4.2 Fuel System Design

The fuel system is defined as consisting of the fuel assembly and the reactivity control assembly. The fuel assembly is comprised of the fuel bundle, channel and channel fastener. The fuel bundle is comprised of fuel rods, water rods, fuel rods containing burnable neutron absorber, spacers, springs and assembly and fittings.

The fuel to be loaded in an ABWR designated as GE12, has been approved for use in the US and is currently operating as reload fuel in Germany, Sweden, Spain and the US.

To demonstrate ABWR system response, a reference core of GE12 fuel is used. This core is shown in Section 4.3; information for this fuel design is provided in Reference 4.2-1.

Regarding the reactivity control system, this Section 4.2 addresses only the reactivity control elements that extend from the coupling interface of the control rod drive mechanism (per Regulatory Guide 1.70). The functional design of the reactivity control system is detailed in Section 4.6.

4.2.1 Design Bases

4.2.1.1 Fuel Assembly

The fuel assembly (comprised of the fuel bundle, channel and channel fastener) is designed to ensure that possible fuel damage would not result in the release of radioactive materials in excess of limits prescribed by 10CFR20, 50 and 100. Evaluations are made in conjunction with the core nuclear characteristics, the core hydraulic characteristics, the plant equipment characteristics, and the instrumentation and protection systems to assure that this requirement is met.

The thermal-mechanical design process emphasizes that:

(1) The fuel assembly provides substantial fission retention capability during all potential operational modes.

(2) The fuel assembly provides sufficient structural integrity to prevent operational impairment of any reactor safety equipment.

The fuel assembly and its components are designed to withstand:

(1) The predicted thermal, pressure and mechanical interaction loadings occurring during startup testing, normal operation, and anticipated operational occurrences

(2) Loading predicted to occur during handling

(3) Incore loading predicted to occur from an operational basis earthquake occurring during normal operating conditions

Operating limits are established to ensure that actual fuel operation is maintained within the fuel rod thermal-mechanical design bases. These operating limits define the maximum allowable fuel pellet operating power level as a function of fuel pellet exposure. Lattice local power and exposure capabilities are applied to transform the maximum allowable fuel pellet power level into Maximum Average Planar Linear Heat Generation Rate (MAPLHGR) limits.

The detailed design bases for each of the fuel assembly damage, failure and coolability criteria defined in Section II.A of Standard Review Plan 4.2 (except control rod reactivity; see Subsection 4.2.1.2) are provided in Section 3.1 of Reference 4.2-2.

4.2.1.2 Control Rods

The control rod is designed to have:

(1) Sufficient mechanical strength to prevent displacement of its reactivity control material

(2) Sufficient strength to prevent deformation that could inhibit its motion

The detailed design bases for the control rod are provided in Appendix 4C.

4.2.2 Description and Design Drawings

4.2.2.1 Fuel Assembly

The reference core uses the GEl2 fuel design (with detailed description provided in References 4.2-1 and 4.2-2). The fuel assembly is shown in Figure 4.2-1, and consists of a fuel bundle and a channel which surrounds the fuel bundle. The GE12 design utilizes a 10x10 fuel rod array which includes 78 full length fuel rods, 14 part length fuel rods and 2 large central water rods. The cast stainless steel lower tie plate includes a conical section which seats into the fuel support and a grid which maintains the proper fuel rod spacing at the bottom of the bundle. The cast stainless steel upper tie plate maintains the fuel rod spacing at the top of the bundle and provides the handle that is used to lift the bundle for transferring the fuel bundle from one location to another. The bundle assembly is held together by eight tie rods located around the periphery of the fuel bundle. The lower tieplate has a nosepiece which has the function of supporting the fuel assembly in the reactor. The upper tieplate has a handle for transferring the fuel bundle from one location to another. The identifying fuel assembly serial number is engraved on the top of the handle; no two assemblies bear the same serial number. A boss projects from one side of the handle to ensure proper orientation of the assembly in the core. Finger springs located between the lower tieplate and channel are utilized to control the bypass flow through that flow path.

Fuel assembly parameters are provided in Table 1.3-1.

4.2.2.1.1 Fuel Rods

Three mechanical types of fuel rods are used in a fuel bundle; tie rods, full length and part length rods. Each tie rod has a threaded lower end plug which screws into the lower tie plate and a threaded upper end plug which extends through a boss in the upper tie plate and is fastened with a nut. A lock tab washer is included under the tie rod nut to prevent rotation of the tie rod and nut The part length rods also have lower end plugs which are threaded into the lower tie plate to prevent movement of the rods during shipping or handling with the bundle oriented horizontally. The tie rods support the weight of the assembly only during fuel handling operations. During operation, the assembly is supported by the lower tieplate.

