# 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, fuel channel and handle with spring. The fuel bundle is comprised of fuel rods, fuel rods containing burnable neutron absorber, spacers, springs and assembly end fittings.

[*Table 8 of DCD/Introduction identifies the commitments on fuel system design criteria and first cycle design and methods, which, if changed, requires NRC Staff review and approval prior to implementation. The applicable portions of the Tier 2 sections, tables and figures, identified on Table 8 of DCD/Introduction for this restriction, are italicized on the sections, tables and figures themselves.*]*

The fuel to be loaded in an ABWR is any fuel design that is approved by the USNRC or that meets the criteria documented in Appendix 4B. Using these designs will assure that all fuel system design requirements are met.

To demonstrate ABWR system response, a reference core of Westinghouse SVEA-96 Optima2 fuel is used. This core is shown in Section 4.3. [*Burnup limits will be specified for fuel used in the ABWR. The current maximum exposure limit for this application is 62 GW•d/tU rod average exposure. Any extension to this maximum exposure limit will be submitted to the NRC for review and approval based on the available supporting materials properties vs. exposure information and planned surveillance program.*]† The compliance of this fuel with the Appendix 4B criteria is documented in Appendix 4D. Each COL applicant may have different fuel and core designs which will be provided by the COL applicant to the USNRC for review and approval.

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, fuel channel and handle with spring) 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.

* See Section 3.5 of DCD/Introduction.

† See Section 4.2, second paragraph.

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 Appendix 4B.

#### 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 Westinghouse SVEA-96 Optima2 fuel design. Information for this fuel design is provided in Reference 4.2-1. The fuel assembly is shown in Figure 4.2-1a, and consists of a fuel bundle, a fuel channel and a handle with spring. The fuel bundle is composed of four sub-bundles in a 5x5-1 lattice. Each sub-bundle contains one 1/3 length rod, located at*

*the outer corner, two 2/3 part length rods, located at the opposite, inner, corner, 1 full length spacer capture rod, located centrally, 2 full length tie rods, and 18 standard full length rods, in total 24 fuel rods. The location of each rod type is illustrated in Figure 4.2-1b. The sub-bundles are separated by a cruciform internal structure (water cross) in the channel. The water cross has a square central canal and smaller water channels in each of the four wings designed to provide non-boiling water during operation.*

*Each sub-bundle is assembled as a separate unit with its own top and bottom tie plates and is held together by the two tie fuel rods and nuts. The fuel rods are guided by their end plugs in the bottom tie plates and for all full length rods also in the top tie plates while the rods laterally are supported by eight spacers, uniformly distributed along the bundle. A spacer capture rod secures the axial positions of the spacers.*

*The sub-bundles are inserted into the channel from the top and are supported at the bottom end by a stainless steel inlet piece (bottom support and transition piece with TripleWave debris filter), which is bolted to the channel. This design principle eliminates any leakage flow problems at the bottom end of the channel and also avoids stresses in the tie rods during normal fuel handling. The bottom support with integrated filter is designed to prevent debris from getting into the fuel bundle.*

*The top tie plate of each sub-bundle has the fuel assembly individual identification number with a sub-channel identity engraved in the side. The number is used for administrative control of the correct positioning of the sub-bundle with respect to sub-channel position. The handle and leaf spring configuration is fitted to the top end of the channel. The handle is designed for lifting with the standard handling equipment at the plant. An individual identification number for the fuel assembly is engraved in the handle. The top end of the channel and the handle are designed such that the handle can be fitted to the channel only in the correct orientation. Therefore, correct orientation of the handle in loading the fuel ensures correct orientation of the fuel assembly in the core.*

*Fuel assembly parameters are provided in Table 1.3-1.*

#### 4.2.2.1.1 Fuel Rods

*The fuel bundle has five mechanically different types of fuel rods; normal rods, tie rods, spacer capture rods, and part length rods with 1/3 and 2/3 active length respectively.*

*The fuel rods consist of a Zircaloy cladding tube, containing a stack of fuel pellets and a compression spring, and sealed by end plugs. The cladding and the end plugs are made of low corrosion type material and the cladding tubes are provided with liner on the inside. In the upper end of the fuel rod there is a space for axial expansion of the fuel stack and for released fission gases from the fuel. Adequate free volume is also provided within each fuel rod in the form of a pellet-to-cladding gap. The fuel stack is prevented from moving up into this space during transport by means of a helical spring.*

