4.5 REACTOR MATERIALS

4.5.1 Control Rod Drive System Structural Materials

GDC 1 and 10 CFR 50.55(a) establish the requirements regarding structures, systems, and components (SSC) important to safety being designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. The specifications and design requirements of the materials selected for the control rod drive mechanism (CRDM) are described in Sections 3.9.4, 4.5, and 5.2.3.

GDC 14 establishes requirements regarding the reactor coolant pressure boundary being designed, fabricated, erected, and tested to have extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture. The pressure boundary of the CRDM is designed in accordance with ASME Code and the materials are selected based on compatibility with their environment as described in Sections 3.9.4, 4.5, and 5.2.3.

GDC 26 establishes the requirements regarding control rods being capable of reliable control of reactivity changes to prevent exceeding fuel design limits under conditions of normal operation, including anticipated operational occurrences. The CRDM material selection and fabrication support reliable rod movement for reactivity control, which is addressed in Sections 3.9.4, 4.5, and 5.2.3.

4.5.1.1 Materials Specifications

Parts exposed to reactor coolant are made of corrosion resistant materials. The CRDM pressure boundary materials exposed to reactor coolant include Type 347 stabilized austenitic stainless steel and ASME SA-479 UNS S41500 (Code Case N-785)/SA-182 Grade F6NM martensitic stainless steel. The CRDM pressure boundary bolting-studs materials not exposed to reactor coolant include Alloy A-286 austenitic stainless steel bolting studs as well as martensitic stainless steel nuts. These materials are listed in Table 5.2-2.

The CRDM pressure boundary materials and pressure boundary weld filler material, which includes Type 347 austenitic stainless steel and alloy 52/52M/152 nickel base alloys, meet the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB (Reference 1). No Alloy 600 base metal or Alloy 82/182 weld metals are used in the CRDM pressure boundary in accordance with GDC 1 and 10 CFR 50.55(a).

Materials used in the CRDM internals are selected based on a proven AREVA design with 30 years of operating experience. CRDM internals are non-pressure boundary and non-structural components, thus the CRDM internals material specifications are not required to be ASME materials. CRDM internals material specifications are typically per European standards and are listed in Table 4.5-1—Control Rod Drive

Mechanism Materials. Table 4.5-1 also provides the material class and comparable material grade for each European standard. In general, the materials used for the CRDM internals are the same types of martensitic stainless steel, nickel-base alloys, and cobalt-base alloys used in current domestic PWR CRDMs, with similar material properties.

Cold-worked grade austenitic stainless steels are not used in the control rod and drive system. No austenitic stainless steel materials with yield strengths greater than 90,000 psi are used in the control rod and drive system.

As described in Section 4.5.1.2 and Section 4.5.1.3, material selection and fabrication support reliable rod movement by selecting materials that are compatible with the operating environment to prevent failure in accordance with GDC 26.

4.5.1.2 Austenitic Stainless Steel Components

4.5.1.2.1 Austenitic Stainless Steel Pressure Boundary Components

Section 5.2.3 describes the processing, inspections, and tests on stabilized austenitic stainless steel pressure boundary components to minimize susceptibility to intergranular corrosion. Section 5.2.3 verifies compliance with the guidelines of RG 1.37 and RG 1.44. Section 5.2.3 describes controls used on welding of austenitic stainless steels to prevent sensitization.

Tools used in abrasive work on austenitic stainless steel surfaces are controlled per the requirements in RG 1.37 to prevent the introduction of contaminants that may promote stress corrosion cracking in accordance with GDC 14.

4.5.1.2.2 Austenitic Stainless Steel Non-Pressure Boundary Components

Austenitic stainless steels are susceptible to different forms of intergranular corrosion in aggressive environments when sensitized. Grain boundary carbide sensitization occurs when chromium carbides precipitate on the grain boundaries when the material is heated between 800 to 1500°F. The austenitic stainless steels used in the non-pressure boundary components of the CRDM are stabilized stainless steels which prevent sensitization. No cold-worked grade stainless steels are used in the non-pressure boundary components of the CRDMs.

