4.5 Reactor Materials

4.5.1 Control Rod Drive System Structural Materials

4.5.1.1 Material Specifications

(1) Material List

The following material listing applies to the control rod drive (CRD) mechanism supplied for this application. The position indicator and minor non-structural items are omitted. The listing includes materials for reactor pressure boundary components that must meet all ASME Code, Section III, Class 1 requirements (Subsection NB).

The properties of the materials selected for the reactor pressure boundary of the CRD mechanism shall be equivalent to those given in Appendix I to Section III of the ASME Code or Parts A and B of Section II of the ASME Code, or are included in Regulatory Guide 1.84, except that cold-worked austenitic stainless steels shall be controlled by limiting hardness, bend radius, or the amount of induced strain.

(a) Spool Piece Assembly

Spool Piece Housing	ASME SA-182/182M Grade F304L, F304*, F316L, F316* or ASME SA-336/336M Grade F304*, F316*
Seal Housing	ASME SA-182/182M Grade F304L, F304*, F316L, F316* or ASME SA-336/336M Grade F304*, F316*
Drive Shaft	ASME SA-479/479M Type 316*, 316L or ASTM A479/479M Type 316*/**, 316L** (Hardsurfaced with Colmonoy No. 6 or equivalent Nickel base alloy)
Ball Bearings (in water)	ASTM A756 Type 440C** or A 276 Type 440C**
Ball Bearings (in air)	AISI 52100**
Gland Packing Spring	AMS 5699 Alloy N07750** (Alloy X-750)

	Separation Spring	AMS 5699 Alloy N07750** (Alloy X-750)
	Separation Magnet	Alnico No. 5 and ASME SA-479/479M Type 316*, 316L or ASTM A479/479M Type 316*/**, 316L**
(b)	Ball Spindle	
	Ball Screw Shaft	ASME SA-564/564M Type 630 Condition H-1100 or ASTM A-564/564M Type 630 (17-4PH)** Condition H-1100
	Ball Nut	ASME SA-564/564M Type 630 Condition H-1100 or ASTM A-564/564M Type 630 (17-4PH) ** Condition H-1100
	Balls	ASTM A756 Type 440C** or A580/580M Type 440C** or A276 Type 440C**
	Guide Roller	Stellite No. 3, or nickel base alloy
	Guide Roller Pin	ASME SA-479/479M Type XM-19 (Nitrided) or ASTM A479/479M Type XM-19** (Nitrided) or equivalent ferrous base alloy
	Spindle Head Bolt	Stellite No. 6B**
	Spindle Head Bushing	Stellite No. 12**
(c)	Buffer Mechanism	
	Buffer Disk Spring	ASME SB-637 Alloy N07750 or ASTM B 637 Alloy N07750** or AMS 5542 Alloy N07750** (Alloy X-750)
	Buffer Sleeve	ASME SA-479/479M Type 316*, 316L (Hard surfaced with Colmonoy No. 6) or ASTM A 479/479M Type 316*/**, 316L** (Hard surfaced with Colmonoy No. 6)

	Guide Roller	Stellite No. 3, or nickel base alloy
	Guide Roller Pin	ASME SA-479/479M Type XM-19 (Nitrided) or ASTM A479/479M Type XM-19** (Nitrided) or equivalent ferrous base alloy
	Stop Piston	ASME SA-479/479M Type 316*, 316L (Hard surfaced with Stellite No.6) or ASTM A 479/479M Type 316*/**, 316L** (Hard surfaced with Stellite No. 6)*
(d)	Hollow Piston	
	Piston Tube	ASME SA-312/312M Grade TPXM-19 or ASTM A 312/312M Grade TPXM-19
	Drive Piston	ASME SA-479/479M Type 316*, 316L (Hard surfaced with Stellite No.6) or ASTM A 479/479M Type 316*/** 316L** (Hard surfaced with Stellite No. 6)
	Latch	ASME SB-637 Alloy N07750 or ASTM B 637 Alloy N07750** (Alloy X-750)
	Latch Spring	AMS 5699 Alloy N07750** (Alloy X-750)
	Bayonet Coupling	ASME SB-637 Alloy N07750 or ASTM B 637 Alloy N07750** (Alloy X-750)
(e)	Guide Tube	
	Guide Tube	ASME SA-312/312M Grade TP316*, TP316L or ASTM A 312/312M Grade TP316*/**, TP316L**

(f) Outer Tube Assembly

Outer Tube	ASME SA-312/312M Grade TPXM-19 or ASTM A 312/312M Grade TPXM-19**
Middle Flange	ASME SA-182/182M Grade F304L, F304*, F316L, F316* or ASME SA-336/336M Grade F304*, F316*

(g) Miscellaneous Parts

Ball for Check Valve	Stellite No.3, or equivalent cobalt base alloy
O-Ring Seal (Between CRD Housing and CRD)	Type 321 stainless steel coated with a qualified material
CRD Installation Bolts	ASME SA-193/193M Grade B7

* The material shall be qualified to ensure that it is free from sensitization. Carbon content specified to be 0.020% maximum.