*The fuel stack consists of sintered and ground uranium dioxide pellets. U-235 enrichments may vary from fuel rod to fuel rod within a bundle to reduce local peak-to-average fuel rod power ratios. The fuel rods are prepressurized with helium before the fuel rod is finally sealed by welding. A few rods also contain pellets with burnable absorber in the form of gadolinium oxide mixed with uranium dioxide.*

*The two tie fuel rods in each sub-bundle are connected to the top and bottom tie plates by threaded end plugs, protruding through the plates, and nuts. They are placed next to the central position and are locked against rotation by slits in the bottom tie plate, which engage the bottom end plugs. Compression springs between the top end plug shoulders of the tie rods and the top tie plate position the spacer and allow for differential growth of standard fuel rods.*

*In each sub-bundle a spacer capture fuel rod is placed in the central position. Above each spacer position it has small heads welded to the cladding tube. These heads provide the spacer capture function. To assure the correct angular orientation of the capture fuel rod it is rotation secured in the top tie plate.*

*Twelve (12) part length rods are included in the fuel bundle. Eight part length rods (two in each sub-bundle) are placed adjacent to the central water channel and four part length rods (one in each sub-bundle) are placed in the outer corner. The part length rods have in principle the same design as full length rods, with plenum and plenum spring in the upper end, and ends mechanically just above the sixth and third spacer respectively. The part length rods have the same type of end plugs and nuts in the bottom as the tie rods, which means that they are rotation secured and axially locked in the bottom tie plate.*

#### 4.2.2.1.2 Not Used

#### 4.2.2.1.3 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.*

#### 4.2.2.1.4 Not Used

#### 4.2.2.1.5 Fuel Channel

*The fuel channel is composed of a Zirconium based alloy with a stainless steel inlet piece, bolted to the channel, and performs the following functions:*

*(1) Forms the fuel assembly flow path outer periphery for assembly coolant flow*

*(2) Forms internal flow paths for non-boiling water in the fuel assembly*

*(3) Carries the fuel assembly load during handling*

*(4) Provides surfaces for control rod guidance in the reactor core*

*(5) Provides structural stiffness to the fuel assembly during lateral loadings applied from fuel rods through the fuel spacers*

*(6) Eliminates coolant bypass flow at the channel/transition piece interface*

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

*(8) Provides a heat sink during loss-of-coolant accident (LOCA)*

*(9) Provides a stagnation envelope for incore fuel sipping*

*The handle is equipped with a double leaf spring which maintains contact with the corresponding springs on adjacent assemblies and firmly presses the fuel assembly into the corner of the upper core grid thus assuring channel-to-channel spacing.*

#### 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 rods consist of four stainless steel blade wings, with horizontally drilled holes to contain absorber material. The wings are discontinuously welded together in the center to form a cruciform shaped rod.*

*Either of the two control rod designs CR82M-1 and CR99 may be used as standard design. In the CR82M-1 control rod design the absorber material is boron carbide powder and hafnium pins, while in the CR99 control rod design the absorber material is boron carbide pins manufactured by Hot Isostatic Pressing (HIP). The main structure of a control rod consists of a top handle, a bottom part with a control rod drive coupling device, and the four absorber wings. The top handle is integrated in the blade wing, which means that the four blade wings are welded together in the center to form the lifting handle. The coupling device is s welded to the blade wings, thus forming a single skeletal structure. Buttons at the top (optional) and rollers at the 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 zones of the CR82M-1 design is compacted to about 70% of its theoretical solid density. The absorber holes in the upper part contain hafnium metal rods instead of boron carbide powder. The CR99 design has instead boron carbide pins of high density in all of the absorber zones. In both designs, the boron carbide contains a minimum of 76.5% by weight of natural boron.*

*The absorber holes are covered with a stainless steel bar that fits into a slot along the outer blade wing edge. A leak tight closure is obtained by welding together the shanks that have been rolled over the bar. The holes are still connected to each other through communication channels so that pressure equalization of the helium gas, which is forming in the boron carbide during irradiation, can take place between holes. Each blade wing thus forms a separate enclosure which is leak tested after welding.*]*

## 4.2.3 Design Evaluation

### 4.2.3.1 Fuel Assembly

#### *4.2.3.1.1* [*Evaluation Methods*

*The thermal-mechanical evaluations described in Appendix 4B are all performed using the NRC-approved Westinghouse fuel rod thermal-mechanical design codes STAV7.2, VIK-3, and COLLAPS-II Version 3.3D. Any changes to this methodology must have prior NRC review and approval.*