Tools used in abrasive work on austenitic stainless steel surfaces are controlled in compliance with RG 1.37 to prevent the introduction of contaminants that may promote stress corrosion cracking in accordance to GDC 14.

4.5.1.3 Other Materials

Materials other than austenitic stainless steels that are used in pressure boundary applications of the CRDM are addressed in Section 5.2.3. The only material other than austenitic stainless steel used in these applications is ASME SA-479 UNS S41500 (Code Case N-785)/SA-182 Grade F6NM. This material is martensitic stainless steel and is delivered in the quenched and tempered condition. The material is tempered between 1050°F and 1120°F as required by the ASME material specifications.

Materials other than austenitic stainless steel used in the non-pressure boundary components of the CRDM include martensitic stainless steel, cobalt-chromium alloy, nickel-base materials, and cobalt base material. The materials not used in pressure boundary applications are selected based on a proven German design with 30 years of operating experience. Materials are selected for their compatibility with the reactor coolant, as described in ASME articles NB-2160 and NB-3120 (Reference 1).

The martensitic stainless steel base metal used in the non-pressure boundary components is delivered in the quenched and tempered condition; tempering is performed at a temperature to between 1256°F and 1436°F.

The cobalt-chromium alloy is delivered in the solution annealed condition.

The nickel-base alloy used is a precipitation hardenable alloy which is extremely resistant to chemical corrosion and oxidation. It is supplied in the solution annealed (followed by quenching) and thermally aged condition for optimum resistance to stress corrosion cracking.

The cobalt alloy is only used in a very small portion of the CRDM where an alternate material will not perform satisfactorily. It has a very low susceptibility to corrosion.

The sliding surfaces of the latch unit are hard chromium plated. This material is only used in a very small portion of the CRDM where an alternate material will not perform satisfactorily.

4.5.1.4 Cleaning and Cleanliness Control

Cleanliness of the CRDMs is controlled during manufacture and installation per the requirements of ASME NQA-1-1994 (Reference 3) and RG 1.37 as addressed in Section 5.2.3.

4.5.2 Reactor Internals and Core Support Materials

GDC 1 and 10 CFR 50.55(a) establish the requirements regarding SSC important to safety being designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. The specifications and design requirements of the materials selected for the reactor internals and core support structures are described in Sections 3.9.5, 4.5, and 5.2.3.

4.5.2.1 Materials Specifications

The major components for the reactor internals are fabricated from austenitic stainless steel except for the hold-down spring, which is made from martensitic stainless steel and pins and inserts which are coated with Stellite 6 or equivalent which is a cobalt alloy. The materials specifications for the reactor internals and core support materials including weld filler materials are listed in Table 4.5-2—Reactor Vessel Internal Materials, which includes the use of ASME Code Case N-60-5 which is listed as an acceptable code case under RG 1.84. There are no other materials used in the reactor internals or core support structures that are not otherwise allowed under ASME Code, Section III, Subsection NG-2120 (Reference 4). Reactor internals and core support structure weld filler materials are specified in ASME BPV Code, Section II (Reference 2) which is in accordance with GDC 1 and 10 CFR 50.55(a).

Design of the reactor internals considers the estimated peak neutron fluence to which the materials may be subjected. The reactor internals materials are evaluated for susceptibility to known aging degradation mechanisms such as irradiation-assisted stress corrosion cracking and void swelling that have been identified in current operating pressurized water reactors and are being addressed in the reactor internals material reliability programs.

4.5.2.2 Controls on Welding

The controls on welding of austenitic stainless steel pressure boundary components provided in Section 5.2.3 apply to the welding of reactor internals and core support components. When Section 5.2.3 is applied to the reactor internals and core support materials, ASME BPV Code, Section III (Reference 4) applies as in accordance with GDC 1 and 10 CFR 50.55(a).

