment and support while not restricting flow.

The incore instrumentation support structure is designed for adequate support of instrumentation during reactor operation and is rugged enough to resist damage or distortion under the conditions imposed by handling during the refueling sequence. Additional information is found in Section 9.2.

3.1.3.3   Reactor Core Components

The reactor core components consist of the fuel assemblies and all components which can be inserted into fuel assemblies to affect reactor power, power distribution, or flow distribution.

Fuel Assemblies

All fuel assemblies are mechanically identical, open cage assemblies (Figure 3.1-16). Fuel assembly design parameters are listed in Table 3.1-2. Each fuel assembly consists of 264 fuel rods, 24 guide thimble tubes, and 1 instrumentation guide thimble supported and aligned by grid assemblies and top and bottom nozzles in a 17 x 17 fuel rod array. The instrumentation guide thimble is located in the center position (Figure 3.1-17) and provides a channel for the insertion of an incore neutron detector dry guide thimble if the fuel assembly is located in an instrumented core position. The instrumentation guide sheath is open at the bottom and closed at the top to prevent core bypass flow.

The absorber rod guide thimbles provide channels for insertion of an RCCA, a neutron source assembly, a burnable poison assembly, or a thimble plug assembly, depending on the position of the particular fuel assembly in the core. Figure 3.1-16 shows a fuel assembly with a full length rod fully inserted. The fuel rods are loaded into the fuel assembly structure so that there is clearance between the fuel rod ends and the top and bottom nozzles to allow for expansion without causing bowing of the rods. Fuel rods provide no structural function for the fuel assembly. All structural strength is supplied by the top and bottom nozzles, the grid assemblies, and the absorber rod guide thimbles.

Each fuel assembly is installed vertically in the reactor vessel and stands upright on the lower core plate, which is fitted with alignment pins to locate and orient the assembly. After all fuel assemblies are set in place, the upper support structure is installed. Alignment pins, built into the upper core plate, engage and locate the upper ends of the fuel assemblies. The upper core plate then bears downward against hold-down springs in the fuel assembly top nozzle (Figures 3.1-18 and 3.1-19), to hold the fuel assemblies in place against any flow induced lifting forces while still allowing differential expansion between the internals and the fuel assemblies.

Fuel Rods

Each fuel rod consists of uranium dioxide ceramic pellets which are placed inside a slightly cold worked zircaloy-4 tube. The tube is then plugged and seal welded at both ends to encapsulate the fuel. Design parameters for the fuel rods are listed in Table 3.1-3.

A schematic of the fuel rod is shown in Figure 3.1-20. The fuel pellets are right circular cylinders consisting of slightly enriched uranium-dioxide powder which has been compacted by cold pressing and then sintered to the required density. (Sintering is high-temperature fusing of metal particles). The ends of each pellet are dished slightly to allow greater axial expansion at the center of the pellets.

To avoid overstressing of the cladding or seal welds, void volume and clearances are provided within the rods to accommodate fission gases released from the fuel, differential thermal expansion between the cladding and the fuel, and fuel density changes during burn-up. Shifting of the fuel within the cladding during handling or shipping prior to core loading is prevented by a stainless steel helical spring which bears on top of the fuel. At assembly the pellets are stacked in the cladding to the required fuel height. The spring is then inserted into the top end of the fuel tube and the end plugs pressed into the ends of the tube and welded.

All fuel rods are internally pressurized with helium during the welding process in order to minimize compressive clad stresses and to prevent cladding flattening due to coolant operating pressures. The helium pre-pressurization may be different for each fuel region. Fuel rod pressurization is dependent on the planned fuel burn-up as well as other fuel design parameters and fuel characteristics (particularly densification potential). The fuel rods are designed such that the internal gas pressure will not exceed the nominal system coolant pressure even during anticipated transients, and clad flattening will not occur during the core life.

Each fuel rod contains approximately six (6) inches of natural uranium at each end of the rod. This design reduces axial leakage, which is desirable, but increases the heat flux hot channel factor (F_Q).

Bottom Nozzle

The bottom nozzle is a box-like structure which serves as the bottom structural element of the fuel assembly and directs the coolant flow to the assembly. The square nozzle is fabricated of type 304 stainless steel and consists of a perforated plate and four angle legs with bearing plates, as shown in Figures 3.1-16 and 3.1-18. The legs form a plenum for the inlet coolant flow to the fuel assembly. The holes in the plate are smaller than the fuel rod diameters and prevent a downward displacement of the fuel rods from their fuel assembly. The bottom nozzle is fastened to the fuel assembly control rod guide tubes by weld-locked screws which penetrate through the nozzle and mate with threaded plugs in the guide tubes.

Coolant flow through the fuel assembly is directed from the plenum in the bottom nozzle upward through the holes in the plate to the spaces between the fuel rods. The penetrations in the plate are positioned between the rows of the fuel rods.

Axial loads (hold-down forces) imposed on the fuel assembly and the weight of the fuel assembly are transmitted through the bottom nozzle to the lower core plate. Indexing and positioning of the fuel assembly is by alignment holes in two diagonally opposite bearing plates, which mate with locating pins in the lower core plate. Any lateral loads on the fuel assembly are transmitted to the lower core plate through the locating pins.

Top Nozzle

The top nozzle functions as the upper structural element of the fuel assembly. In addition, the top nozzle provides a partial protective housing for a rod cluster control assembly or other insert. It consists of an adapter plate, enclosure, a top plate, hold down springs, clamps, and pads, as shown in Figures 3.1-18 and 3.1-19. The springs and bolts are made of inconel 718, whereas other components are made of type 304 stainless steel.

The square adapter plate is provided with round and oblong penetrations to permit the flow of coolant upward through the top nozzle. Other round holes are provided to accept sleeves which are welded to the adapter plate and mechanically attached to the thimble tubes. The holes in the plate are of smaller diameter than the fuel rods and prevent their upward ejection from the fuel assembly. The enclosure is simply a sheet metal shroud between the adapter plate and the top plate. The top plate has a large square hole in the center to accept a control rod and the control rod spider when the rod is inserted. Hold-down springs are mounted on the top plate and are fastened in place by bolts and clamps located at two diagonally opposite corners. On the other two corners are located the holes which accept the alignment pins of the upper core plate.

A serial number is stamped on the top nozzle of each fuel assembly for quality assurance tracking purposes. The assembly can thus be tracked through construction, shipment, core loading, and shuffling during refueling. These serial numbers are normally scanned by a television camera located on the refueling crane to verify proper core loading.

Absorber Rod Guide and Instrument Thimbles

The guide thimbles are the major structural members of the fuel assembly (Figures 3.1-16 and 3.1-17). They also provide channels for neutron absorber rods, burnable poison rods, neutron sources, or thimble plug assemblies. Each RCCA guide thimble is fabricated from zircaloy-4 tubing of two different diameters. The top of the thimble has a larger diameter to produce little restriction during a reactor trip and to allow short rod insertion times. Toward the bottom of the thimble is a transition to a smaller diameter tube. This produces a dashpot effect and slows the RCCA after a trip. Four small flow holes are located just above the dashpot region to reduce rod drop time, provide a path for water displaced from the dashpot by the RCCA, and allow some flow through the guide thimble to cool the control rod (this coolant is considered a design core bypass flow).

The dashpot is closed at the bottom by means of an end plug, which has a small flow port to avoid fluid stagnation in the dashpot volume during normal operation. The top end of the guide thimble is fastened to a tubular sleeve by three expansion swages. The sleeve fits into and is welded to the top nozzle adapter plate. The lower end of the guide thimble is fitted with an end plug, which is then fastened into the bottom nozzle by a weld-locked hollow screw.

The central instrumentation thimble (also called the instrument guide sheath) of each fuel assembly is not rigidly attached to either the top or the bottom nozzle, but

the thimble is constrained by its seating in the counterbore of each nozzle. The thimble internal diameter does not vary. An incore neutron detector guide thimble is installed through the bottom nozzle's large counterbore into the instrument guide sheath.

Grid Assemblies

The fuel rods are supported laterally at intervals along their length by spring clip grid assemblies (Figures 3.1-21 and 3.1-22), which maintain the lateral spacing between the rods throughout the design life of the assembly. Each fuel rod is afforded lateral support at six contact points within each grid by a combination of support dimples and spring fingers. The magnitude of the grid restraining force on the fuel rod is set high enough to minimize possible fretting, without overstressing the cladding at the points of contact between the grids and fuel rods. The grid assemblies also allow axial thermal expansion of the fuel rods without imposing restraint sufficient to develop buckling or distortion of the fuel rods.

Two types of grid assemblies are used in each fuel assembly. Both types consist of individual slotted straps interlocked in an "egg-crate" arrangement. The straps contain spring fingers, support dimples, and mixing vanes. One type, used in the high flux region of the fuel assemblies, consists of zircaloy straps permanently joined by welding at their points of intersection. This material is chosen primarily for its low neutron absorption properties. The internal straps include mixing vanes which project into the coolant flow and promote mixing of the coolant.

The other grid type, located at the ends of the fuel assemblies, does not include mixing vanes on the internal straps. The material of these grid assemblies is inconel-718, chosen because of its corrosion resistance and high strength. Joining of the individual straps is achieved by brazing at the points of intersection.

The outside straps on all grids contain mixing vanes which, in addition to their mixing function, aid in guiding the grids and fuel assemblies past projecting surfaces during handling or during loading and unloading of the core.

Handling of Fuel Assemblies

Due to its method of construction (long, square array supported by the long, small diameter RCCA guide thimbles), the fuel assembly exhibits excellent structural strength in the axial direction, but cannot accept large mechanical loads in the radial direction. A fuel assembly is, therefore, handled by grasping the top nozzle with a special tool and moving it while in the vertical position. If a fuel assembly is to be oriented horizontally, it must be supported at the grid locations to prevent bowing.

Other Fuel Designs

The description of the fuel assembly above is of the optimized fuel design. There are some other fuel designs that provide some improvements to the basic optimized fuel assembly.

One change is a debris filter bottom nozzle. The examination of leaking fuel over the years has shown that about 75% of the leakers were due to debris-induced fretting. The debris filter bottom nozzle helps mitigate the effects of debris in the coolant system by trapping it at the entrance of the fuel assembly. The bottom nozzle has a pattern of many small holes which allow reactor coolant to pass through while minimizing the passage of debris large enough to cause wear or fretting. Although the holes are smaller than the earlier design bottom nozzles, the hydraulic performance is the same, and there is no difference in coolant flow or heat transfer.

Another change is the addition of intermediate flow mixing grids. These grids are nonstructural grids located in the three uppermost spans between the zircaloy mixing vane structural grids. They incorporate a similar mixing vane array, with the prime function of mixing in the hottest fuel assembly spans. The increased mixing increases the heat transfer in the upper part of the core. Therefore, the margin to departure from nucleate boiling is increased. The intermediate flow mixing grids are physically shorter than the structural grids, and thus the mixing is accomplished with a minimal pressure drop.

A change has also been made to the material of choice for the guide thimbles, instrument tube, fuel cladding, and some of the grids. This new material is an improved zirconium alloy which contains reduced tin content and now contains niobium. This new material is more resistant to corrosion but has the strength and performance of zircaloy-4.

The top nozzle of the fuel assembly has also undergone some design changes. The material of construction is now a low cobalt stainless steel, which helps reduce radiation levels due to the activation of cobalt. Also, the top nozzle is manufactured to be removable. This allows the removal of leaking fuel rods from a fuel assembly and then replacing them with other fuel rods, stainless steel rods, or water holes. This allows the burnup of fuel rods that are not leaking, which results in fuel savings for the plant.

One of the driving forces behind these and other fuel design changes is longer operating cycles. Burning as much of the fuel as possible is much less expensive than using higher enrichment fuel. However, the longer operating cycle also means that more fission products are produced than with the lower burnup fuel. Therefore, changes must be made to allow the fission product gases to be collected inside the cladding without having excessive stresses. The thickness of the top and bottom nozzles has been reduced. This allows the fuel rods to be slightly longer. However, since the fuel length has not changed, the plenum area of each rod is now longer. The design of the plenum spring has also been changed to allow more space for the gases.

Full Length Rod Cluster Control Assemblies (RCCAs)

The RCCAs (also called control rods) provide a rapid means for reactivity control during both normal operating and accident conditions. RCCA design parameters are listed in Table 3.1-4.

The rod cluster control assemblies are divided operationally into two categories: control banks and shutdown banks. The control banks may be inserted or withdrawn to compensate for various reactivity changes during operation of the reactor and can trip (scram) to provide shutdown capability. The shutdown banks are reserved for shutdown use only and are always fully withdrawn from the core when the reactor is critical. They are inserted only when a reactor trip occurs.

Two criteria are employed for the design of the RCCAs. First, the total reactivity worth must be adequate to meet the nuclear requirements of the reactor. Second, since some of these rods may be partially inserted at power operation, the total power peaking factor should be low enough to ensure that full power capability can be met. The control and shutdown banks provide adequate shutdown margin. Shutdown margin is defined as the amount of reactivity by which the core would be subcritical if all RCCAs are tripped, assuming that the highest worth RCCA remains fully withdrawn.

An RCCA consists of a group of individual neutron absorber rods fastened at the top end to a common spider assembly, as illustrated in Figure 3.1-23. A cutaway of a fuel assembly with an RCCA inserted is shown in Figure 3.1-16.

The absorber material used in the control rods is silver-indium-cadmium alloy (Ag-In-Cd). The silver-indium-cadmium alloy is in the form of extruded rods which are sealed in stainless steel tubes to prevent the poisoning material from coming in direct contact with the coolant. The stainless steel tubing is sealed at the bottom and the top by welded end plugs. Sufficient clearance is provided to accommodate thermal expansion. The bottom plugs are made bullet-nosed to reduce the hydraulic drag during a reactor trip and to allow smooth insertion into the dashpot sections of the fuel assembly guide thimbles. Each upper plug is threaded for assembly to the spider and has a reduced end section to make the joint more flexible.

The spider assembly is in the form of a central hub with radial vanes containing cylindrical fingers from which the absorber rods are suspended. Handling detents and detents for connection to the drive rod assembly are machined into the upper end of the hub. A coil spring inside the spider body absorbs the impact energy at the end of a trip insertion. The radial vanes are joined to the hub by welding and brazing, and the fingers are joined to the vanes by brazing. All components of the spider assembly are made from types 304 and 308 stainless steel, except for the spring retainer, which is 17-4 pH stainless steel, and the springs, which are inconel 718 alloy.

The absorber rods, also called rodlets, are fastened securely to the spider to assure trouble free service. The rods are first threaded into the spider fingers and then pinned to maintain joint tightness, after which the pins are welded in place. The end plugs below the pin positions are designed with reduced-diameter sections to permit flexing of the rods to correct for small operating or assembly misalignments. The overall length is such that when the assembly is fully withdrawn, the tips of the absorber rods remain engaged in the guide thimbles, so that alignment between the rods and the thimbles is always maintained. Since the rods are long and slender,

they are flexible enough to conform to any small misalignments within the guide thimbles.

A long, hollow, grooved drive shaft (Figure 3.1-24) is attached to the spider hub of each RCCA by a split coupling. The drive shaft extends through the upper core support structure and through a reactor head penetration to the control rod drive mechanism. A disconnect rod, used during core disassembly, is located inside this shaft. When the disconnect rod is inserted into the drive shaft, it expands the split coupling and locks it into place in the hub.

Figure 3.1-25 shows the relative positions of the RCCA and associated equipment in the reactor. Since the poison rods are long and slender, they must be supported and aligned as they are withdrawn from the fuel assembly. The control rod guide tubes of the upper core support structure shown in Figures 3.1-2 and in 3.1-13 perform this function.

Burnable Poisons

Burnable poisons are added to the core to provide fixed discrete poisons when needed due to nuclear considerations, such as controlling power peaking and the moderator temperature coefficient. These discrete poisons may be in the form or burnable poison rod assemblies and/or a poison coating on the fuel pellets.

Figure 3.1-26 shows a burnable poison rod assembly (BPRA). BPRA design parameters are listed in Table 3.1-5.

The poison rods of the burnable poison assemblies are suspended from a flat spider plate and are inserted into the RCCA guide thimbles of selected fuel assemblies at selected unrodded locations. The spider plate fits within a fuel assembly top nozzle and rests on its top adapter plate. A T-bar and spring assembly is attached to the spider. As the upper core support structure is installed, the upper core plate contacts the T-bar and compresses the spring holding the burnable poison assembly in place.

Two designs of the poison rods could be used in the burnable poison assemblies. The poison rods in the older design, Figure 3.1-27, consist of borosilicate glass tubes contained within type 304 stainless steel tubular cladding, which is plugged and seal welded at the ends to encapsulate the glass. Each glass tube is also supported along the length of its inside diameter by a thin wall 304 stainless steel tubular inner liner. The top end of the liner is open to permit the diffused helium to pass into the void volume and the liner extends beyond the glass. The liner is flanged at the bottom end to maintain the position of the liner with the glass.

The rods are designed in accordance with the standard fuel rod design criteria; that is, the cladding is free standing at reactor operating pressures and temperatures and sufficient cold void volume is provided within the rods to limit internal pressures to less than the reactor operating pressure, assuming the total release of all helium generated in the glass as a result of the B-10 (n,α) reaction. The large void volume required for the helium is obtained through the use of glass in tubular form, which provides central voids along the length of the rods.

Based on available data on properties of borosilicate glass and on nuclear and thermal calculations for the rods, gross swelling or cracking of the glass tubing is not expected during operation. Some minor creep of the glass at the hot spot on the inner surface of the tube is expected to occur, but it continues only until the glass comes into contact with the inner liner.

The inner liner is provided to maintain the central void along the length of the glass and to prevent the glass from slumping or creeping into the void as a result of softening at the hot spot. The wall thickness of the inner liner is sized to provide adequate support in the event of slumping, but to collapse locally before rupture of the exterior cladding if large volume changes due to swelling or cracking should occur. The top end of the inner liner is open to receive the helium which diffuses out of the glass.

The second burnable poison design is called the wet annular burnable absorber, Figure 3.1-28. This design uses aluminum oxide/boron carbide as the absorber. The poison is in the form of a stack of hollow pellets wrapped inside and out with stainless steel cladding and pressurized with helium. Water is allowed to flow in the central passage. This allows for an increase in moderation in the center of the poison rod, which allows for better absorption of neutrons and a more complete burnout of the poison material.

Zirconium boride is used as the poison that is coated on the fuel pellets. Fuel assemblies which have coated fuel pellets are called integral fuel burnable absorbers (IFBAs). One of the advantages of using integral absorbers is that burnable absorbers can be placed in fuel assemblies that also have control rods inserted. The neutron flux shape can be more controlled by the placement of the absorber material and by controlling the number of fuel rods with absorber material, as dictated by individual plant needs.
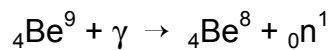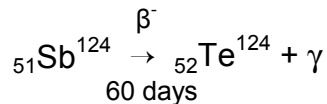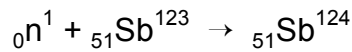
Neutron Source Assemblies

Prior to initial reactor operation and after long shutdown periods, the core neutron level may be too low to be detected by the installed excore nuclear instrumentation system. To insure adequate indication for the operator during long-term reactor shutdowns and during reactor startups, neutron source assemblies are installed in the core. These sources, in conjunction with subcritical multiplication, produce a neutron level high enough to be monitored by the source range nuclear instrumentation channels (2 cps required). It would be unacceptable for the core to achieve criticality with no indication of reactor power or rate of change of power. The sources are also necessary to provide measurable neutron flux levels during fuel loading. A source is not required to enable the reactor to achieve criticality.

There are two types of source assemblies employed in the Westinghouse design: primary source assemblies (Figure 3.1-29) and secondary source assemblies (Figure 3.1-30).

The primary source spontaneously produces neutrons for indication for the initial reactor startup while the secondary source (which is activated only after being exposed to neutron bombardment) provides neutrons for subsequent startups.

Both types of source assemblies are constructed as burnable poison assemblies, with several of the poison rods replaced by source rods. The primary source rods for the Trojan plant were capsules of californium. Californium fissions spontaneously and thereby produces neutrons directly.