*The STAV7.2 code calculates the variation with time of all significant fuel rod performance quantities including fuel and cladding temperatures, fuel densification, fuel swelling, fission product gas release, rod internal pressure, and pellet-cladding gap conductance. Stresses and strains in the cladding due to elastic, thermal, creep and plastic deformations are calculated. Also, cladding oxidation is evaluated and included in the evaluation of fuel rod performance parameters. Other sub-models include burnup-dependent radial power distributions for both* $UO_2$ *and* $UO_2$+$Gd_2O_3$ *fuel, fuel grain growth, and helium release.*

*The cladding stress analysis code VIK-3 evaluates classical stress-strain expressions to determine cladding stresses in light water reactor (LWR) fuel rod cladding as a function of fuel burnup or irradiation time. Both fully recrystallized and cold work stress-relieved Zircaloy cladding can be evaluated.*

*The cladding creep code COLLAPS-II version 3.3D evaluates the cladding cross-sectional ovality in BWR fuel rods as a function of irradiation time to evaluate margins to cladding collapse.*

*NRC approval of the Westinghouse fuel rod performance codes and their application methodology is provided in References 4.2-1 and 4.2-2.*]*

#### 4.2.3.1.2 Evaluation Results

The fuel rod thermal-mechanical evaluations described in Appendix 4B have been completed for the reference fuel design (SVEA-96 Optima2 design) using the methodologies described in Subsection 4.2.3.1.1. The evaluations demonstrate that the criteria of Appendix 4B are satisfied

* See Section 4.2.

for the reference fuel design. The NRC previously reviewed and approved this in References 4.2-1 and 4.2-2. The approval includes some conditions which are also stated in Reference 4.2-2.

#### 4.2.3.2 Control Rods

##### 4.2.3.2.1 Evaluation Results

The control rod criteria and evaluations described in Section 4C.2 have been completed for the reference control rods. The evaluations demonstrate that the criteria of Appendix 4C are satisfied for the reference $B_4C$ control rods.

### 4.2.4 Testing, Inspection, and Surveillance Plans

Westinghouse has an active program of surveillance of fuel, both production and developmental. Reference 4.2-1 provides an overview of this program. [*The NRC has reviewed the Westinghouse program and approved it in Reference 4.2-1.*]*

### 4.2.5 References

4.2-1 [*Fuel System and Fuel Assembly Design*

a. *"Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors – Supplement 1 to CENPD-287," WCAP-15942-P-A, March 2006.*

b. *"Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors," CENPD-287-P-A, July 1996.*

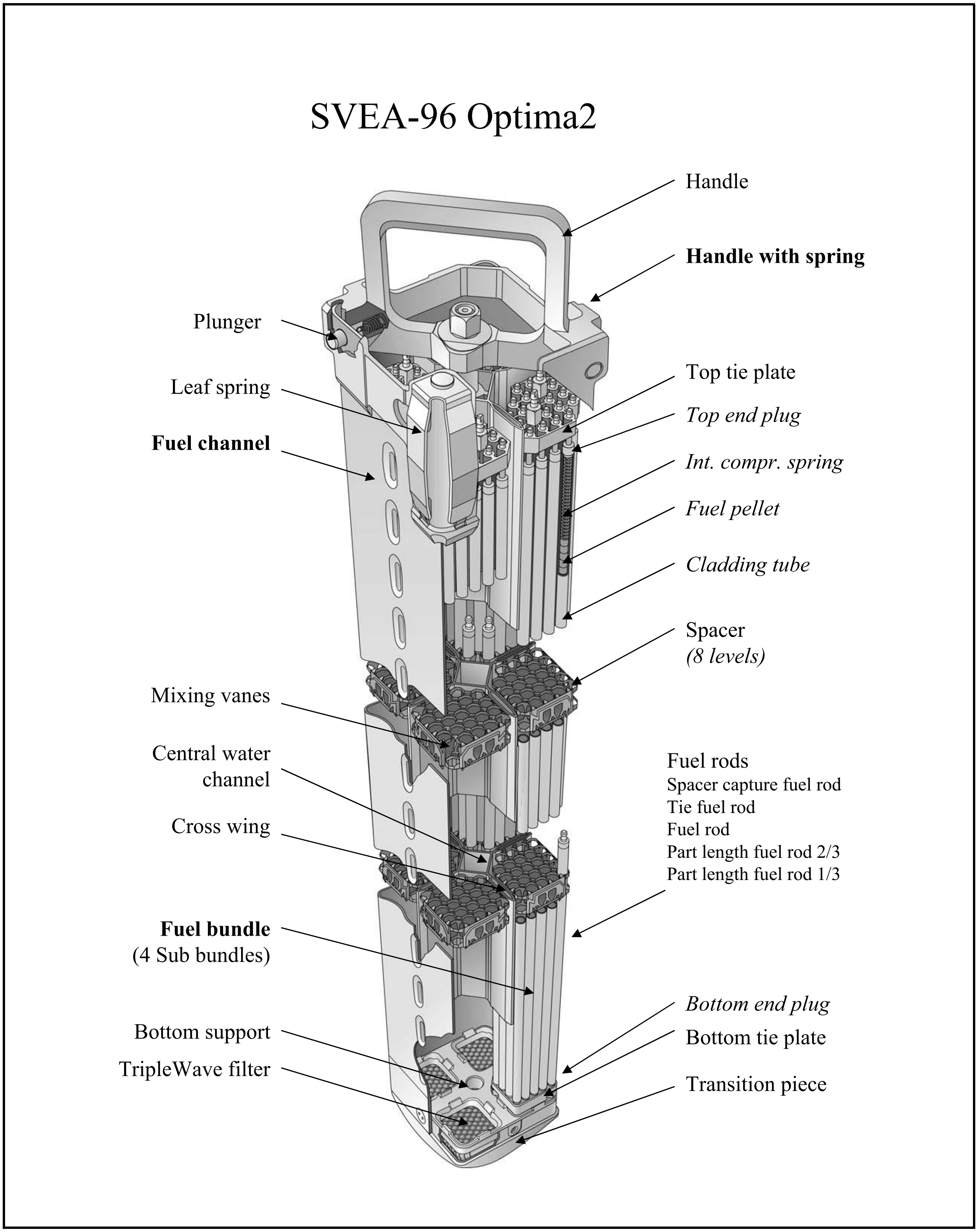
4.2-2 *Fuel Evaluation Methods and Results*