4.5.2.3 Nondestructive Examination

Nondestructive examination (NDE) of base materials is in accordance with ASME Code Section III, Division I, NG-2500 (Reference 4). The NDE methods and acceptance criteria for welds are in accordance with the requirements of the ASME Code Section III, Division 1, NG-5000 (Reference 4) and GDC 1 and 10 CFR 50.55(a).

4.5.2.4 Fabrication and Processing of Austenitic Stainless Steel Components

The details provided in Section 5.2.3 concerning the processing, inspections, and tests on unstabilized austenitic stainless steel components to minimize susceptibility to intergranular corrosion caused by sensitization are applicable to the austenitic stainless steel materials used in the reactor internals and core support structures. Section 5.2.3 verifies compliance of reactor internals and core support structures with RG 1.44. The reactor internals and core support structures are fabricated from low carbon austenitic stainless steels which are heat treated in accordance with RG 1.44 to minimize their susceptibility to stress corrosion cracking. Cold-worked Type 316 austenitic stainless steel used in reactor internals support pins and bolting have a maximum specified room temperature yield strength of 90,000 psi as determined by the 0.2 percent offset method.

The information provided in Section 5.2.3 is applicable to the reactor internals and core support structures and verifies compliance with NQA-1-1994 specifications and RG 1.37.

Tools used in abrasive work on austenitic stainless steel surfaces are controlled per the requirements in RG 1.37 to prevent the introduction of contaminants that may promote stress corrosion cracking in accordance with GDC 14.

4.5.2.5 Other Materials

The hold-down spring is made from martensitic stainless steel, AISI Type 403 Modified (Code Case N-4-11) Heat Treated. This martensitic stainless steel is delivered in the quenched and tempered condition. The material is tempered at a minimum of 1125 F° as required by ASME Code Case N-4-11.

The Stellite 6 or equivalent cobalt alloy is used only in a portion of the reactor internals where an alternate material will not perform satisfactorily. It has a low susceptibility to corrosion.

This material was selected for compatibility with reactor coolant, as described in ASME articles NB-2160 and NB-3120.

4.5.3 References

1. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, “Class 1 Components,” The American Society of Mechanical Engineers, 2004.

2. ASME Boiler and Pressure Vessel Code, Section II, Part C, “Specifications for Welding Rods, Electrodes and Filler Materials,” The American Society of Mechanical Engineers, 2004.

3. NQA-1-1994, “Quality Assurance Requirements for Nuclear Facility Applications (QA),” ASME, The American Society of Mechanical Engineers, 1994.

4. ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, “Core Support Structures,” The American Society of Mechanical Engineers, 2004.

Table 4.5-1—Control Rod Drive Mechanism Materials
Sheet 1 of 2

CRDM Component	Material Class	Material Grade / Material Standard	Comparable Material Grade
Latch Unit – Magnetic Parts • Holding Armature Upper & Lower Part • Shim Washer & Ring • Gripping Armature • Lifting Armature • Lifting Pole with Dashpot Ring • Holding Pole • Ring Drive Rod • Coupling Sleeve • Disconnect Rod • Ring • Gate Valve • Disconnect Rod Head • Coupling Clamp • Grooved Tube	Martensitic Stainless Steel	Material 1.4006 according to: DIN EN 10088-3 (bars), DIN 17456 (seamless tubes), or X12Cr13 according to RCC-M 3207	ASME SA-479 Type 410 (bars) ASME SA-268 TP 410 (seamless tubes)
Latch Unit • Guide Sleeve • Holding Latch Carrier • Collar • Lifting Latch Carrier • Latch Drive Rod • Guide Sleeve of Compression Spring • Interlock Button	Austenitic Stainless Steel	Material 1.4550 according to: DIN EN 10088-3 (bars), or Z6CNNb18-11 according to RCC-M 3306	ASME SA-479 Type 347
Latch Unit – Non-Magnetic Part • Articulated Lever Drive Rod • Pin	Austenitic Stainless Steel	Material 1.4571 according to: DIN EN 10088-3 (bars), or Z8CNDT18-12 according to RCC-M 3306	ASME SA-479 Type 316Ti