Each of the two (2) secondary sources contains a symmetrical grouping of four (4) secondary source rods and twenty thimble plugs. The secondary sources are constructed of antimony beryllium (SbBe), which is activated only after exposure to neutron flux during reactor operation. The secondary source produces neutrons by the following reactions

$$_0n^1 + {}_{51}Sb^{123} \rightarrow {}_{51}Sb^{124}$$

$$_{51}Sb^{124} \xrightarrow[\text{60 days}]{\beta^-} {}_{52}Te^{124} + \gamma$$

$$_4Be^9 + \gamma \rightarrow {}_4Be^8 + {}_0n^1$$

Neutron source assemblies are located at diametrically opposite sides of the core at locations close to the source range nuclear instrumentation detectors. These assemblies are inserted into the rod cluster control guide thimbles in fuel assemblies at selected unrodded locations.

Thimble Plugging Assemblies (Thimble Plugs)

In order to limit core bypass flow through the absorber rod guide thimbles in the fuel assemblies not containing control rods, source assemblies, or burnable poison rods, the fuel assemblies at these locations are fitted with thimble plugging assemblies (Figure 3.1-31).

A thimble plug consists of a flat spider plate with short rods suspended from the bottom surface, and a spring pack assembly and mixing device attached to the top surface. When installed in the core, the plugging device fits within a fuel assembly top nozzle and rests on its adaptor plate.

The short rods project into the upper ends of the guide thimbles to reduce the bypass flow area. The spring pack is compressed by the upper core plate contacting the T-bar when the upper internals package is lowered into place. When the core is fully assembled, all fuel assembly absorber rod guide tubes will have control rods, burnable poison rods, source rods, or thimble plugs inserted into them. All components of the plugging device, except for the springs, are constructed of Type 304 stainless steel. The springs (one per plugging device) are wound from an age-hardened nickel base alloy to obtain high strength.

3.1.3.4   Control Rod Drive Mechanisms (CRDMs)

The control rod drive mechanisms are electromechanical devices (magnetic jacks) used to position the rod cluster control assemblies (control rods) in the reactor core. Each CRDM is capable of withdrawing or inserting a control rod in discrete

increments (steps) or holding it at a constant position. Tripping (scramming) is accomplished by simply de-energizing the mechanisms and allowing the control rods to fall by gravity into the core. Each RCCA is operated by its own individual CRDM.

The complete drive mechanism, shown in Figures 3.1-32 and 3.1-33, consists of an internal latch assembly, the drive shaft assembly, the pressure vessel (including the rod travel housing), the operating coil stack, and the individual rod position indication coil stack. Reactor coolant at full system pressure fills the pressure housing and rod travel housing. All moving parts are immersed in reactor coolant. This housing forms the RCS pressure boundary.

Each assembly is an independent unit which can be dismantled or assembled separately. The mechanism pressure housing is threaded onto an adaptor atop the reactor pressure vessel head and seal welded. The operating drive assembly is connected to the control rod (directly below) by means of a grooved drive shaft. The upper section of the drive shaft is suspended from the working components of the drive mechanism. The drive shaft and control rod remain connected during reactor operation, including tripping of the rods.

Three magnetic coils, which surround the rod drive pressure housing, induce magnetic flux through the pressure housing wall to operate the working components. They move two sets of latches which lift, lower, or hold the grooved drive shaft. To move the control rod, the three magnets are turned on and off in a fixed sequence by the solid-state full length rod control system (Section 8.1). The sequencing of the magnets produces discrete steps (5/8 in. each) of rod motion over the 144 inches of normal control rod travel.

The mechanism develops a lifting force approximately two times the static lifting load. Therefore, extra lift capacity is available for overcoming mechanical friction between the moving and the stationary parts. Gravity provides the driving force for rod insertion and the weight of the whole rod assembly is available to overcome any resistance.

The mechanisms are designed to operate in water at 650°F and 2485 psig. The temperature at the mechanism head adaptors is much less than 650°F because they are located in regions where there is a limited flow of water from the reactor core, while the pressure is the same as in the reactor pressure vessel.

Latch Assembly

The latch assembly consists of the components which engage and support the grooved drive shaft during insertion, withdrawal, and holding operations. All latch components are located inside the pressure housing.

The primary components are the two latches which engage the drive shaft: the stationary gripper latch and the movable gripper latch. A number of pole pieces, springs, pivot pins, and linkages are provided to support and align the latches during movement or holding operations.

The upper set of latches (movable grippers) is engaged when the movable gripper coil is energized and can move upward 5/8 inch when the lift coil is energized. The lower set of latches (stationary grippers) is engaged when the stationary gripper coil is energized and can move only 1/16 inch axially to allow load transfer between the movable and stationary grippers during rod movement. The stationary gripper latches are normally engaged during periods of no rod motion (holding operations). The insertion and withdrawal sequences are discussed in Section 8.1.

Pressure Vessel

The pressure vessel associated with each CRDM consists of the pressure housing and rod travel housing. The pressure housing is the lower portion of the vessel and contains the latch assembly. The rod travel housing is the upper portion of the vessel. It provides space for the drive shaft during its upward movement as the control rod is withdrawn from the core.

Operating Coil Stack

The operating coil stack is an independent unit which is installed on the drive mechanism by sliding it over the outside of the pressure housing. It rests on a pressure housing flange without any mechanical attachment and can be removed and installed while the reactor is pressurized. Forced air from the CRDM cooling fans flows along the outside of the coil stack to maintain a coil casing temperature of approximately 248°F or lower. These fans must be operating whenever RCS temperature is greater than 350°F.

Drive Shaft Assembly

The main function of the drive shaft, as shown in Figure 3.1-24, is to connect the control rod to the control rod drive mechanism. Grooves for engagement and lifting by the latches are located throughout the 144 in. of control rod travel. The grooves are spaced 5/8 inch apart to coincide with the mechanism step length and have 45° angle sides. The drive shaft is attached to the control rod by a split coupling. The coupling engages the grooves in the spider assembly hub.

A 1/4-in. diameter disconnect rod extends inside the length of the hollow drive shaft. It has a locking button at its lower end to expand and lock the coupling to the control rod hub. At its upper end, there is a disconnect assembly. For remote disconnection of the drive shaft assembly from the control rod, a button at the top of the drive rod actuates the connect/disconnect assembly. The drive shaft assembly can be attached and removed from the control rod only when the reactor vessel head is removed.

During refueling, the drive shafts are uncoupled from the control rod spiders and are removed as the upper internals (upper core support structure) are removed. The control rods themselves remain in the fuel assemblies.

Individual Rod Position Indication (IRPI) Coil Stack

One type of rod position instrumentation, the IRPI coil stack, is installed around the rod travel housing. It detects control rod position by means of a cylindrically wound differential transformer which spans the normal length of rod travel (144 inches). As the drive shaft moves inside the rod travel housing, it changes the coupling between the primary and secondary coils and produces a signal proportional to control rod height.

More detailed descriptions of the individual rod position indication system are found in Sections 8.3 and 8.4.

Materials of Construction

All components exposed to reactor coolant, such as the pressure vessel, latch assembly, and drive rod, are made of or clad with materials which resist the corrosive boric acid. Three types of metals are used exclusively: stainless steels, Inconel, and cobalt-based alloys. Wherever magnetic flux is carried by parts exposed to the main coolant, 400 series stainless steel is used.

Cobalt-based alloys are used for the pins, latch tips, and bearing surfaces. Inconel X is used for the springs of both latch assemblies, and 304 stainless steel is used for all pressure containment. Hard chrome plating provides wear surfaces on the sliding parts and prevents galling between mating parts (such as threads) during assembly. Outside of the pressure vessel, where the metals are exposed only to the reactor plant containment environment and cannot contaminate the reactor coolant, carbon and stainless steels are used. Carbon steel, because of its high permeability, is used for flux return paths around the operating coils. It is zinc plated (0.001 in. thickness) to prevent corrosion.

3.1.4 System Interrelationships

3.1.4.1   Reactivity Control

Reactivity control is accomplished by positioning control rods and by adjusting the concentration of the soluble neutron absorber (boric acid) in the moderator. The boric acid concentration is varied to control long-term reactivity changes such as:

1. Fuel depletion and fission product buildup,
2. The reactivity change associated with the transition from cold shutdown to hot zero power,
3. Reactivity changes produced by intermediate-term fission products such as xenon and samarium, and
4. Burnable poison depletion.

Control rod position is varied to control more rapid reactivity changes due to:

1. Shutdown,
2. Reactivity changes due to coolant temperature changes in the power range,

3. Reactivity changes associated with the power coefficient of reactivity, and
4. Reactivity changes due to void formation.

Due to operating restrictions, some of the reactivity changes designed to be compensated by control rod motion are now accomplished by boron concentration changes. These are associated with planned power changes during operation.

3.1.4.2   Vessel Flowpath

As shown in Figure 3.1-34, reactor coolant enters the reactor vessel through the four inlet nozzles, impinges against the upper core barrel, and flows downward through the annulus between the core barrel and the vessel wall. In passing the neutron shield pads, some flow goes between the neutron shield pads and the vessel. The downward coolant flow continues between the radial support members into the lower vessel head plenum among the tie plates and instrument guide columns, where the flow is directed upward.

The coolant then passes through the lower core plate and into the core to remove the heat generated in the fuel assemblies. Flow continues upward through the fuel assemblies (cross-flow between assemblies is also possible) and exits the core through the upper core plate. The coolant then flows laterally past the support columns and control rod guide tubes of the upper core support structure to the outlet nozzles of the core barrel.

These outlet nozzles have flanges which direct the flow. The flanges maintain small clearances with the vessel outlet nozzles. Ninety-three and one half percent (93.5%) of the total coolant flow is available for core heat removal. The remainder (6.5%) bypasses the core. Core bypass flows and their values consist of:

1. Nozzle bypass flow, from the reactor vessel inlet nozzles directly to the outlet nozzles through the small clearances between the core barrel outlet nozzles and the reactor vessel outlet nozzles. This flow accounts for 0.68% of total coolant flow.

2. RCCA guide thimble bypass flow through the small flow holes at the dashpot sections of the guide thimbles. This flow provides cooling for any inserted control rods and burnable poison assemblies and accounts for 3.85% of total coolant flow.

3. Core baffle bypass flow between the core barrel and the core baffle through holes machined in the former plates for cooling. This flow accounts for 1.84% of total coolant flow. Included in this value is 1.51% for actual design flow through the core baffle, 0.23% for outer fuel assembly to baffle gap leakage, and 0.10% for leakage through the plugged barrel flow holes.

4. Head cooling bypass flow through holes drilled in the core barrel flange and corresponding holes in the upper support plate flange, which provides some reactor inlet flow into the head area for cooling. This flow passes through holes in the upper guide tubes to rejoin the rest of the coolant outlet flow. This flow accounts for 0.13% of total coolant flow.

3.1.5   Summary

The reactor vessel and internals support and align the reactor core and its associated components. Additionally, the vessel and internals provide a flowpath to ensure adequate heat removal from the fuel assemblies.

The cylindrical reactor vessel has a removable head with penetrations for the control rod drive mechanisms and incore temperature monitoring instrumentation. Incore nuclear instrumentation enters through penetrations in the bottom of the reactor vessel. The vessel is supported from pads welded to its nozzles.

The lower internals (lower core support structure) hang from the reactor vessel support ledge and align and contain the fuel assemblies. The core barrel is aligned and supported radially by several keys at its bottom, which mate with keyways attached to the reactor vessel wall. Neutron shield pads are attached to the core barrel at core level to reduce radiation damage (primarily neutron embrittlement) to the reactor vessel. Retrievable specimens of reactor vessel materials are attached to the core barrel to monitor radiation-induced changes in the reactor vessel. A core baffle surrounds the core to guide most of the coolant flow through the fuel assemblies.

The upper internals are also supported by a flange at the reactor vessel support ledge. Control rod guide tubes support and align the RCCAs when they are withdrawn from the fuel assemblies. The support columns provide structural strength to transfer normal and accident loads to the reactor vessel support ledge and support the incore temperature detection system.

Each fuel assembly contains 264 fuel rods arranged in a 17x17 array. Each fuel rod is a long, thin zircaloy tube containing slightly enriched uranium dioxide in the form of ceramic pellets. Structural strength for the fuel assemblies is provided by the control rod guide thimbles, grid straps, and top and bottom nozzles. The fuel rods do not provide any structural support for the fuel assembly. The fuel assemblies are aligned by pins in the upper and lower core plate, which mate with holes in the top and bottom nozzles. All control rod guide thimbles are filled with control rods, burnable poison assemblies, source assemblies, or thimble plugging assemblies.

Full length control rod drive mechanisms are magnetic jack assemblies which move control rods in discrete steps. Tripping is accomplished by de-energizing the mechanisms. The control rods are designed to respond to fast reactivity changes, while slow changes such as fuel burnup are compensated by boron concentration changes.

Nearly all reactor coolant flow is available for core cooling, with a small portion bypassing the core at the core barrel to vessel gap, head cooling, control rod guide thimble cooling, and core baffle flowpaths.

Table 3.1-1
Reactor Vessel Design Parameters

Hydrostatic test pressure	3,107 psig
Design pressure	2,485 psig
Design temperature	650°F
Reactor vessel height	525.8"
Number of closure head studs	54
Closure head stud - diameter	7.0"
Vessel flange - width	32.5"
Vessel shell - inside diameter	173"
Inlet Nozzle - inside diameter	27.2"
Outlet Nozzle - inside diameter	28.8"
Closure head - thickness	6.5"
Beltline - thickness	8.5"
Lower hemispherical head - thickness	5.5"
Vessel cladding - thickness	0.156"
Stainless steel insulation - thickness	3.0"

Table 3.1-2
Fuel Assembly Design Parameters

Number of fuel assemblies	193
Number of fuel rods per assembly	264
Number of guide thimbles per assembly	24
Number of grid straps per assembly	8
Rod array	17 x 17
Fuel (UO_2) - weight	222,739 lbs
Cladding (Zr_4)- weight	50,913lbs
Grid straps (Inconel-718) - weight	2,324
Guide thimble - outside diameter	0.482"
Guide thimble - inside diameter	0.450"

Table 3.1-3
Fuel Rod Design Parameters

Number of fuel rods (total)	50,952
Fuel rod - outside diameter	0.374"
Gap - diameter	0.0065"
Fuel rod cladding - thickness	0.0225"
Fuel rod cladding material	Zr_4
Fuel pellet - diameter	0.3225"
Fuel pellet - length	0.530"
Fuel pellet - density	95% theoretical
Fuel pellet material	UO_2

Table 3.1-4
RCCA Design Parameters

Neutron absorber	Ag-In-Cd
Neutron absorber composition	80%-15%-5%
Number of RCCAs	53
Number of rodlets per RCCA	24
RCCA rodlet - cladding material	304 SS
Cladding - thickness	0.0185"
RCCA - weight	157 lbs

Table 3.1-5
BPRA Design Parameters

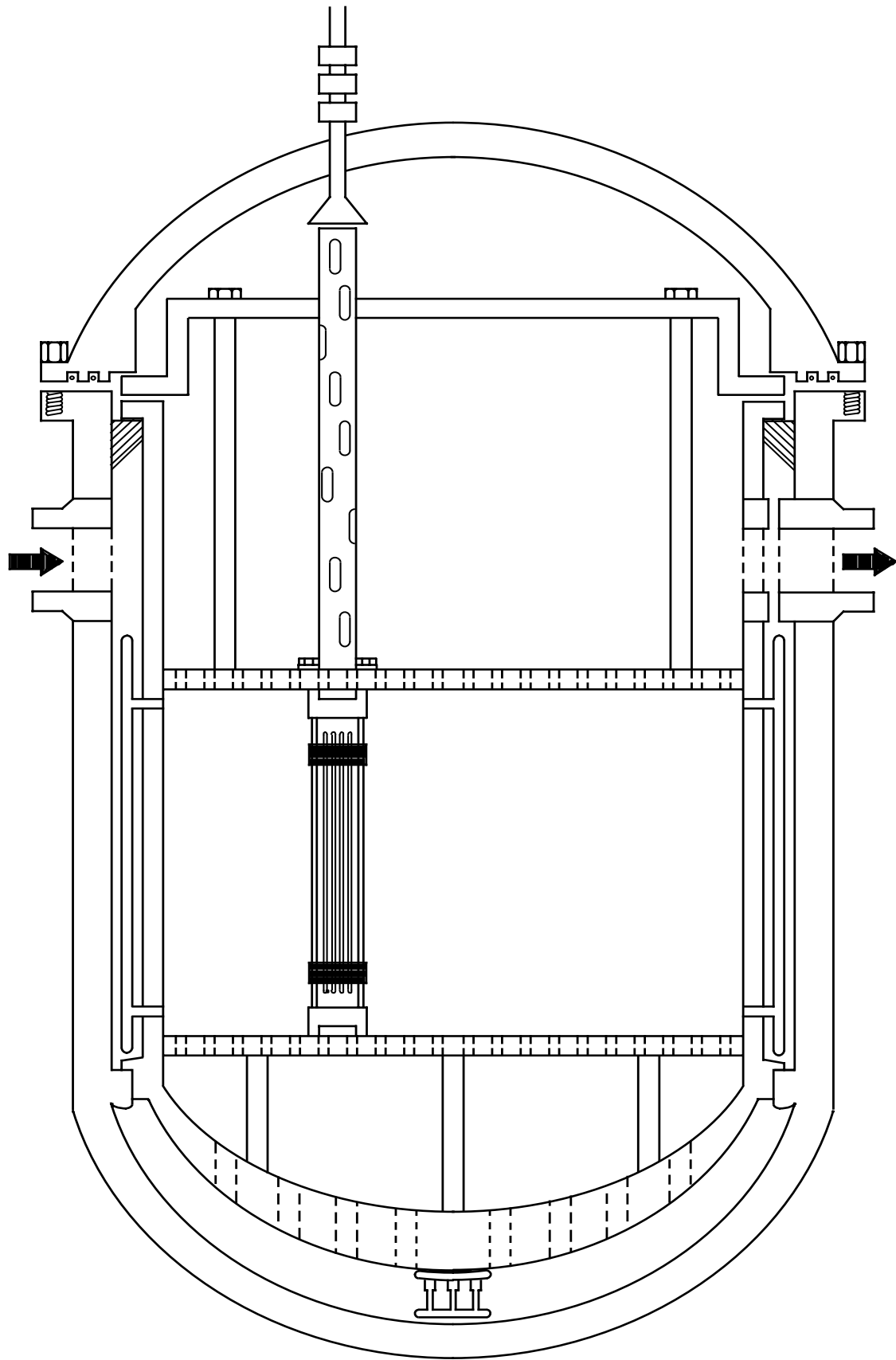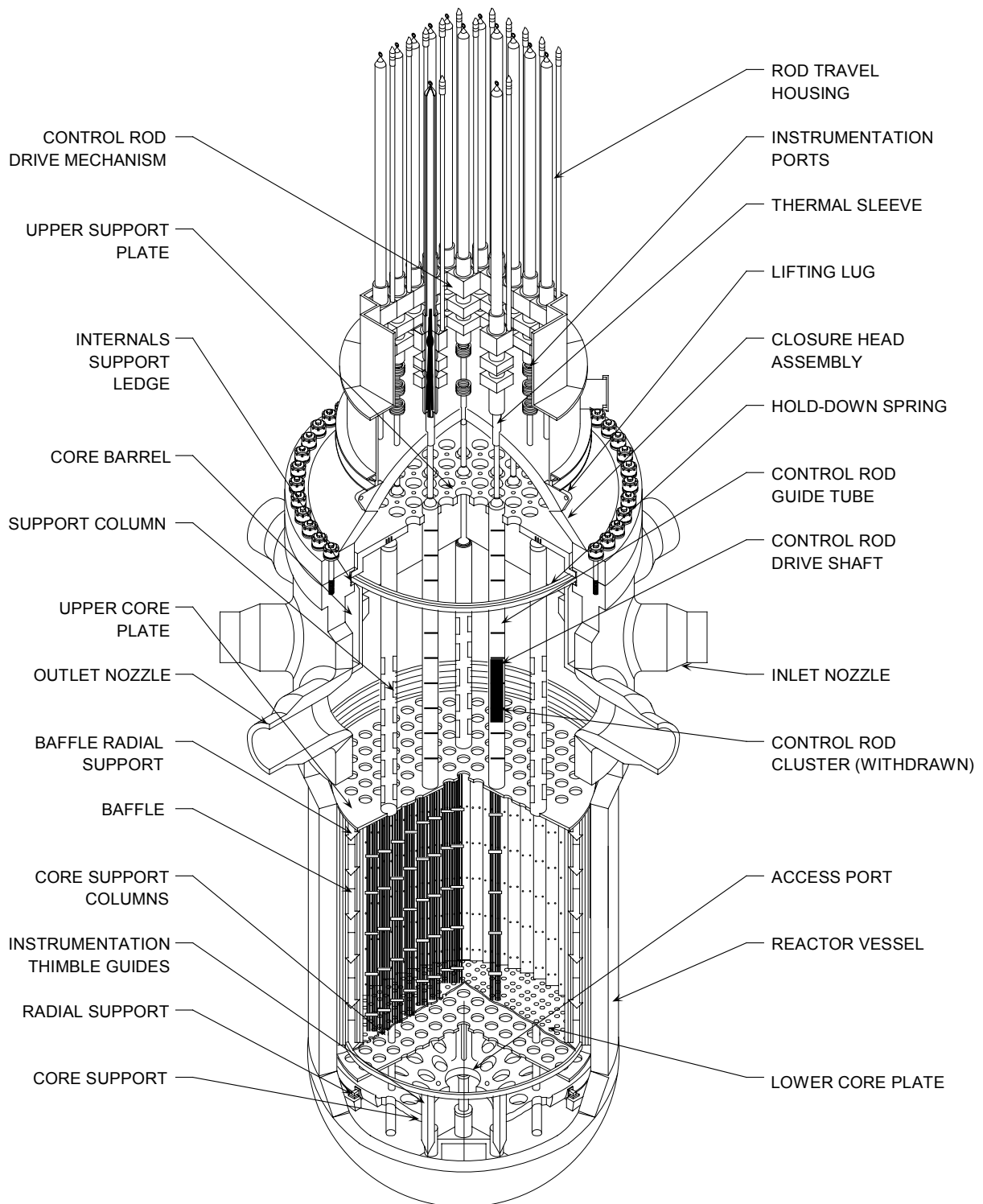|	
Number of burnable poison rods	1,440
Burnable poison rod material	Borosilicate glass
BPRA rodlet - outside diameter	0.381"
BPRA rodlet - cladding material	304 SS
BPRA rodlet - boron loading (B_2O_2)	12.5% weight
Reactivity worth - hot	7,630 pcm
Reactivity worth - cold	5,500 pcm