a. *"Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1," WCAP-15836-P-A, April 2006.*

b. *"Fuel Rod Design Methods for Boiling Water Reactors," CENPD-285-P-A, July 1996.*]*

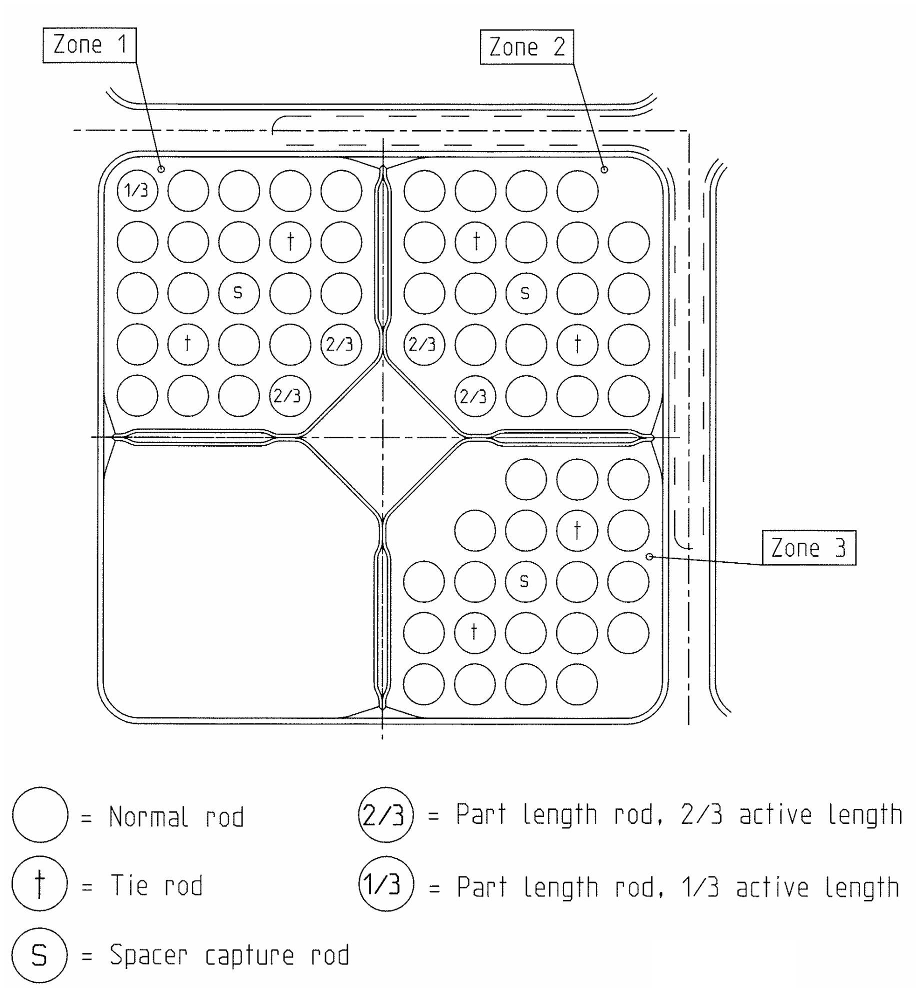
4.2-3 Not Used

* See Section 4.2.