The upper end plugs of the full length fuel rods and water rods have extended shanks that protrude through bosses in the upper tie plate to accommodate the differential growth expected for high exposure operation. Expansion springs are also placed over each upper end plug shank to assure that the full length fuel rods and water rods are properly seated in the lower tie plate.

Each fuel rod contains high density ceramic uranium dioxide fuel pellets stacked within Zircaloy cladding. The fuel rod is evacuated, backfilled with helium, and sealed with end plugs welded into each end. U-235 enrichments may vary from fuel rod to fuel rod within a bundle to fuel rod within a bundle to reduce local peak-to-average fuel rod power ratios. Selected fuel rods within each bundle include small amounts of gadolinium as a burnable poison along the length of the fuel rod to provide axial power shaping and cold shutdown zone shaping characteristics.

Adequate free volume is provided within each fuel rod in the form of a pellet-to-cladding gap and a plenum region at the top of each fuel rod to accommodate thermal and irradiation expansion of the UO_2 and the internal pressure resulting from the helium fill gas, impurities, and gaseous fission products liberated over the life of the fuel. A plenum spring, or retainer, is provided in the plenum space to minimize the movement of the column of fuel pellets inside the fuel rod during shipping and handling. A hydrogen getter is also provided in the plenum space as assurance against chemical attack from inadvertent admission of moisture or hydrogenous impurities into the fuel rod during manufacture.

4.2.2.1.2 Water Rods

Water rods are hollow Zircaloy tubes with several holes around the circumference near each end to allow coolant to flow through. The GEl2 fuel design includes two large central water rods identical in size to replace eight fuel rod locations and provide improved moderation.

4.2.2.1.3 Fuel Spacer

The primary function of the spacer is to provide lateral support and spacing of the fuel rods, with consideration of thermal-hydraulic performance, fretting wear, strength, neutron economy, and producibility. The GEI2 design includes a new high performance spacer developed to meet the low pressure drop requirement for a 10x10 design and to provide excellent critical power performance. Eight spacers are employed for the GE12 design. To minimize pressure drop, the spacer thickness has been reduced.

4.2.2.1.4 Finger Springs

Finger springs are employed to control the bypass flow through the channel-to-lower tieplate flow path.

4.2.2.1.5 Channels

The fuel channel is composed of a Zirconium based material or equivalent, and performs the following functions:

(1) Forms the fuel bundle flow path outer periphery for bundle coolant flow.

(2) Provides surfaces for control rod guidance in the reactor core.

(3) Provides structural stiffness to the fuel bundle during lateral loadings applied from fuel rods through the fuel spacers.

(4) Minimizes, in conjunction with the finger springs and bundle lower tieplate, coolant bypass flow at the channel/lower tieplate interface.

(5) Transmits fuel assembly seismic loadings to the top guide and fuel support of the core internal structures.

(6) Provides a heat sink during loss-of-coolant accident (LOCA).

(7) Provides a stagnation envelope for incore fuel sipping.

The channel is open at the bottom and makes a sliding seal fit on the lower tieplate surface. The upper end of the fuel assemblies in a four-bundle cell are positioned in the corners of the cell against the top guide beams by the channel fastener springs. At the top of the channel, two diagonally opposite corners have welded tabs which support the weight of the channel on the threaded raised posts of the upper tieplate. One of these raised posts has a threaded hole. The channel is attached to the fuel bundle using the threaded channel fastener assembly, which also includes the fuel assembly positioning spring. Channel-to-channel spacing is assured by the fuel bundle spacer buttons located on the upper portion of the channel adjacent to the control rod passage area. Channels for the GEI2 design have thinner sides and thicker corners to provide sufficient strength in the regions of highest stress while minimizing material for neutron economy. This interactive channel design also includes flow trippers (or shallow pockets) machined into the inside wall of the upper regions of the channel. The flow trippers disrupt the laminar flow along the inner surface of the channel and direct the flow toward the peripheral fuel rods for improved critical power performance.

4.2.2.2 Control Rods

The control rod assemblies (Figure 4.2-2) perform the functions of power shaping, reactivity control, and scram reactivity insertion for safety shutdown response. Power distribution in the core is controlled during operation of the reactor by manipulating selected patterns of control rods to counterbalance steam void effects at the top of the core.