Figure 3.1-1 Reactor Vessel Cutaway

0199-3

ROD TRAVEL
HOUSING

INSTRUMENTATION
PORTS

THERMAL SLEEVE

LIFTING LUG

CLOSURE HEAD
ASSEMBLY

HOLD-DOWN SPRING

CONTROL ROD
GUIDE TUBE

CONTROL ROD
DRIVE SHAFT

INLET NOZZLE

CONTROL ROD
CLUSTER (WITHDRAWN)

ACCESS PORT

REACTOR VESSEL

LOWER CORE PLATE

CONTROL ROD
DRIVE MECHANISM

UPPER SUPPORT
PLATE

INTERNALS
SUPPORT
LEDGE

CORE BARREL

SUPPORT COLUMN

UPPER CORE
PLATE

OUTLET NOZZLE

BAFFLE RADIAL
SUPPORT

BAFFLE

CORE SUPPORT
COLUMNS

INSTRUMENTATION
THIMBLE GUIDES

RADIAL SUPPORT

CORE SUPPORT

Figure 3.1-2 Reactor Vessel Internals

CORE
BAFFLE

CORE
BARREL

REACTOR
VESSEL

IRRADITION
SPECIMEN GUIDE
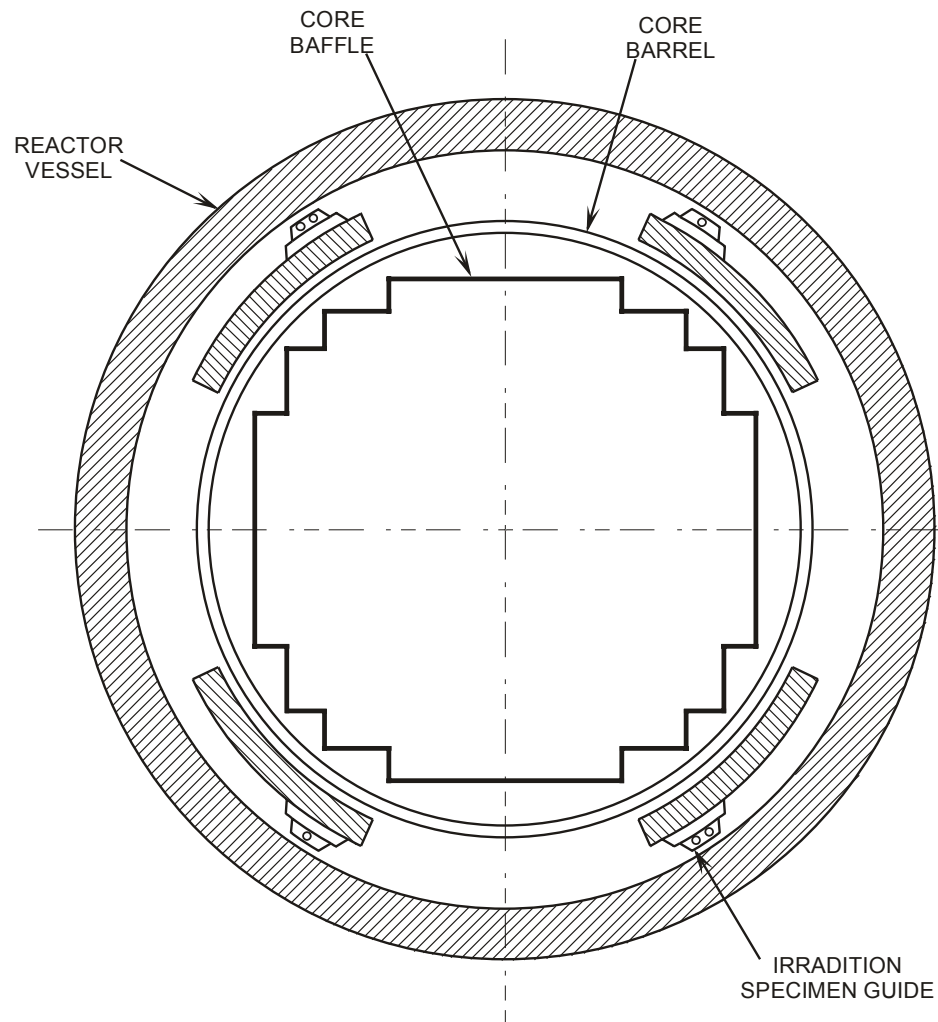
Figure 3.1-3   Reactor Vessel Cross Section
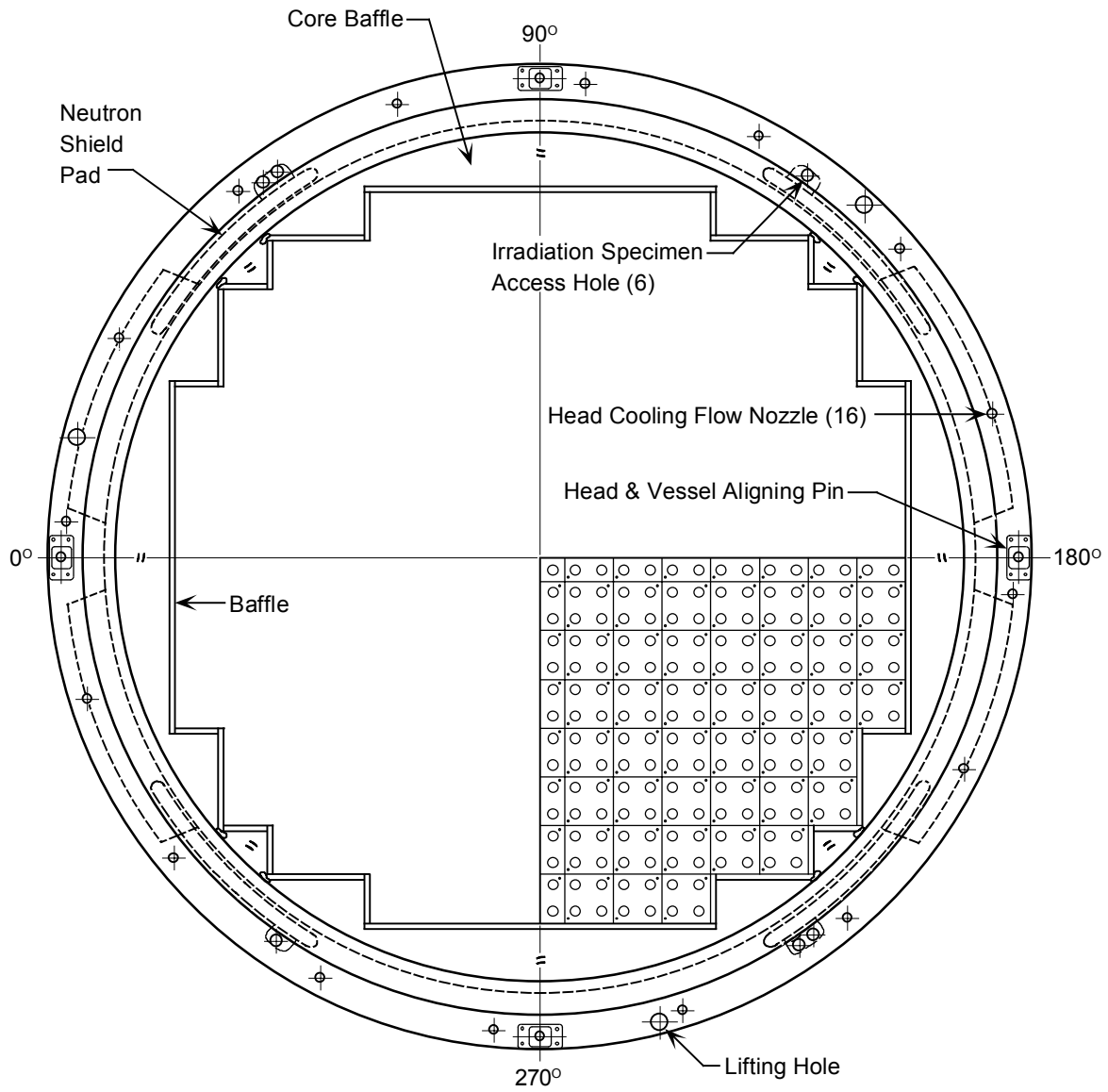
Figure 3.1-4 Core Barrel Flange

Figure 3.1-5 Core Loading Arrangement

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1					N02 K-05	L13 K-15 Cy12	N19 E-04	R33	N23 J-06	N29 K-11	N08 L-04				
2			N14 D-14	R17	R14	R30	R32	N04 J-10	R07	R25	R18	R35	N18 M-14		
3			N06 B-12	D38R K-10	R37	M17 N-05	M45 G-15	L11 A-06 Cy12	P06 G-12	M14 L-03	M48 F-15	M20 K-15	R43	F11 F-10	N13 P-12
4		R16	R38	P28 J-12	P18 H-12	P17 D-10	Q18 E-02	P38 G-14	Q26 L-02	P34 M-10	P08 J-05	P07 M-07	R41	R10	
5	N12 M-11	R12	M19 A-10	P21 L-09	Q04 N-03	Q17 C-04	P04 G-09	P40 J-14	P19 L-11	Q21 N-04	Q01 C-03	P09 M-08	M07 E-03	R20	N15 E-06
6	N32 E-10	R28	M43 A-06	P27 F-12	Q11 M-13	F04R H-09	Q27 K-14	F07R H-10	Q07 F-14	F56R J-08	Q24 D-13	P11 K-12	M26 R-09	R29	L12 R-06 Cy12
7	N22 K-09	R09	M15 N-11	Q20 P-11	P13 E-11	Q08 B-06	P29 G-05	N34 H-14	P25 E-09	Q15 P-06	P20 J-09	Q23 B-11	L23 F-15 Cy12	R24	N24 D11
8	R04	N25 F-09	P35 D-07	P42 B-07	P41 B-09	F18R F-08	N36 B-08	D12 H-13 Cy 4	N33 P-08	F05R K-08	P37 P-07	P39 P-09	P16 M-09	N21 K-07	R03
9	N11 M-05	R36	L09 K-01 Cy12	Q28 P-05	P03 G-07	Q22 B-10	P33 L-07	N35 H-02	P02 J-11	Q14 P-10	P24 L-05	Q19 B-05	M36 C-05	R21	N26 F-07
10	L20 A-10 Cy12	R01	M47 A-07	P23 F-04	Q09 M-03	F03R G-08	Q13 K-02	F02R H-06	Q06 F-02	F21 H-07	Q10 D-03	P15 K-04	M18 R-10	R27	N27 L-06
11	N20 L-10	R15	M05 L-13	P01 D-08	Q03 N-13	Q05 C-12	P22 E-05	P44 G-02	P05 J-07	Q12 N-12	Q02 C-13	P32 E-07	M38 R-06	R08	N09 D-05
12		R11	R40	P26 D-09	P30 G-11	P36 D-06	Q16 E-14	P43 J-02	Q25 L-14	P12 M-06	P14 H-04	P10 G-04	R39	R19	
13			N10 B-04	F30 F-06	R44	M30 F-01	M32 K-01	M46 E-13	P31 J-04	L30 R-10 Cy12	M04 J-01	M24 C-11	R42	F19R K-06	N05 P-04
14			N16 D-02	R05	R23	R26	R02	N28 G-06	R22	R13	R31	R06	N07 M-02		
15					N03 E-12	N31 F-05	N30 G-10	R34	N17 L-12	L01 F-01 Cy12	N01 F-11				

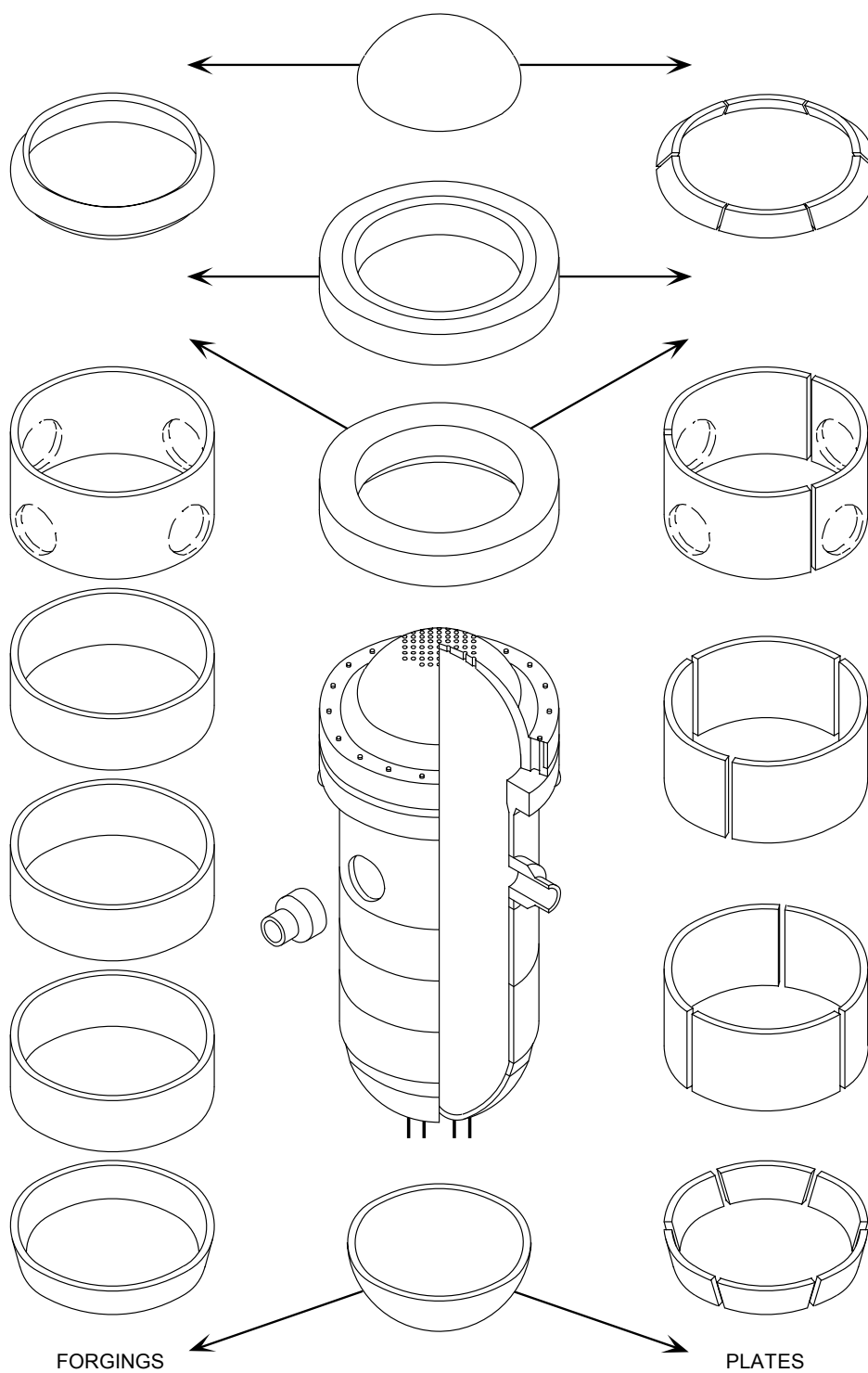|	
XXX	Assembly Identity
XXX	Position in Previous Cycle
XXX	Discharge Cycle of Reinserts

Figure 3.1-5 Core Loading Arrangement

FORGINGS

PLATES

Figure 3.1-6   Reactor Vessel Construction

CLADDING
HEAD FLANGE
SELF ENERGIZING
METALIC " O - RING "
GASKETS

HEAD FLANGE

A

A

VESSEL FLANGE
LEAKOFF CONNECTIONS

CLADDING

TE

REACTOR COOLANT
DRAIN TANK

N.C.

N.O.