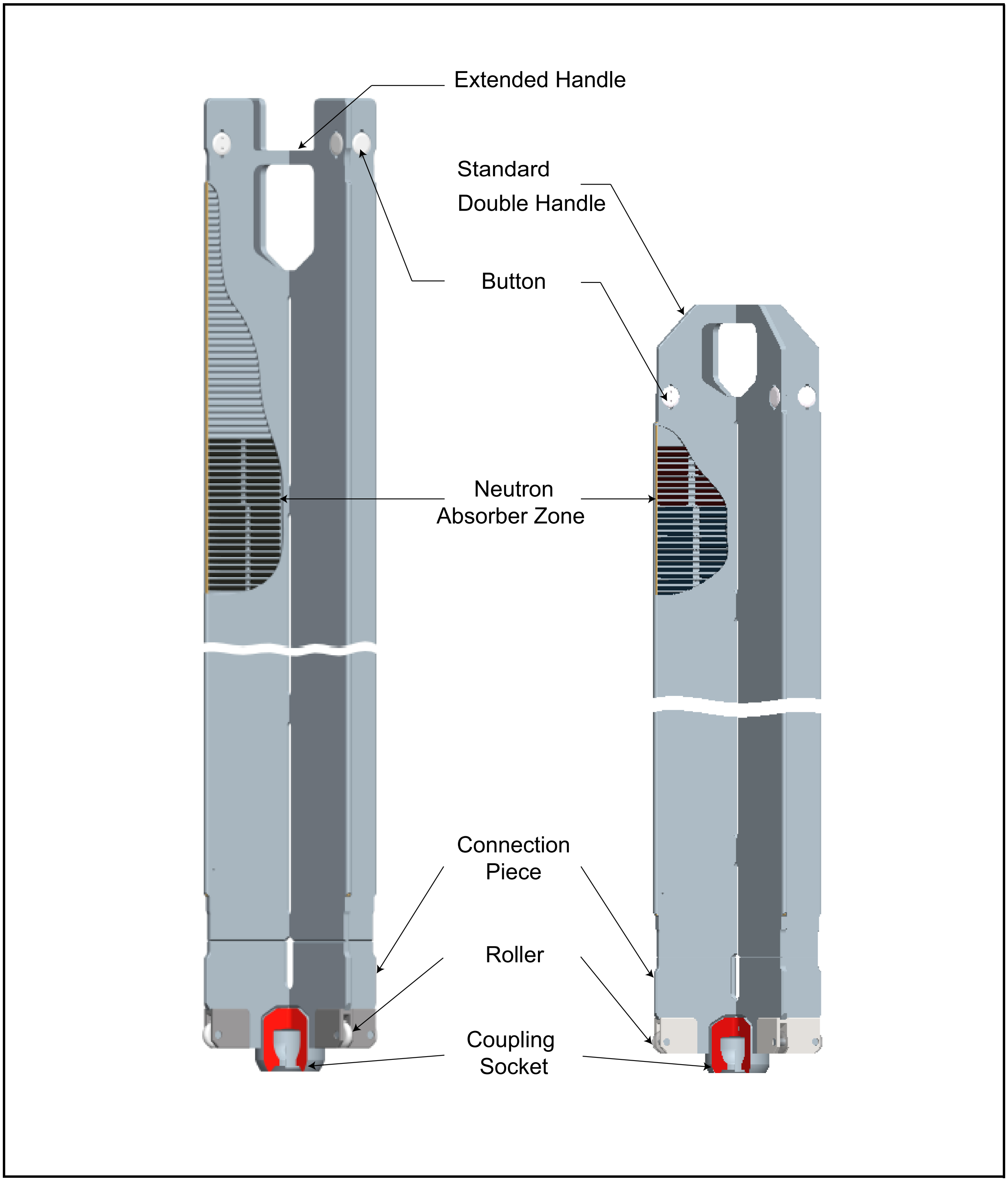

**[*Figure 4.2-1a Fuel Assembly*]***

* See Section 4.2 for restriction to change this figure.




**[*Figure 4.2-1b Fuel Assembly*]***

* See Section 4.2 for restriction to change this figure.




**[*Figure 4.2-2 Control Rod Assembly*]***

* See Section 4.2 for restriction to change this figure.