The control rod assembly consists of a sheathed cruciform array of either stainless steel tubes filled with boron carbide powder or solid hafnium rods. The main structure of a control rod consists of a top handle, a bottom casting and control rod drive coupling, a vertical center post, and four U-shaped absorber tubes. The top handle, bottom casting and center post are welded into a single skeletal structure. The U-shaped sheaths are welded to the center post, handle and castings to form a rigid housing to contain the absorber tubes and rollers. Rollers at the top and bottom of the control rod guide the control rod as it is inserted and withdrawn from the core.

The boron carbide powder in the absorber tubes is compacted to about 70% of its theoretical density and contains a minimum of 76.5% by weight of natural boron. The boron-10 minimum content of the boron is 18% by weight. The absorber tubes are sealed by a plug welded into each end. The boron carbide is longitudinally separated into individual compartments by stainless steel balls at approximately 25 cm intervals. The steel balls are held in place by a slight crimp of the tube.

4.2.3 Design Evaluation

4.2.3.1 Fuel Assembly

4.2.3.1.1 Evaluation Methods

The design evaluations for each of the fuel system damage, failure, and coolability criteria identified in Section II.C of Standard Review Plan 4.2 are provided in Subsection 3.2 of Reference 4.2-2.

4.2.3.2 Control Rods

4.2.3.2.1 Evaluation Results

The control rod evaluations described in Section 4C.3 will be completed for the control rod. The evaluations will demonstrate that the criteria of Appendix 4C are satisfied.

4.2.4 Testing, Inspection, and Surveillance Plans

GE has an active program of surveillance of fuel, both production and developmental. The NRC has reviewed the GE program and approved it in Reference 4.2-3.

4.2.5 References

4.2-1 *GE Fuel Bundle Designs*, NEDE-31152P, Revision 6, April 1997 (Proprietary).

4.2-2 *GESTAR III Republic of China, General Electric Standard Application for Reactor Fuel*, NEDE-24011-P-A-7 RC, August 1995.

4.2-3 Letter, L. S. Rubenstein (NRC) to R. L. Gridley (GE), *Acceptance of GE Proposed Fuel Surveillance Program,* June 27, 1984.