LEAKOFF CONNECTIONS

VESSEL FLANGE

O-RING GASKETS

WIRE CLIPS

SECTION A-A

SECTION THRU REACTOR VESSEL

O-RING GASKET

WIRE CLIP

SCREW

BACKING PLATE

HEAD FLANGE

O RING GASKET FASTENING DETAIL
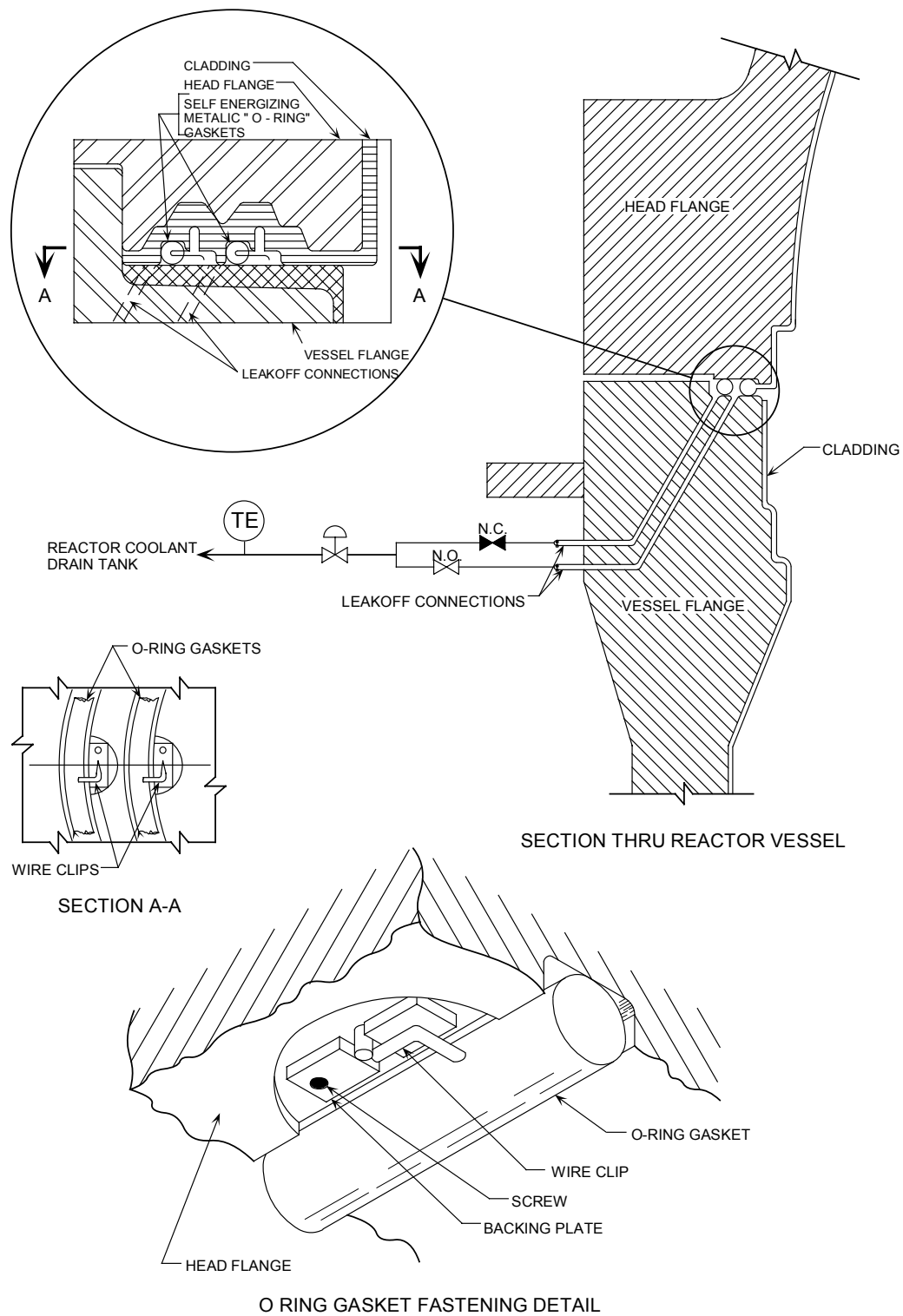
Figure 3.1-7   Reactor Vessel Seal

BLIND
FLANGE

1" HEAD VENT

SOLENOID OPERATED GLOBE VALVE

3/8" ORIFICE

8001A   S   S   8002A

1" MAN.
GLOBE
VALVE

S   S

8001B   8002B

CONTAINMENT
ATMOSPHERE
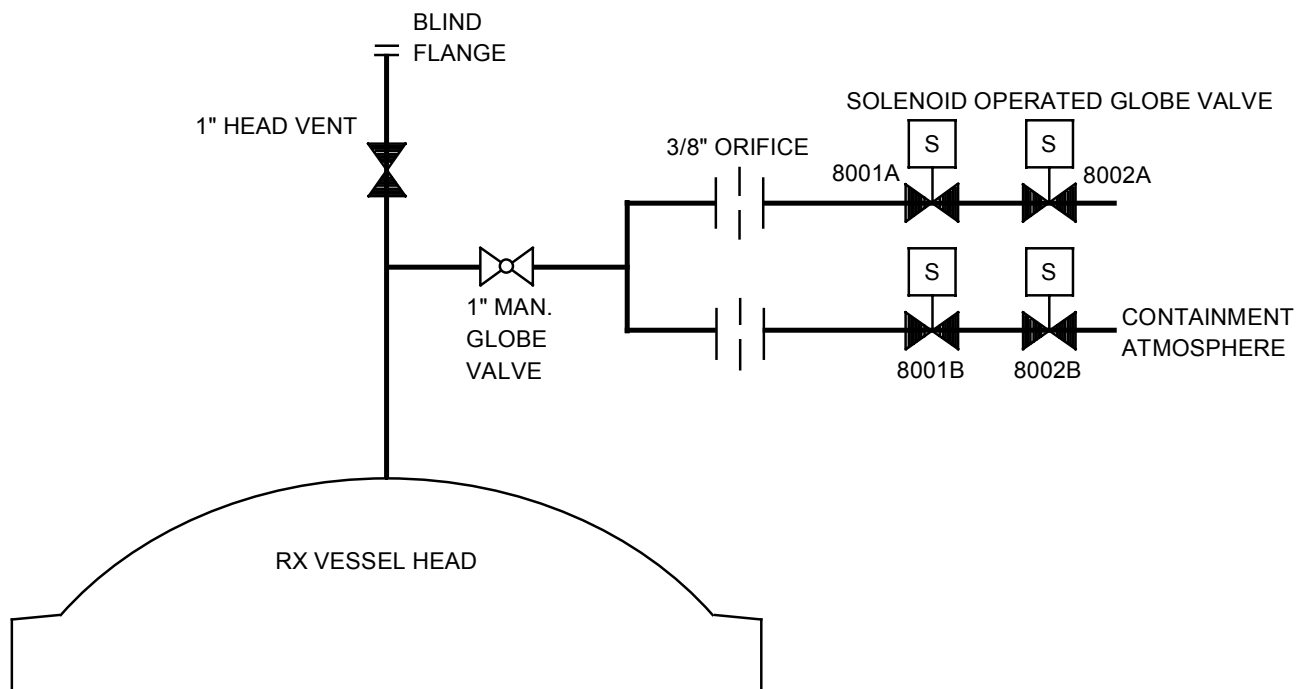
RX VESSEL HEAD

Figure 3.1-8 Reactor Vessel Head Venting System

VENT OPENING

REACTOR SUPPORT

ANCHOR BOLTS

VENT OPENING
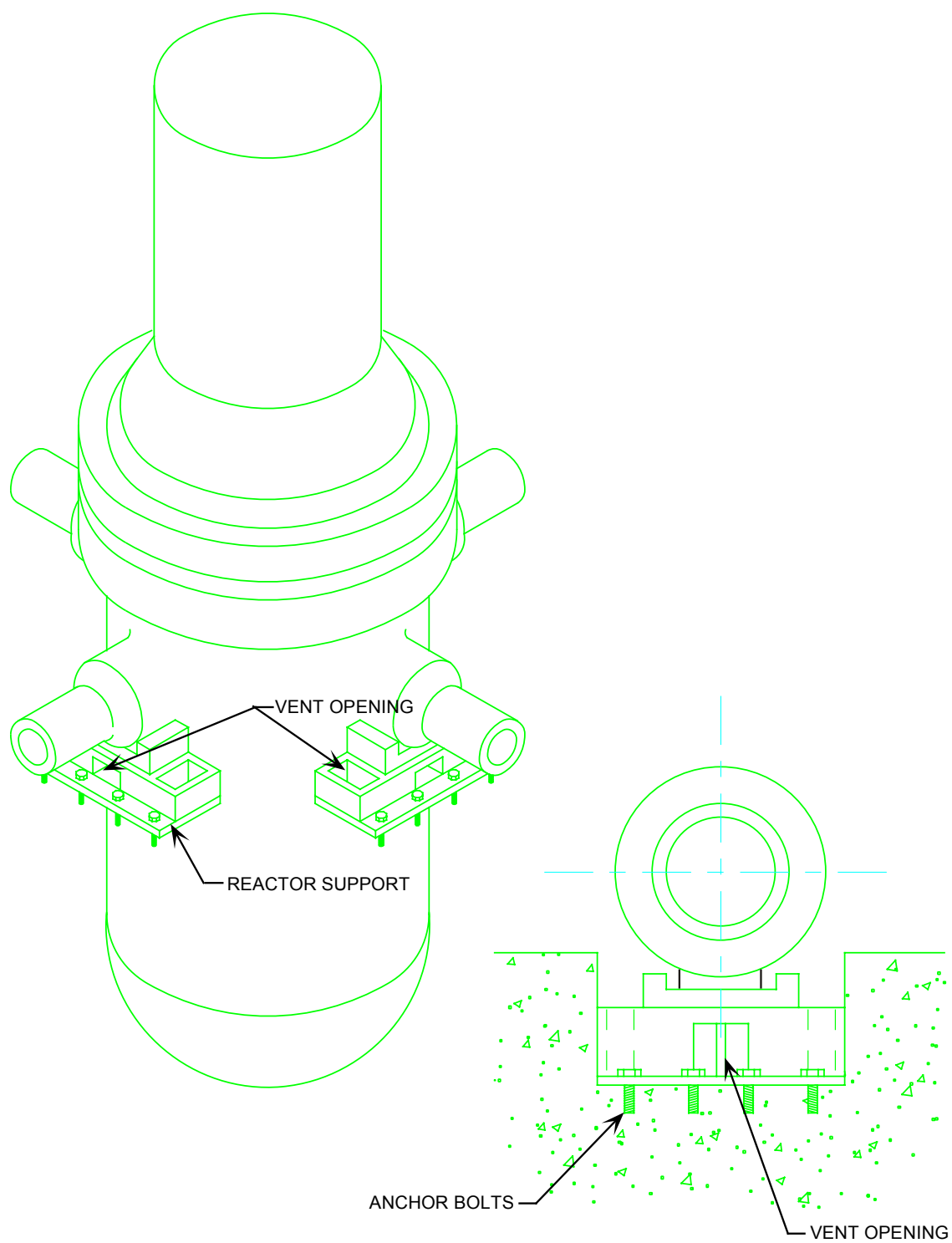
Figure 3.1-9   Reactor Vessel Supports

CORE BARREL FLANGE

UPPER CORE
BARREL

NEUTRON PAD

LOWER CORE BARREL

IRRADIATION
SPECIMEN GUIDES

FORMER

ACCESS PORT

BAFFLE

LOWER CORE
PLATE

LOWER
SUPPORT COLUMN

DIFFUSER PLATE

CORE SUPPORT

SECONDARY
SUPPORT
ASSEMBLY

INSTRUMENTATION
THIMBLE GUIDES
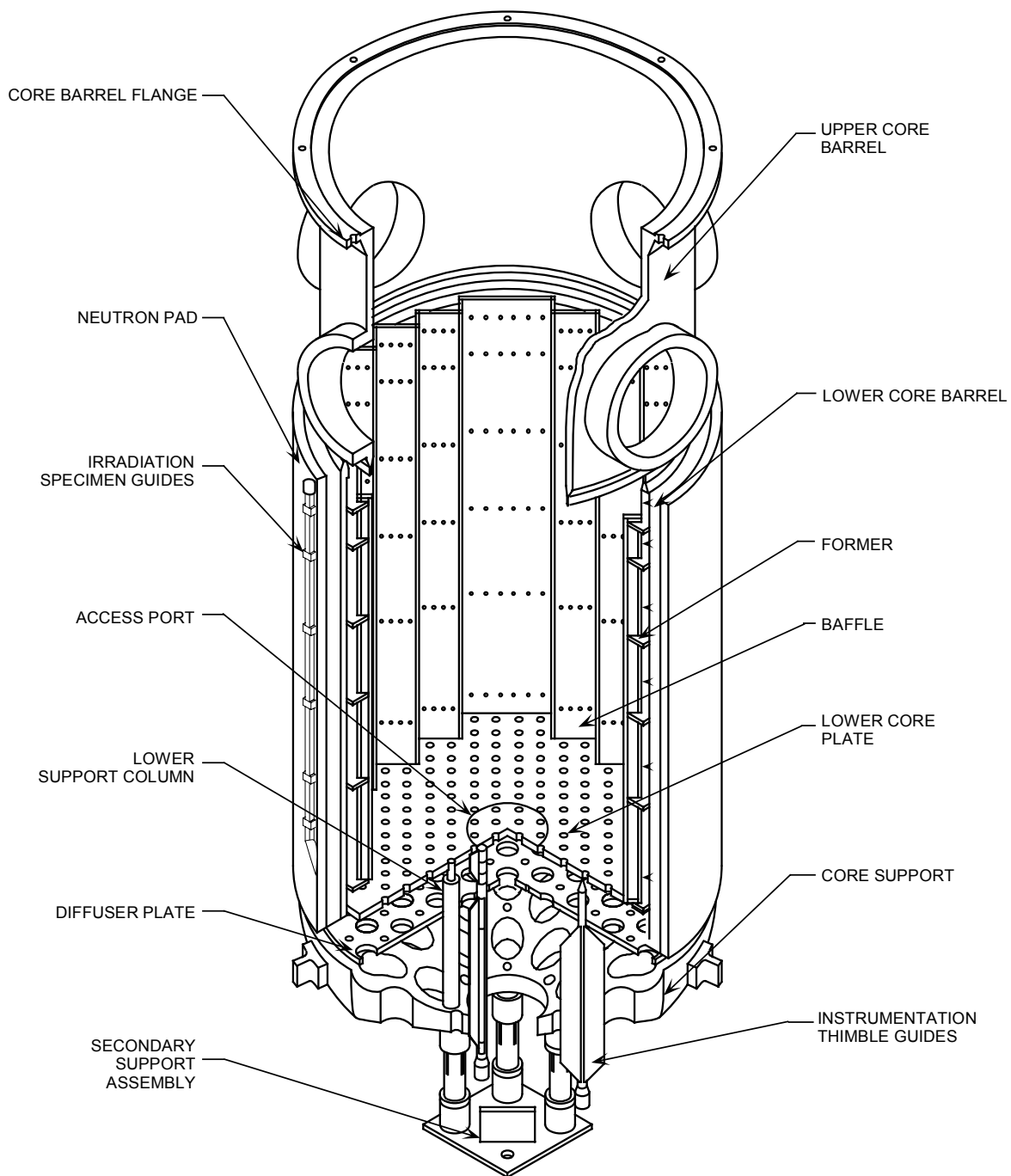
Figure 3.1-10   Lower Core Support Structure
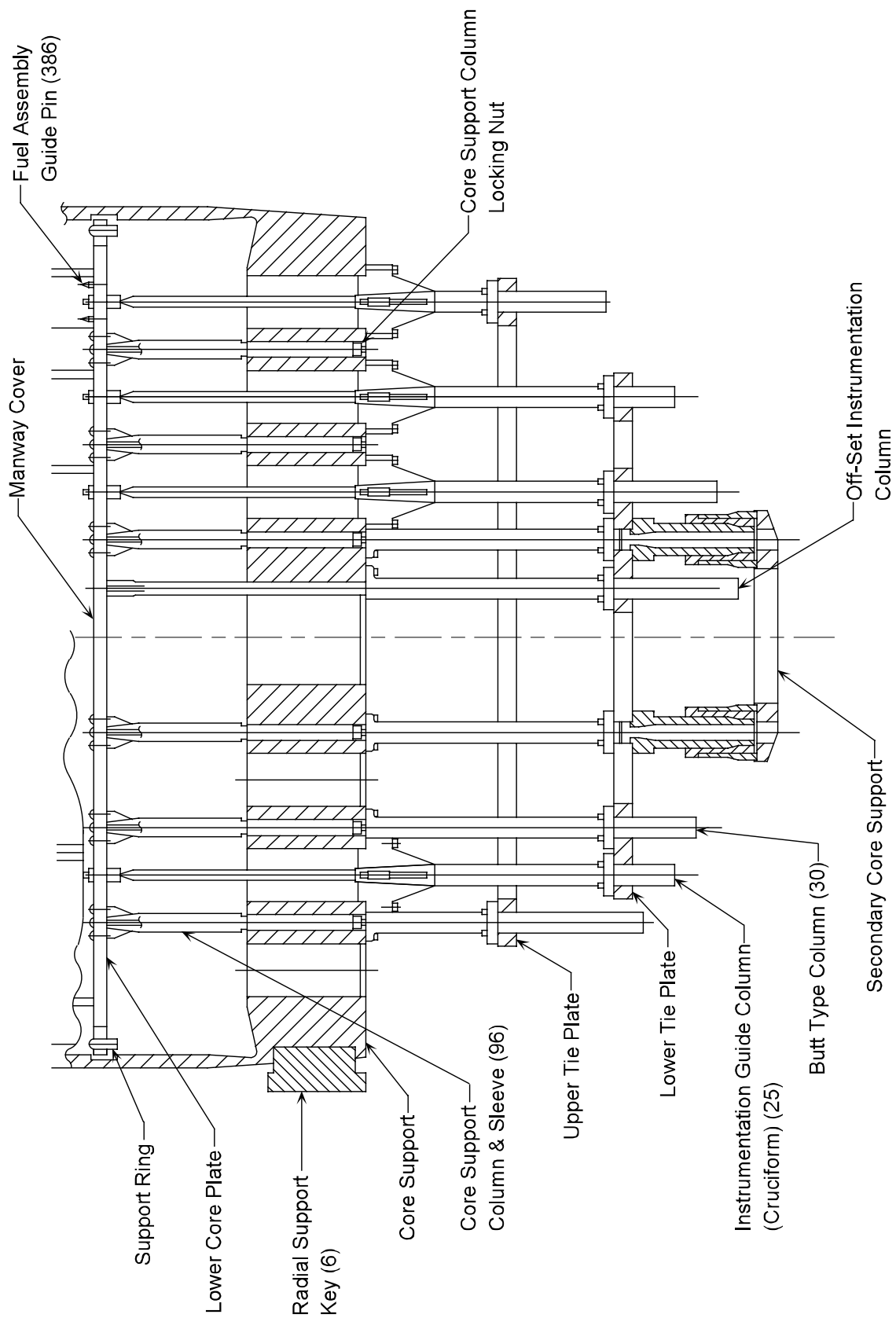
Figure 3.1.11 Instrument Guide and Secondary Core Support Assembly

THERMOCOUPLE COLUMN

CONTROL ROD
GUIDE TUBE
EXTENSION

UPPER SUPPORT
PLATE

CONTROL ROD
GUIDE TUBE
ASSEMBLY

SUPPORT
COLUMN
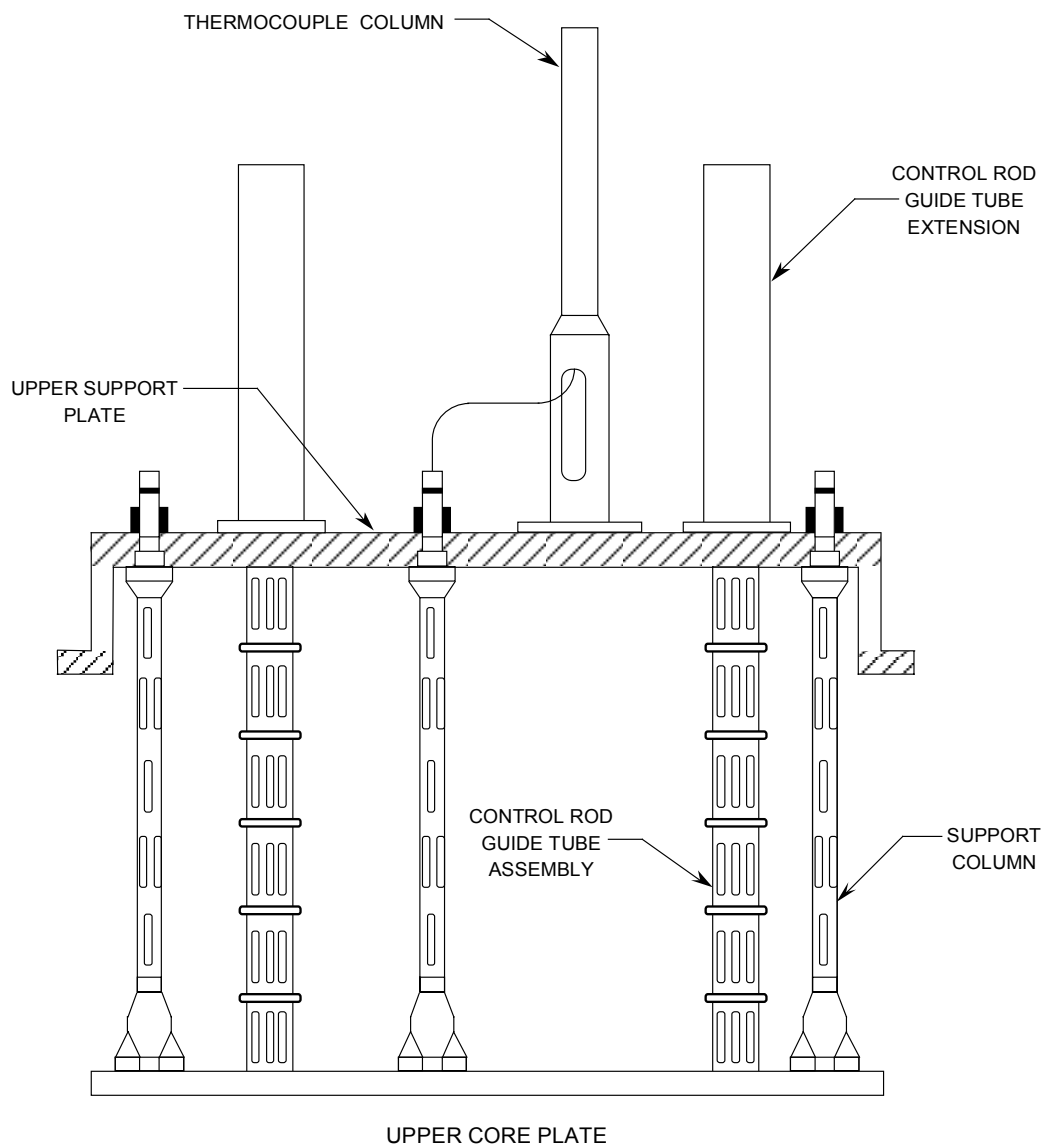
UPPER CORE PLATE

Figure 3.1-12   Upper Core Support Structure
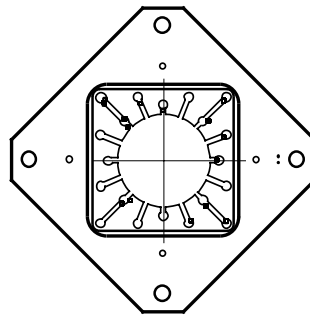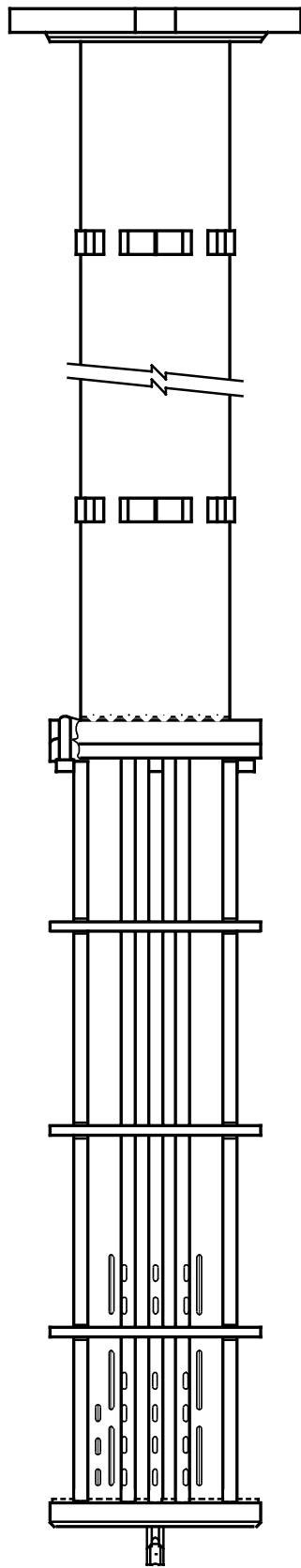
TOP VIEW
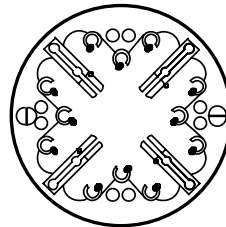
BOTTOM VIEW