Table 4.5-1—Control Rod Drive Mechanism Materials
Sheet 2 of 2

CRDM Component	Material Class	Material Grade / Material Standard	Comparable Material Grade
Latch Unit – Non-Magnetic Parts • Separating Shim • Locking Screw • Cylinder Pin Threaded	Austenitic Stainless Steel	Material 1.4571 according to: DIN EN 10088-3 (bars), or Z8CNDT18-12 according to RCC-M 3306	ASME SA-479 Type 316Ti
Latch Unit – Sliding Surfaces	Hard Chromium Plated	Hard Chromium Plated	Hard Chromium Plated
Latch Unit • Pins Drive Rod • Spreader Button	Cobalt-Chromium Alloy	Haynes 25 SAE/AMS 5759	Haynes 25 SAE/AMS 5759
Latch Unit • Compression Springs Drive Rod • Compression Spring	Nickel-Base Alloy	Alloy X-750 SAE/AMS 5698	Alloy X-750 SAE/AMS 5698
Hard Facing of Latch Tips	Cobalt Based Material	Stellite 6	ASME SFA 5.21 ERCoCr-A (rod) ASME SFA 5.21 ERCC0Cr-A (wire) ASME SFA 5.13 ECoCr-A (electrode)
Drive Rod • Disconnect Rod Weld	Martensitic Stainless Steel	G(W) Z 17 Ti based on DIN EN 12072	ASME SFA 5.9 ER430

Table 4.5-2—Reactor Vessel Internal Materials

Component	Material Specifications
Lower Internals Assembly	ASME SA-182 Grade F304 (see Notes 1&2) ASME SA-336 Grade F304 (see Notes 1&2) ASME SA-240 Type 304 (see Notes 1&2) ASME SA-479 Type 304 (see Notes 1&2) ASME SA-479 Type 316 Strain Hardened Level 1 (Code Case N-60-5) Carbon content shall be 0.03 wt% or less ASME SB-168 UNS-N06690 ASME SB-637 UNS-N07750, Type 2 Stellite 6 (see Note 3) or equivalent (hard facing)
Upper Internals Assembly	ASME SA-182 Grade F304 (see Notes 1&2) ASME SA-336 Grade F304 (see Notes 1&2) ASME SA-376 Grade TP304 (see Notes 1&2) ASME SA-240 Type 304 (see Notes 1&2) ASME SA-479 Type 304 (see Notes 1&2) ASME SA-479 Type 316 Strain Hardened Level 1 (Code Case N-60-5) Carbon content shall be 0.03 wt% or less Stellite 6 (see Note 3) or equivalent (hard facing)
Heavy Reflector	ASME SA-336 Grade F304 (see Notes 1&2) ASME SA-240 Type 304 (see Notes 1&2) ASME SA-336 Grade F304 (see Notes 1&2) ASME SA-479 Type 304 (see Notes 1&2) ASME SA-479 Type 316 Strain Hardened Level 1 (Code Case N-60-5) Carbon content shall be 0.03 wt% or less Stellite 6 (see Note 3) or equivalent (hard facing)
Control Rod Guide Assembly	ASME SA-182 Grade F304 (see Notes 1&2) ASME SA-240 Type 304 (see Notes 1&2) ASME SA-479 Type 304 (see Notes 1&2) ASME SA-376 Grade TP304 (see Notes 1&2)
Hold Down Spring	AISI Type 403 Modified (Code Case N-4-11) Heat Treated
Reactor Vessel Internals Welds	Type 308L/309L/316L austenitic stainless steel per SFA 5.4, 5.9, or 5.22

Notes:

1. Solution annealed and rapidly cooled.

2. Carbon content not exceeding 0.03 wt%.

3. ASME SFA-5.21 ERCCoCr-A or ERCoCr-A, ASME SFA-5.13 ECoCr-A.