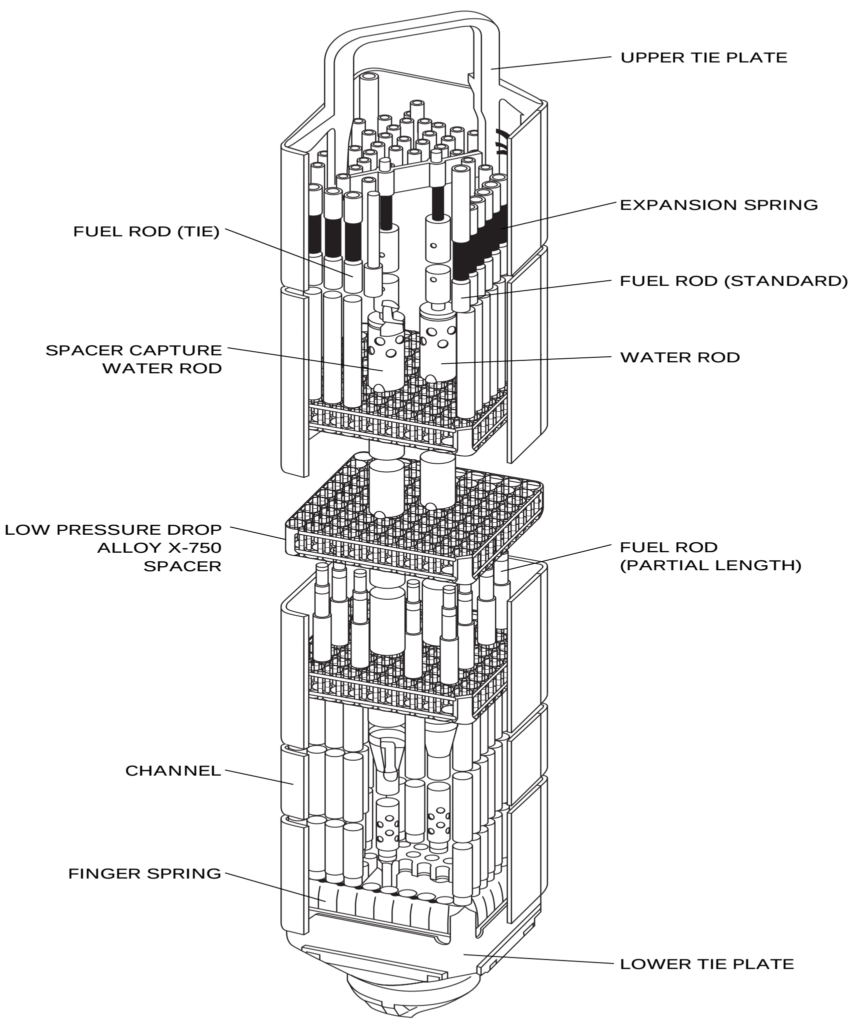

Figure 4.2-1 GE12 Fuel Bundle Design

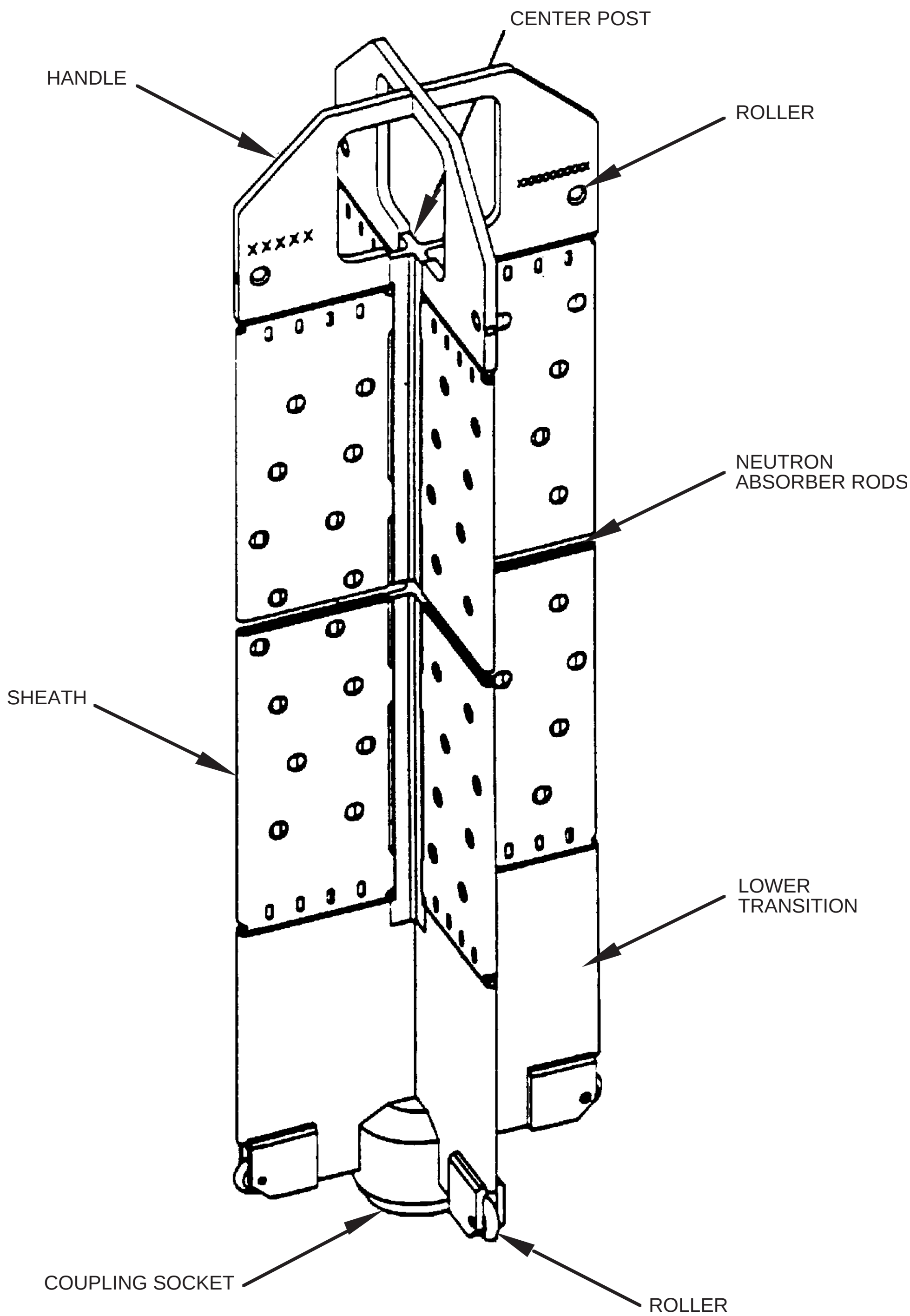

Figure 4.2-2 Control Rod Assembly