Figure 3.1-13 Control Rod Guide Tube Assembly

HEAD AND VESSEL
ALIGNMENT PIN
LOCATION

GUIDE TUBE ASSEMBLY
LOCATIONS

FLOW HOLES
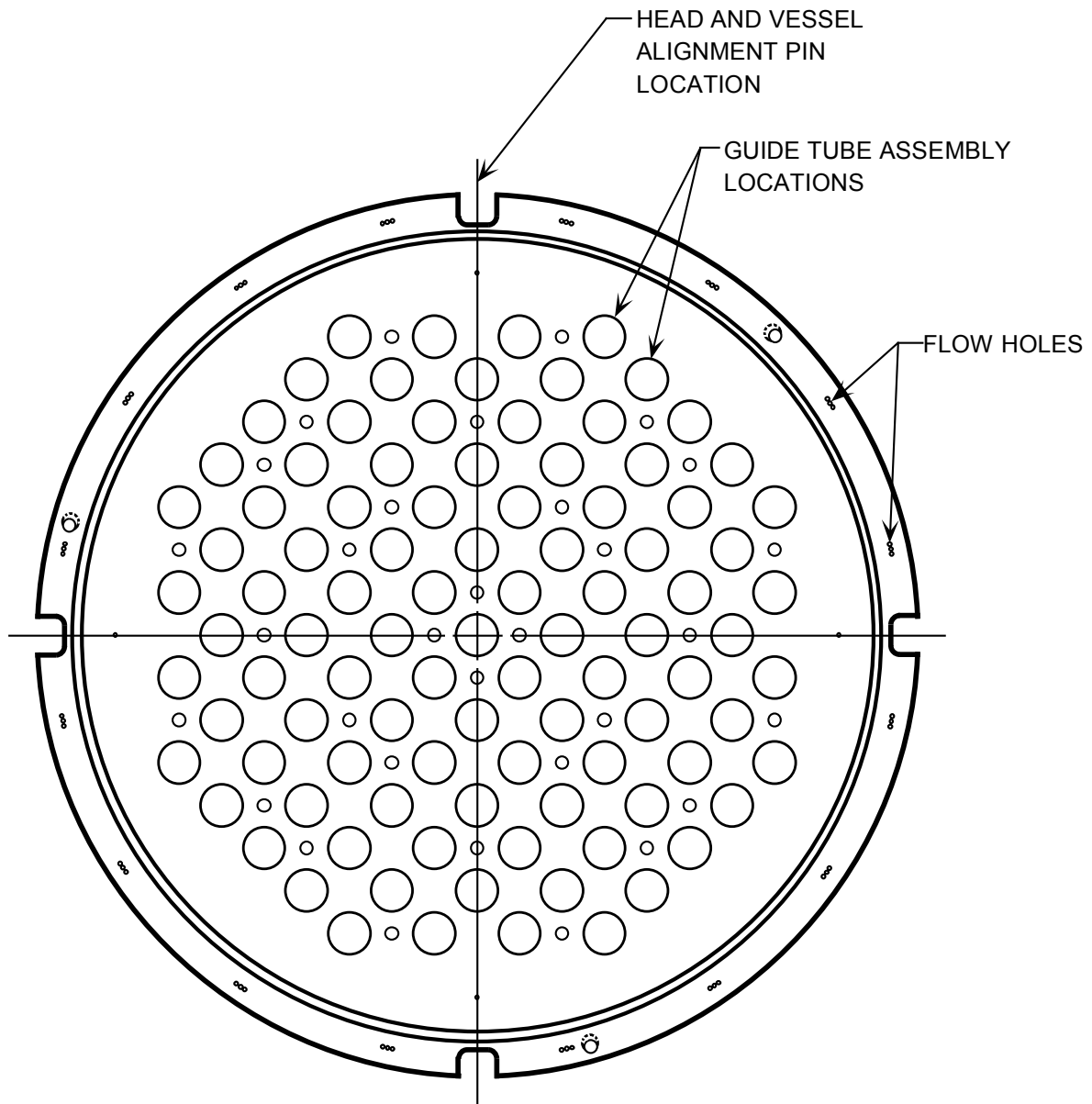
Figure 3.1-14 Upper Core Plate
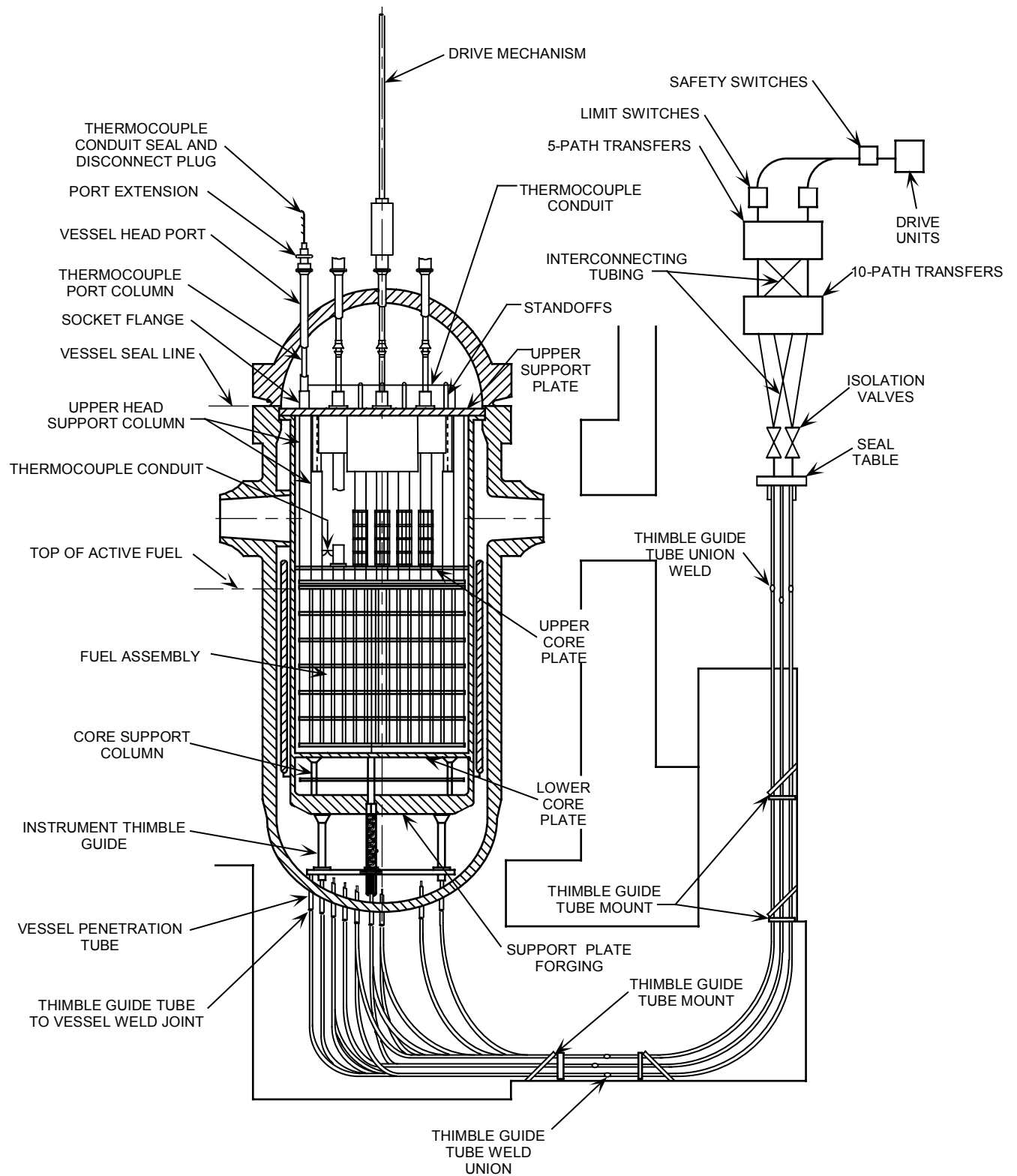
Figure 3.1-15 In-Core Instrumentation
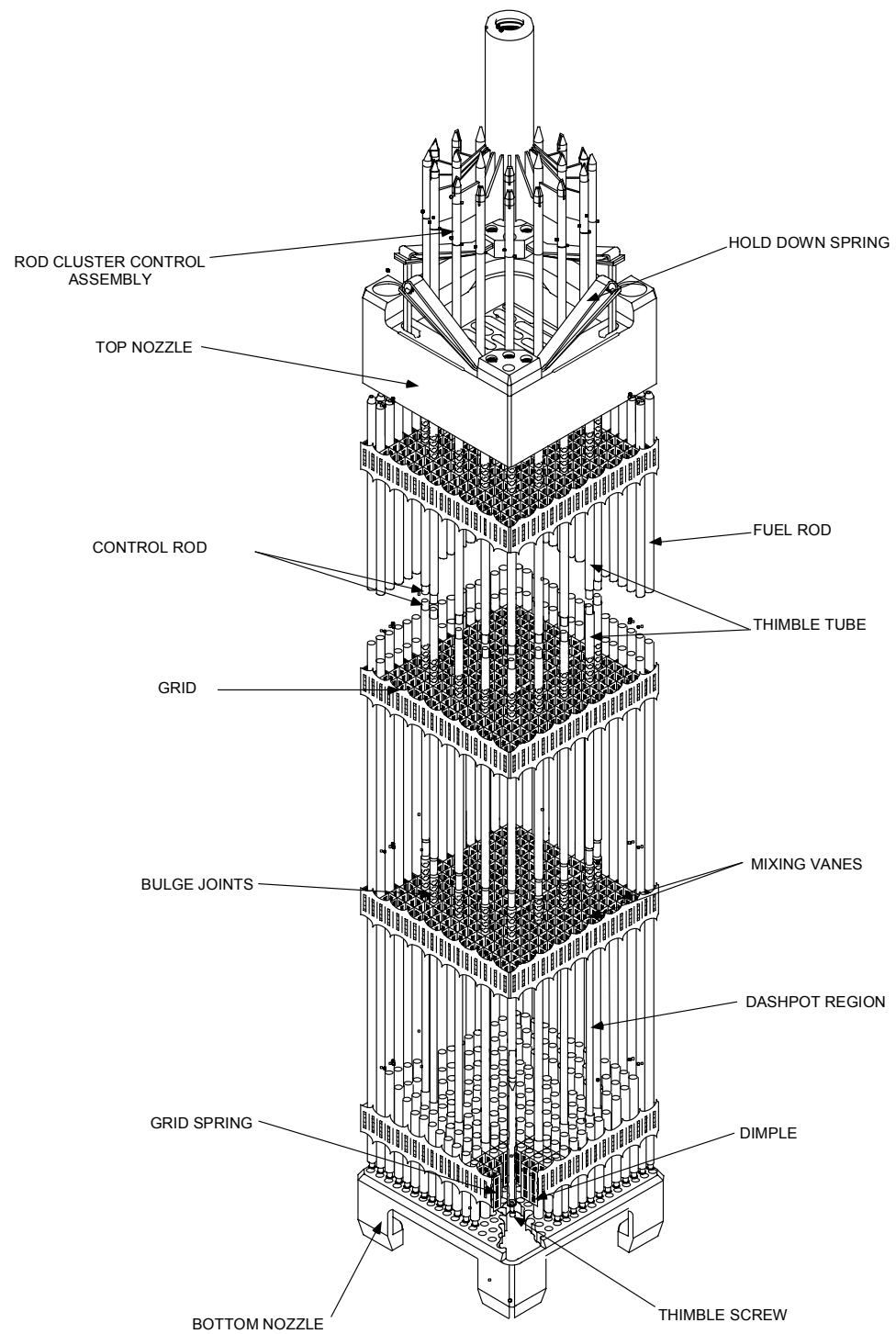
Figure 3.1-16 Fuel Assembly and RCCA Cutaway

8.426 REF

16 SPACES AT 0.496 = 7.936

0.245   0.122   0.530

FUEL ASSEMBLY
WITH ROD
CLUSTER CONTROL

11.973 FUEL ASS'Y
AND CONTROL ROD
PITCH

0.058

0.496

1.488   0.068

2.976

GUIDE
THIMBLE

8.466
TYP

.040
TYP

INSTRUMENTATION
SHEATH

FUEL ASSEMBLY
WITHOUT ROD
CLUSTER CONTROL

CONTROL CLUSTER
ELEMENT

FUEL RODS 264 REQ'D
OD = 0.374
CLAD THICKNESS = 0.0225
CLAD MATERIAL = ZIRC-4
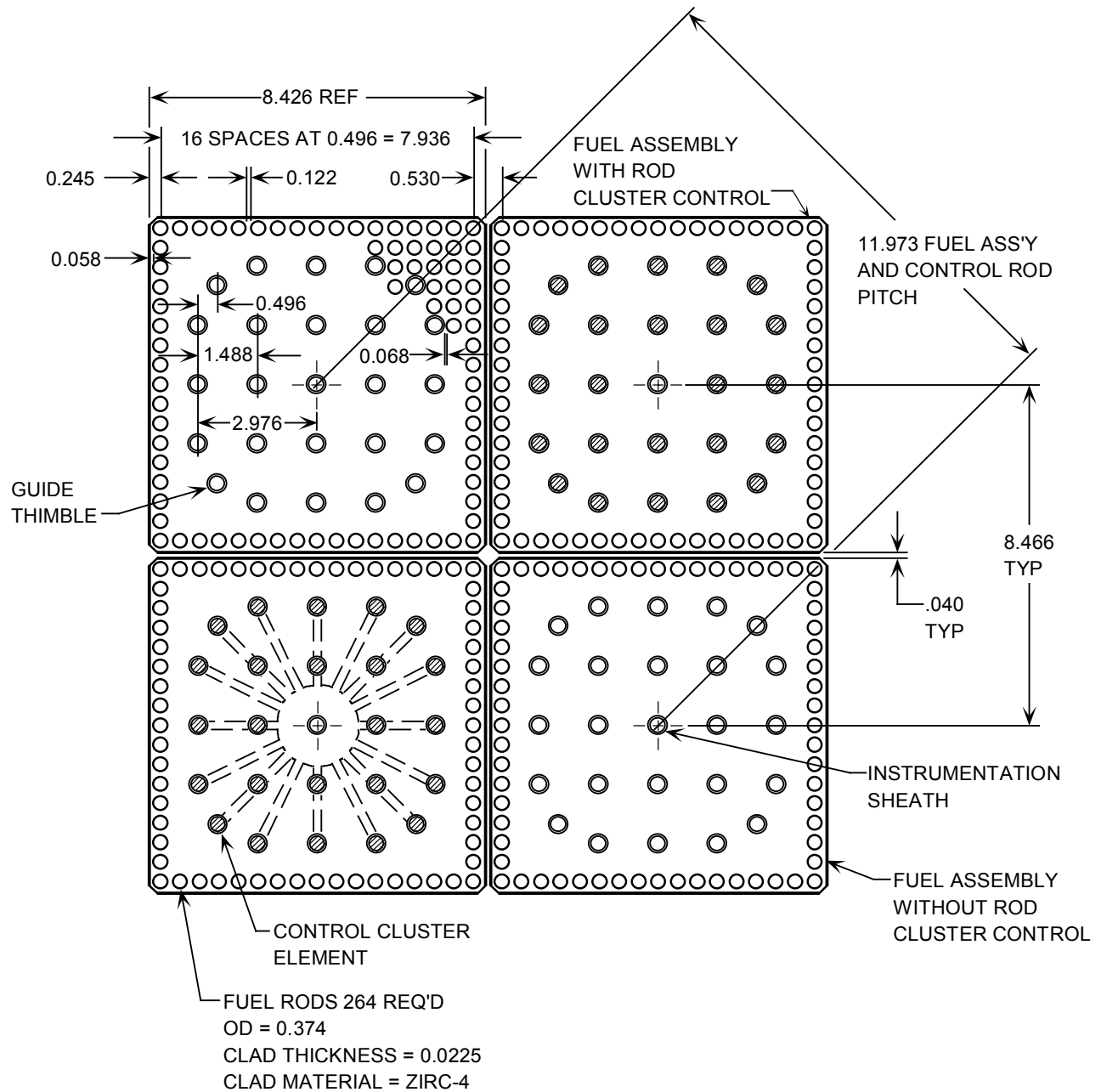
Figure 3.1-17 17 X 17 Fuel Assembly Cross Section

TOP VIEW

0.875 DIA REF

8.404 SQ REF

0.551 DIA REF

7.162 REF

Top Nozzle

BOTTOM VIEW

Bottom Nozzle

0.875 DIA REF

8.424 SQ REF

6.750 REF

Clamp

ROD CLUSTER CONTROL ASS'Y

Triple Leaf Spring

Pad

CONTROL ROD

Adapter Plate

Top Plate

Enclosure

154.0 REF

135.4 REF

109.2 REF

83.0 REF

56.8 REF

30.6 REF

159.8 REF

FUEL ROD

GRID ASSEMBLY

151.63 REF

Perforated Plate

Angle Leg

Bearing Plate

Plenum

6.2 REF

2.7 REF

NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 3.1-18 17 X 17 Fuel Assembly Outline

HOLD DOWN
SPRINGS

TOP
NOZZLE
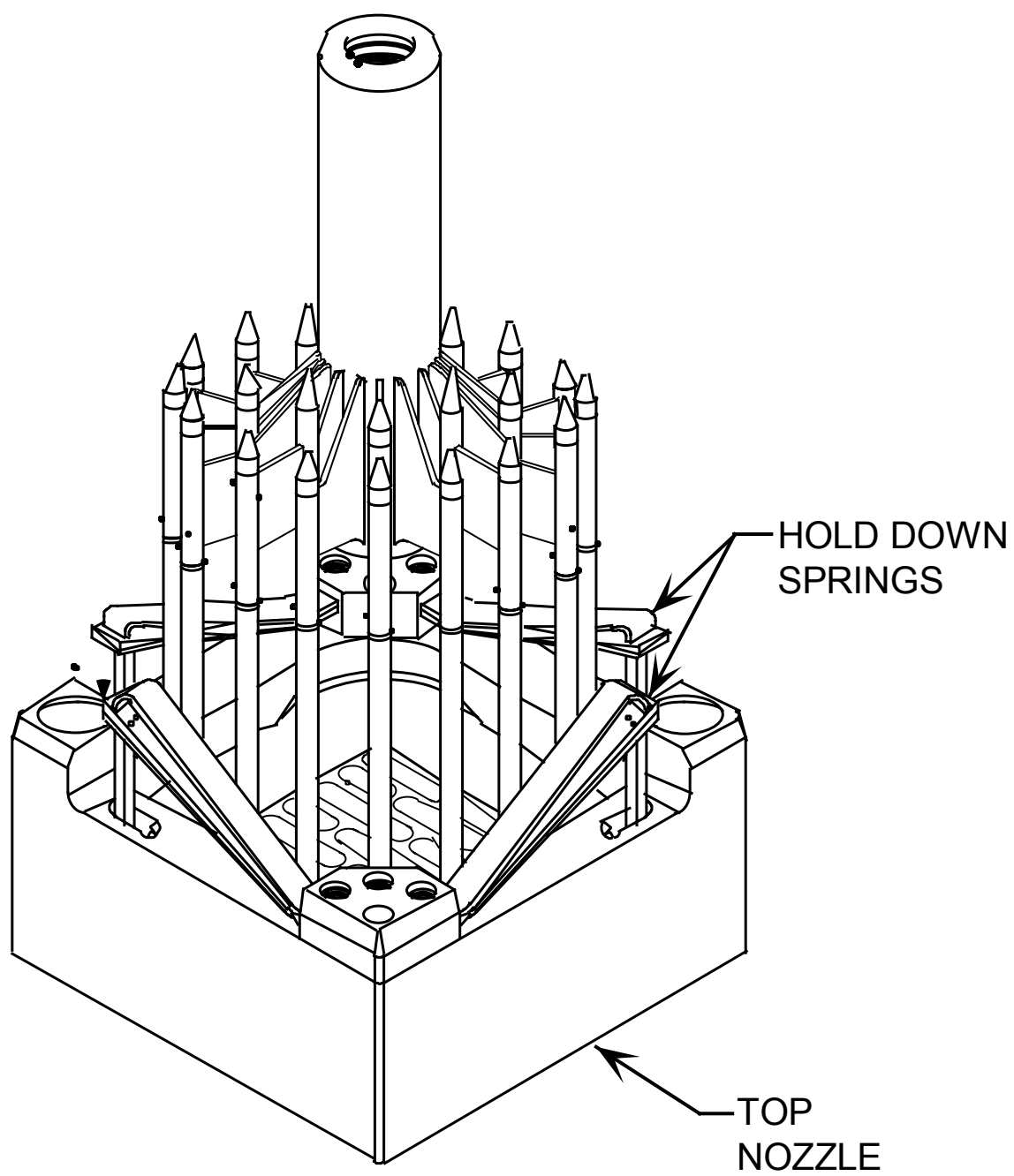
Figure 3.1-19 Upper Fuel Assembly and RCCA Spider

END PLUG

SPRING

6.3"
(TYP)

UO$_2$ PELLETS

151.6"
(REF)

FUEL-CLAD GAP

144.0"
(TYP)

ZIRCALOY CLAD
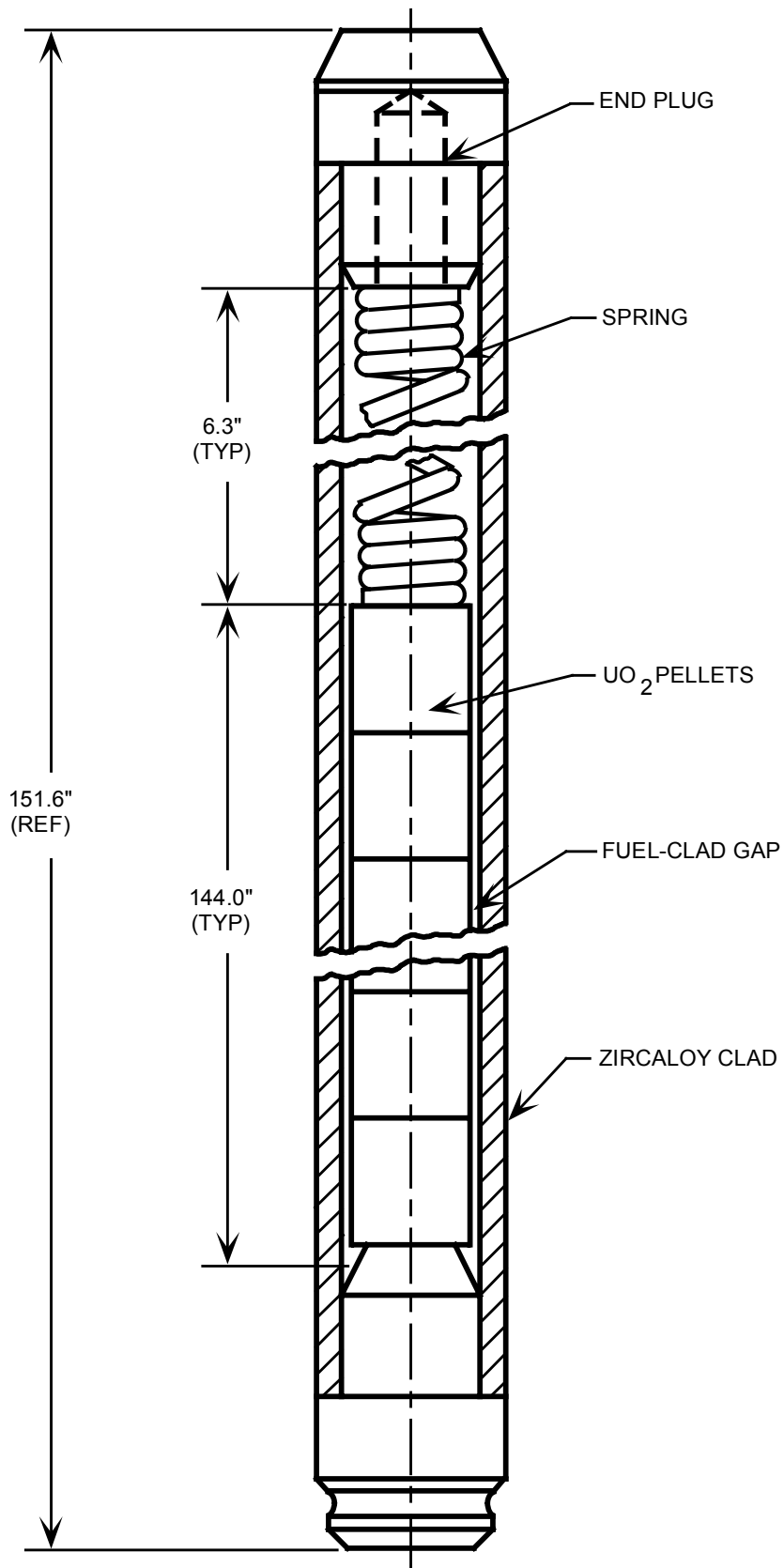
SPECIFIC DIMENSIONS DEPEND ON DESIGN VARIABLES SUCH AS
PRE-PRESSURIZATION, POWER HISTORY, AND DISCHARGE BURNUP

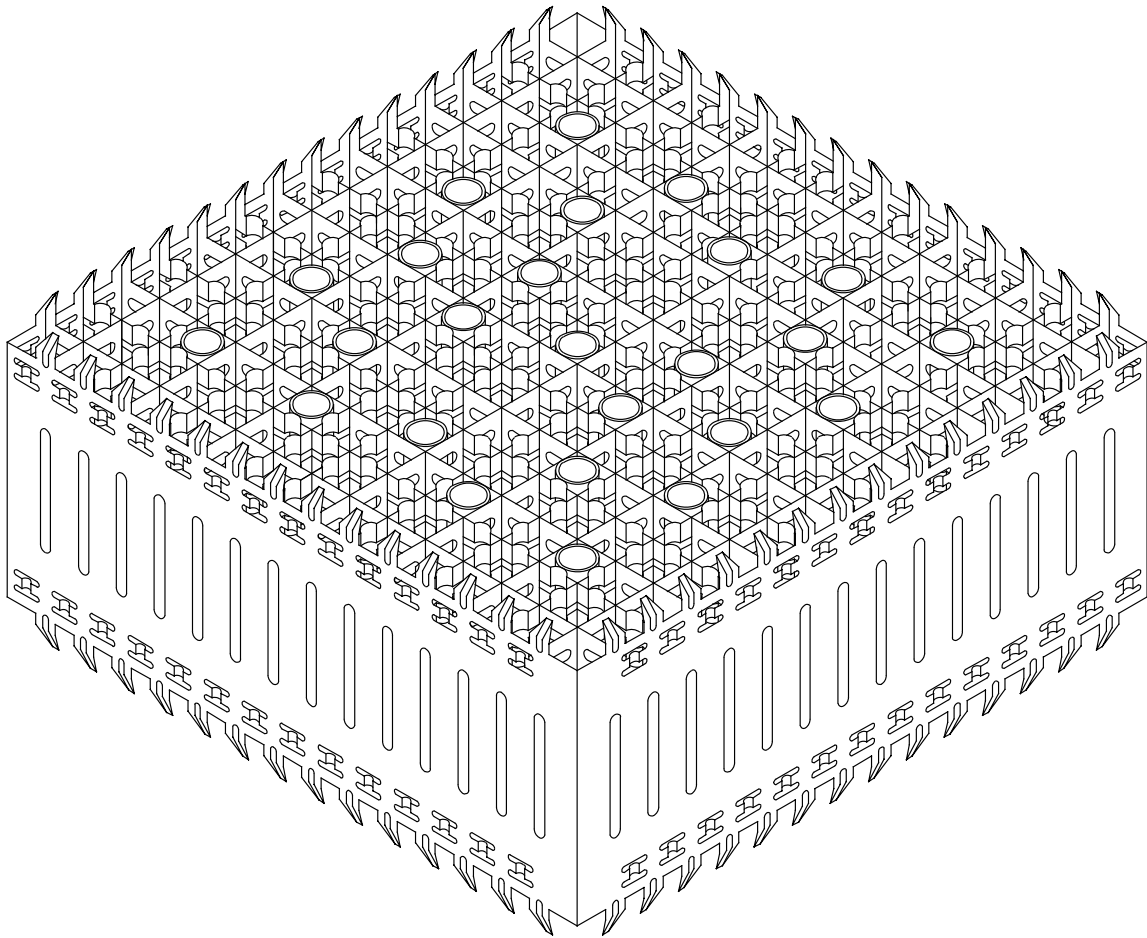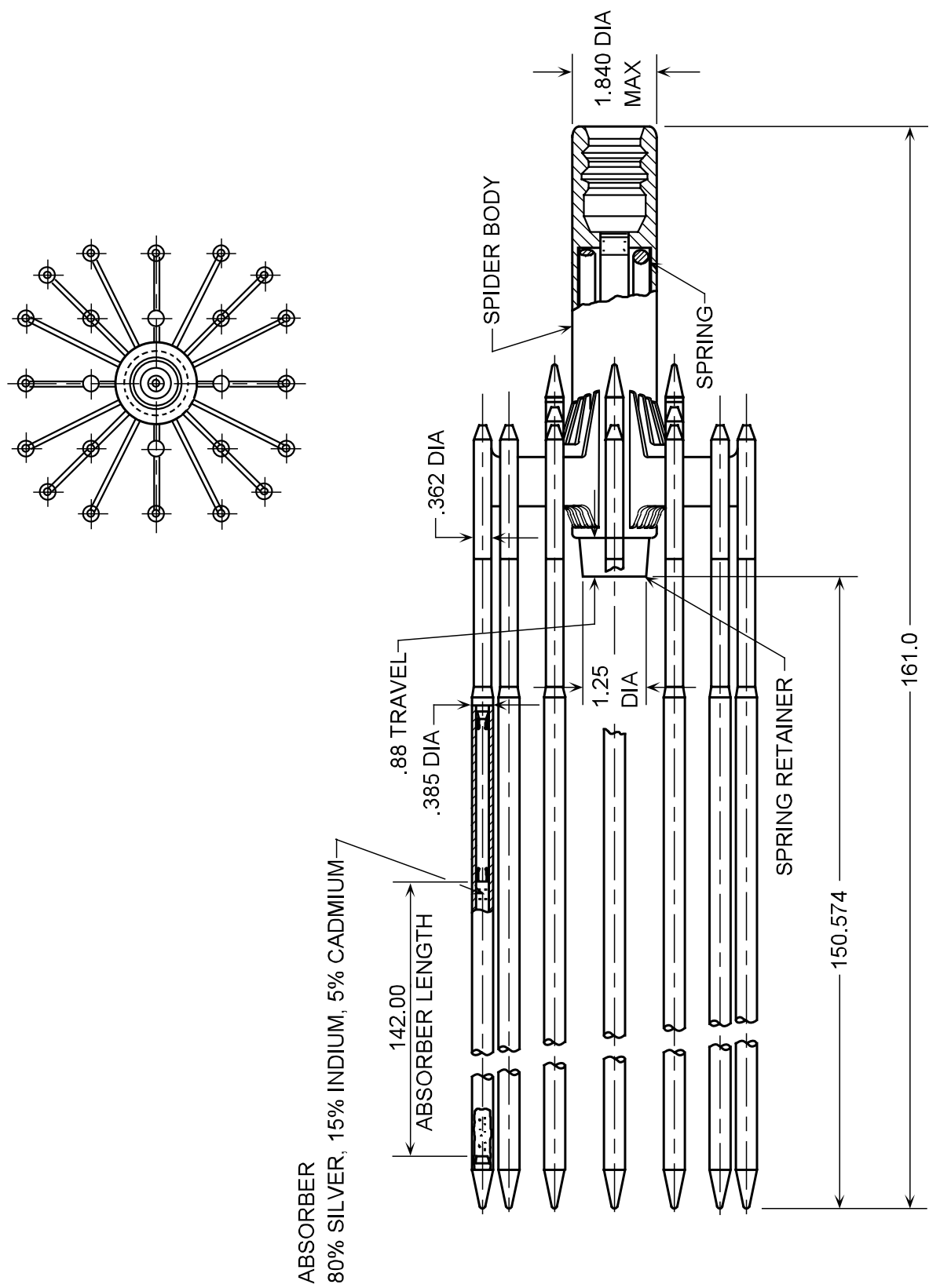Figure 3.1-20 Fuel Rod
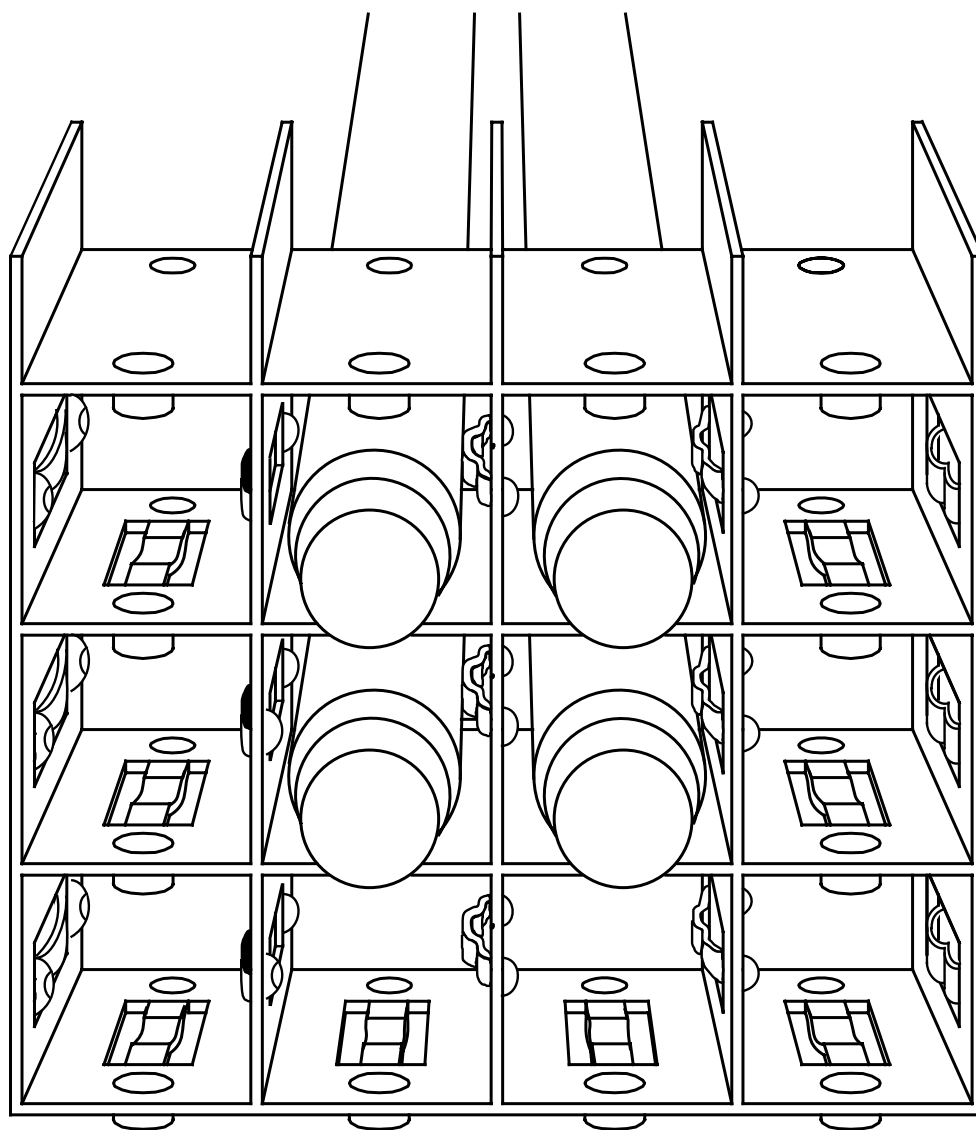
Figure 3.1-21   Spring Grid Clip Assembly

Figure 3.1-22   Spring Grid Assembly
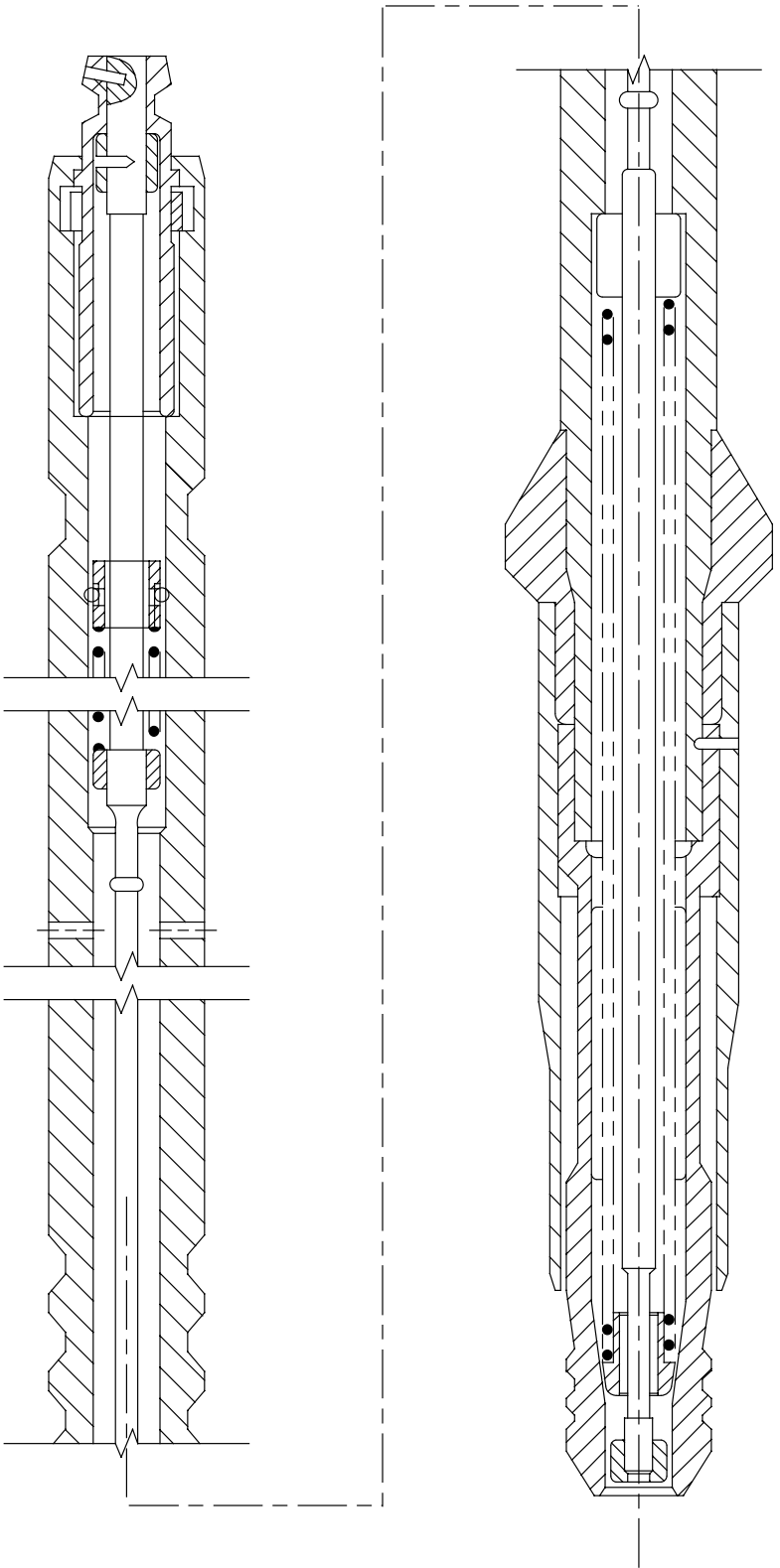
Figure 3.1-23 Rod Cluster Control Assembly

Figure 3.1-24   RCCA Drive Shaft
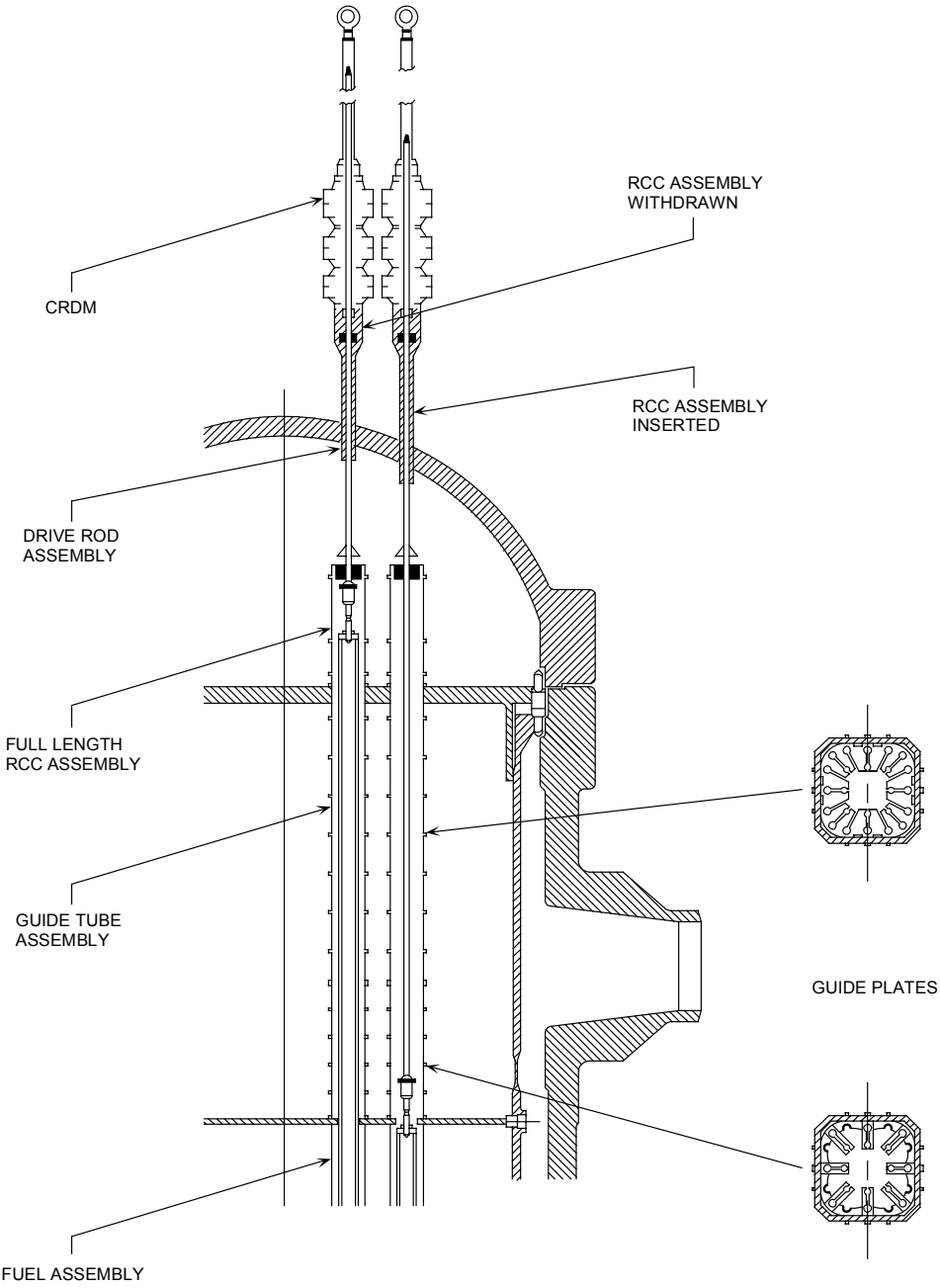
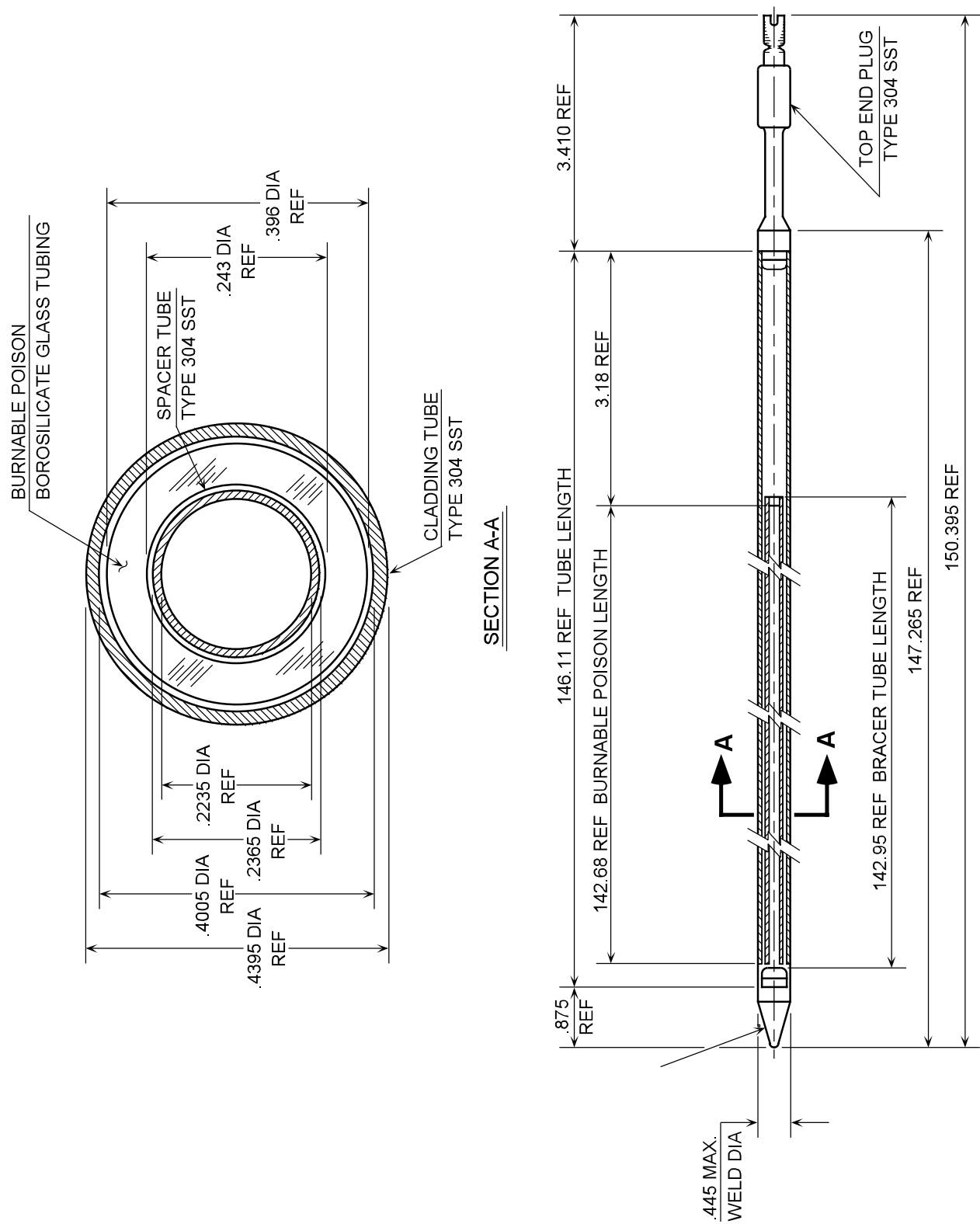Figure 3.1-25   Full Length Rod with Interfacing Components

SPRINGS

151.605

141.560
POISON LENGTH

① THIMBLE PLUG

STAINLESS STL

0.436 DIA

② BURNABLE POISON ROD

BOROSILICATE GLASS TUBE

0.381 DIA
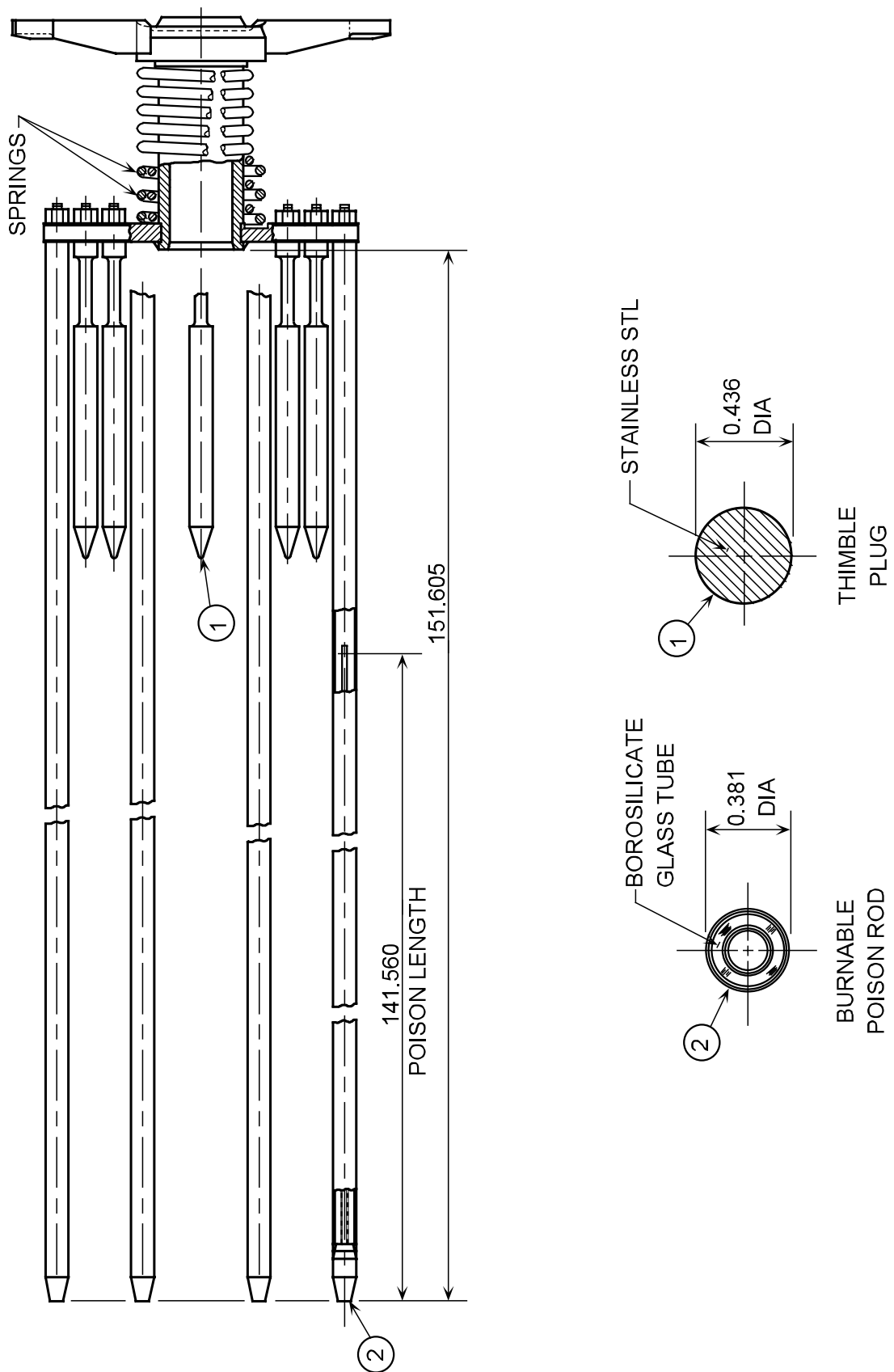
NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 3.1-26 Burnable Poison Rod Assembly

BURNABLE POISON
BOROSILICATE GLASS TUBING

SPACER TUBE
TYPE 304 SST

.243 DIA
REF

.396 DIA
REF

CLADDING TUBE
TYPE 304 SST

.2235 DIA
REF

.2365 DIA
REF

.4005 DIA
REF

.4395 DIA
REF

SECTION A-A

TOP END PLUG
TYPE 304 SST

3.410 REF

3.18 REF

146.11 REF TUBE LENGTH

150.395 REF

142.68 REF BURNABLE POISON LENGTH

147.265 REF

142.95 REF BRACER TUBE LENGTH

A

A

.875 REF

.445 MAX.
WELD DIA

NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 3.1-27 Burnable Poison Rod

SECTION A-A

FLOW PATH

UPPER END PLUG

ANNULAR PLENUM

150.0 TYPICAL

ZIRCALOY TUBES

HOLDDOWN DEVICE

A   A

134.0 TYPICAL ABSORBER LENGTH

Al_2O_3-B_4C ANNULAR PELLETS

FLOW PATH

Water

Zircaloy

Helium

Al_2O_3-B_4C

Helium
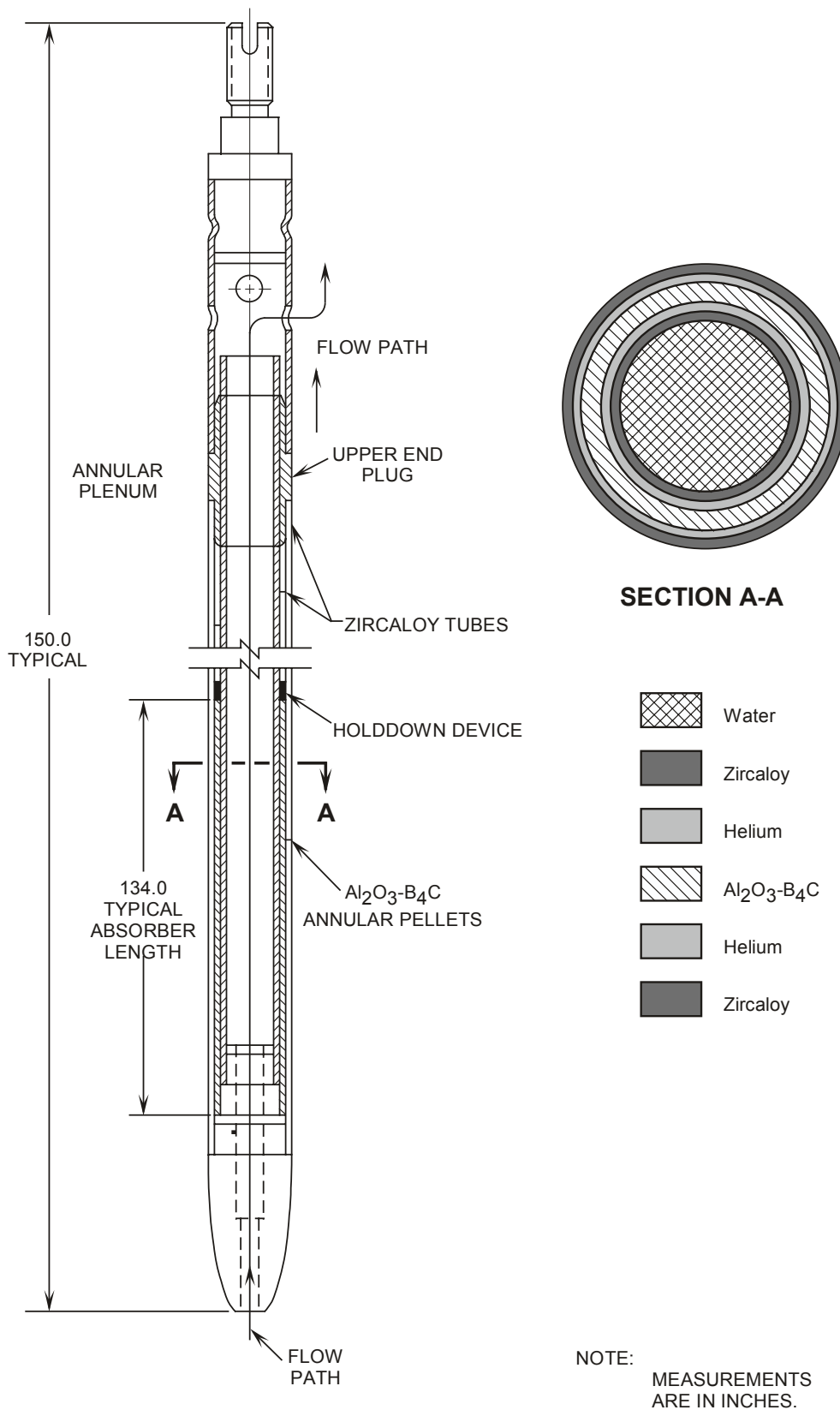
Zircaloy

NOTE:

MEASUREMENTS ARE IN INCHES.

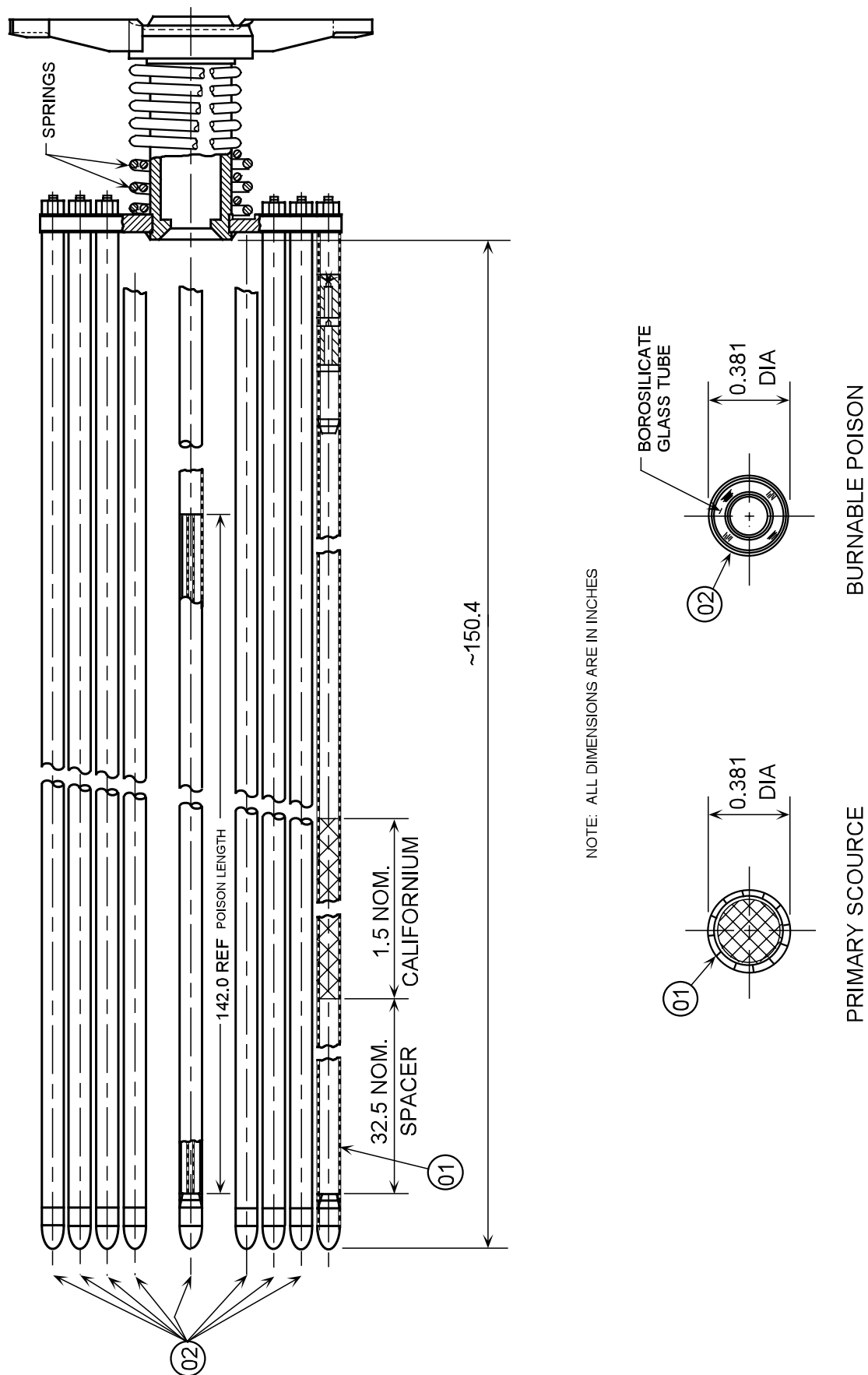Figure 3.1-28   Wet Annular Burnable Absorber
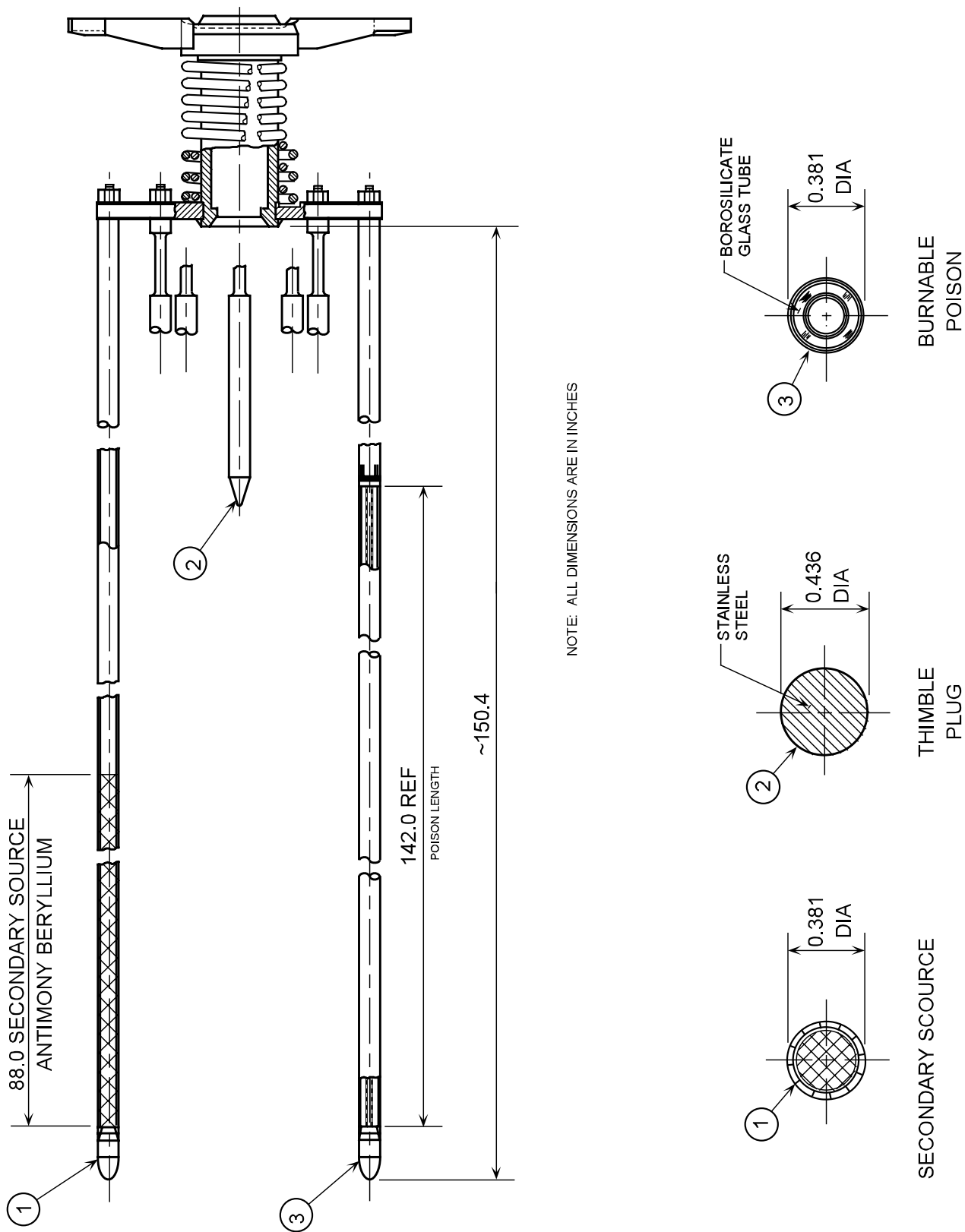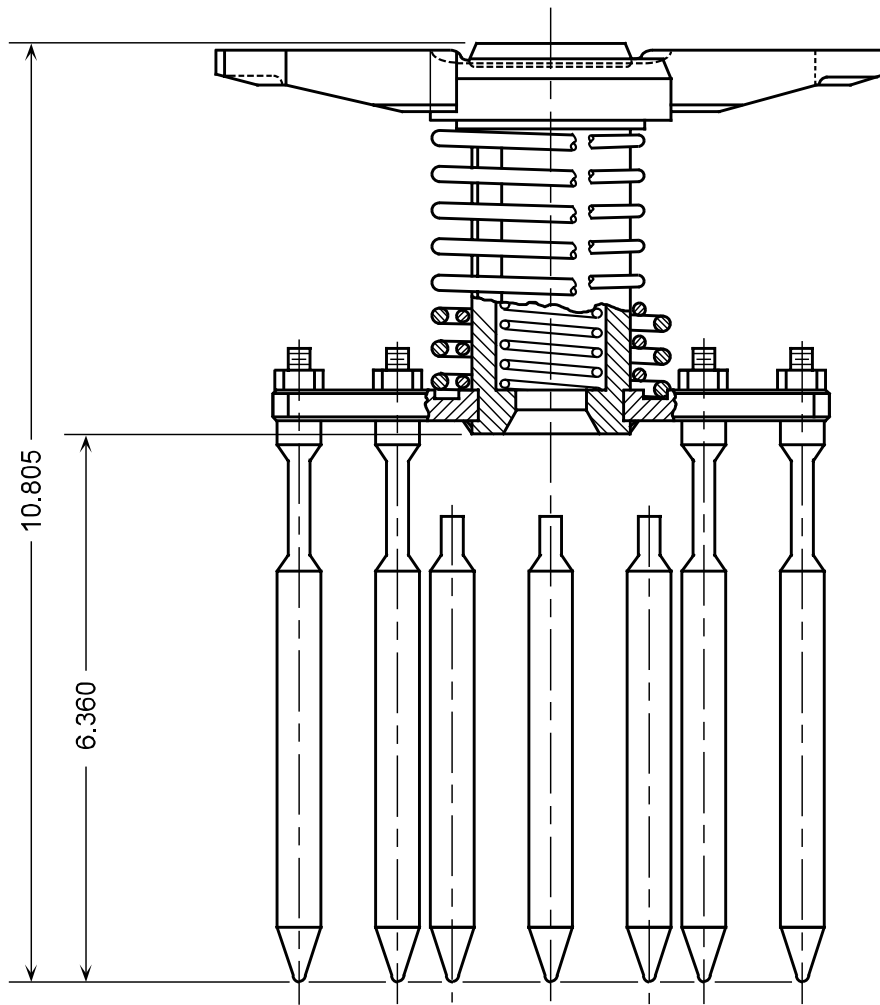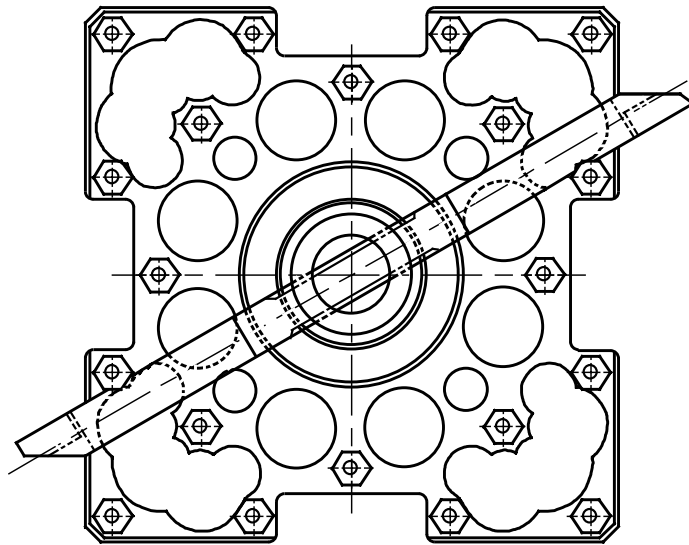
Figure 3.1-29 Primary Source Assembly

Figure 3.1-30 Secondary Source Assembly

NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 3.1-31 Thimble Plug Assembly

DISCONNECT ROD

LIFT POLE

LIFT COIL

GUIDE TUBE

MOVABLE GRIPPER POLE

MOVABLE GRIPPER COIL

MOVABLE LATCH SUPPORT TUBE

MOVABLE LATCH LOCK PLUNGER

MOVABLE GRIPPER LATCHES

LINKS

STATIONARY GRIPPER POLE

STATIONARY GRIPPER COIL

PLUNGER HALF

SHIM

STATIONARY LATCH LOCK PLUNGER

STATIONARY LATCH SUPPORT TUBE

STATIONARY GRIPPER LATCHES

LINKS

DRIVE SHAFT

PRESSURE HOUSING

$\frac{1}{32}$

AXIAL CLEARANCE

Figure 3.1-32   Control Rod Drive Mechanism

CABLE CONNECTION

3.75

213.00

10.718 X 10.718

39.875

49.75

OPERATING COIL STACK ASSEMBLY
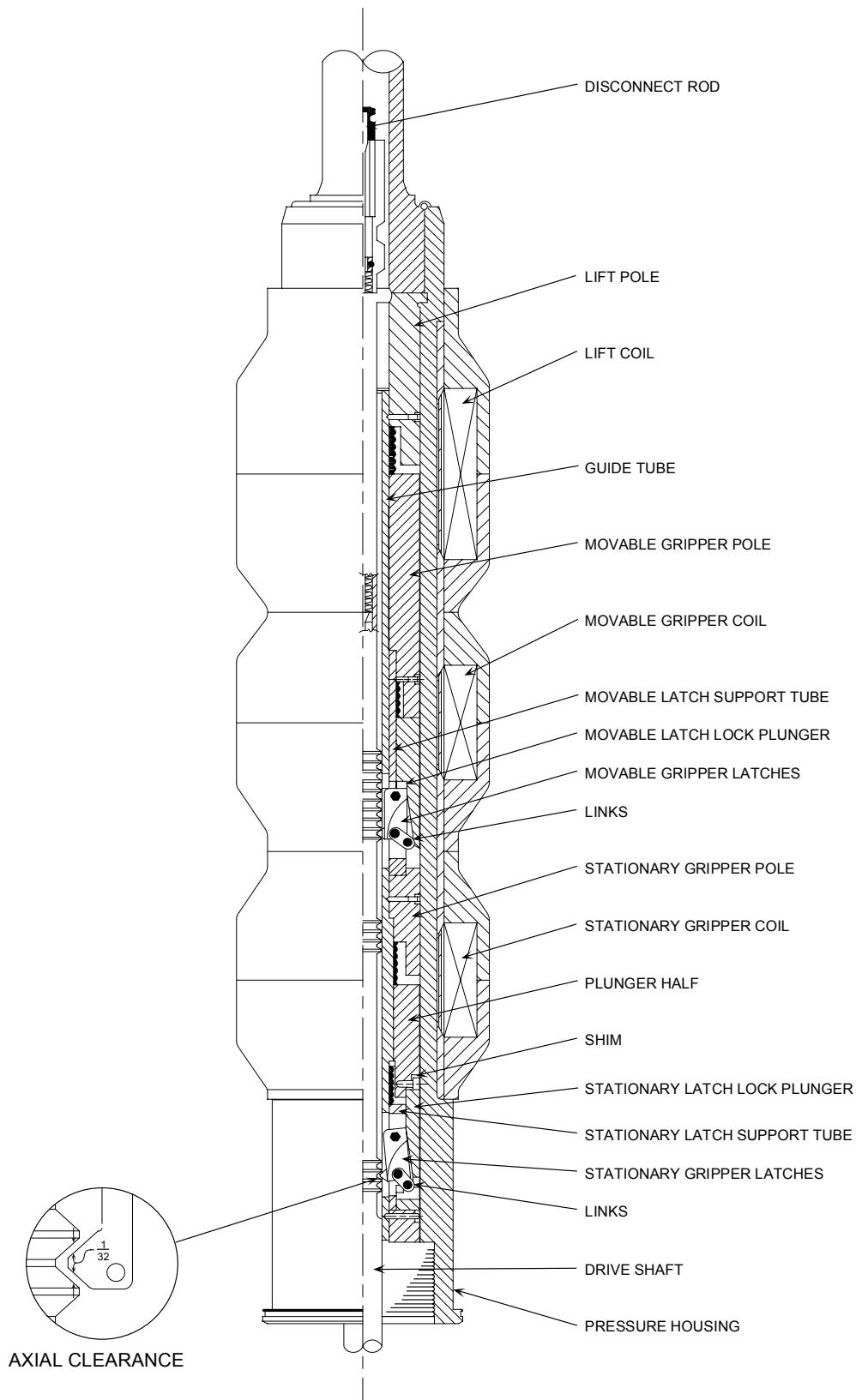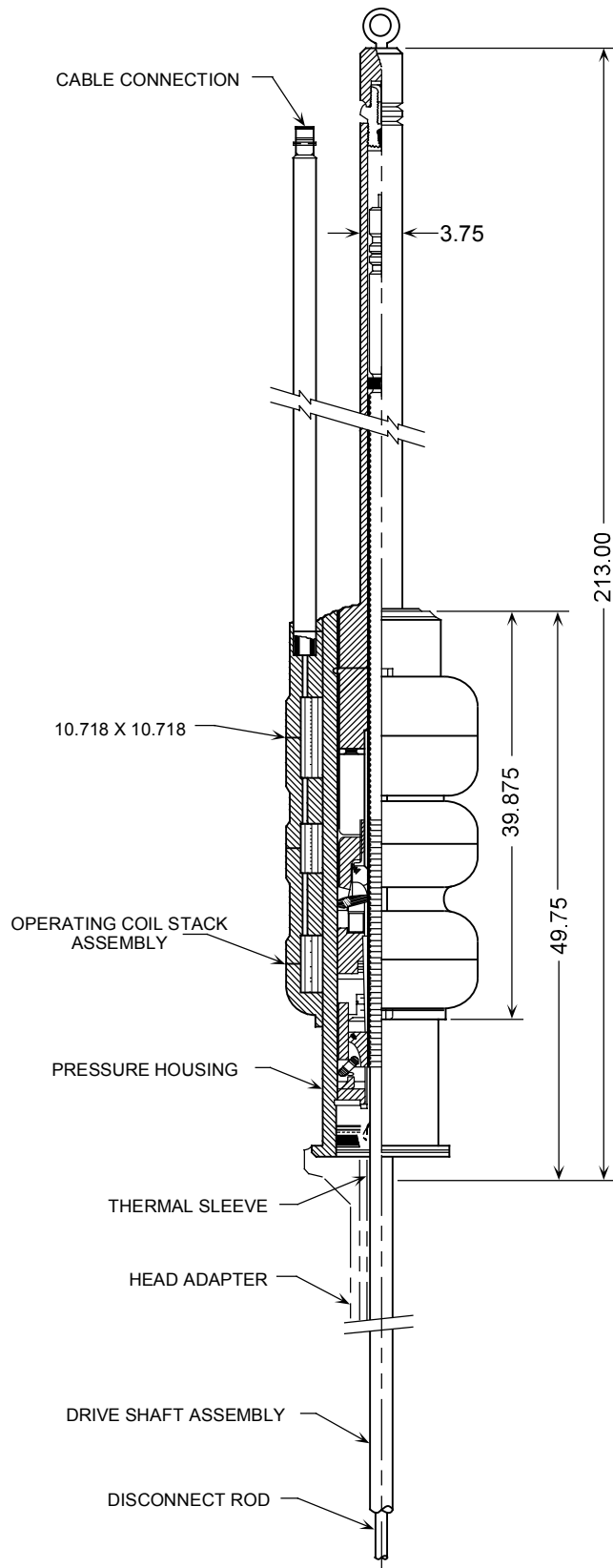
PRESSURE HOUSING

THERMAL SLEEVE

HEAD ADAPTER

DRIVE SHAFT ASSEMBLY

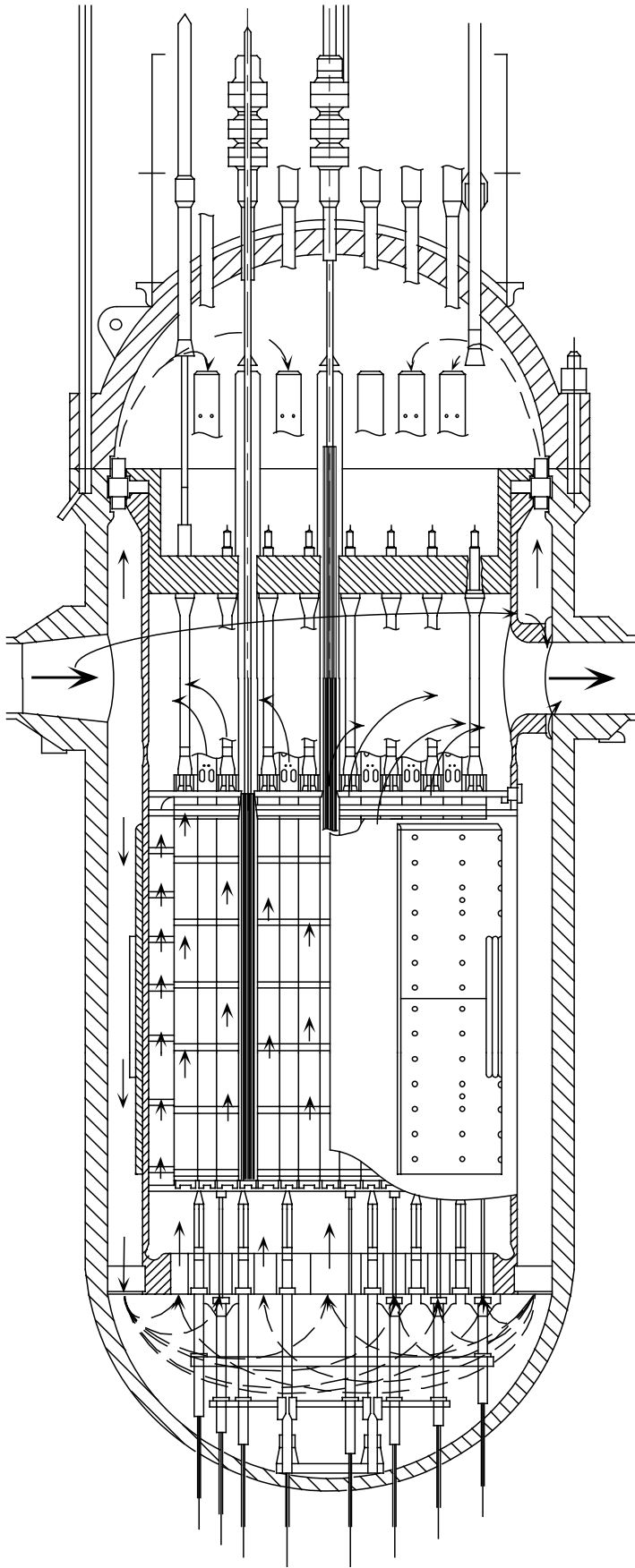DISCONNECT ROD

NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 3.1-33 Control Rod Drive Mechanism Assembly

Figure 3.1-34 Core Flow Paths