** Equivalent materials have been provided. Materials with similar chemical composition, mechanical properties, and operating experience are considered equivalent.

(2) Special Materials

The bayonet coupling and latch are fabricated from Alloy X-750 in the high temperature (1093°C) solution heat treated condition, and aged 20 hours at 704°C to produce a tensile strength of 1034 MPa minimum, yield of 655 MPa minimum, and elongation of 20% minimum. The ball screw shaft and ballnut are ASTM A-564, Type 630 (17-4PH) (or its equivalent) in condition H-1100 (aged 4 hours at 593°C), with a tensile strength of 965 MPa minimum, yield strength of 795 MPa minimum, and elongation of 14% minimum.

These are widely used materials, whose properties are well known. The parts are readily accessible for inspection and replaceable if necessary.

All materials for use in this system shall be selected for their compatibility with the reactor coolant as described in Articles NB-2160 and NB-3120 of the ASME Code.

Special materials (X-750, 17-4PH) have been successfully used for at least 25 years in similar drive mechanisms (LPCRD or FSCRD).

No cold-worked austenitic stainless steels except those with controlled hardness or strain are employed in the Control Rod Drive (CRD) System. During fabrication and installation, special controls are used to limit the induced strain, and the bend radii are kept above a minimum value.

4.5.1.2 Austenitic Stainless Steel Components

(1) Processes, Inspections and Tests

All austenitic stainless steels are used in the solution heat treated condition. In all welded components which are exposed to service temperature exceeding 93°C, the carbon content of 300 series stainless steel is limited not to exceed 0.020%. On qualification, there is a special process employed which subjects selected 300 series stainless steel components to temperatures in the sensitization range. The drive shaft, buffer sleeve, drive piston, and stop piston are hard surfaced with Colmonoy No. 6 (or an equivalent). Hard-surfaced components have performed successfully for the past 25 to 30 years in drive mechanisms. It is normal practice to remove some CRDs at each refueling outage. At this time, hard-surfaced parts are accessible for visual examination. This inspection program is adequate to detect any incipient defects before they could become serious enough to cause operating problems (see Subsection 4.5.3.1 for COL license information). The degree of conformance to Regulatory Guide 1.44 is presented in Subsection 4.5.2.4.

(2) Control of Delta Ferrite Content

Discussion of this subject and the degree of conformance to Regulatory Guide 1.31 is presented in Subsection 4.5.2.4.

4.5.1.3 Other Materials

These are presented in Subsection 4.5.1.1(2).

4.5.1.4 Cleaning and Cleanliness Control

All the CRD parts listed in Subsection 4.5.1.1 are fabricated under a process specification which limits contaminants in cutting, grinding and tapping coolants and lubricants. It also restricts all other processing materials (marking inks, tape, etc.) to those which are completely

removable by the applied cleaning process. All contaminants are then required to be removed by the appropriate cleaning process prior to any of the following:

(1) Any processing which increases part temperature above 93°C

(2) Assembly which results in decrease of accessiblity for cleaning

(3) Release of parts for shipment

The specification for packaging and shipping the control rod drive provides the following:

The CRD is rinsed in hot deionized water and dried in preparation for shipment. The ends of the drive are then covered with a vapor-tight barrier with dessicant. Packaging is designed to protect the drive and prevent damage to the vapor barrier. Audits have indicated satisfactory protection.

Semiannual examination of 10% of the units humidity indicators is required to verify that the units are dry and in satisfactory condition. This inspection shall be performed with a vendor designated representative present. The position indicator probes are not subject to this inspection.

Site or warehouse storage specifications require inside heated storage comparable to Level B of NQA-1, Part II, Subpart 2.2.

The degree of surface cleanliness obtained by these procedures meets the requirements of Regulatory Guide 1.37.

4.5.2 Reactor Internal Materials

4.5.2.1 Material Specifications

Materials Used for the Core Support Structure:

- **Shroud Support—**Niobium modified Nickel-Chromium-Iron Alloy 600 per ASME Code Case No. N-580-2
- **Shroud, Core Plate, and Grid—**ASME SA-240/240M Type 316L or Type 316* and SA479/479M Type XM-19, SA-479/479M Type 316L, SA-182/182M Grade F316L
- **Peripheral Fuel Supports—**ASME SA-479/479M Type 316* or Type 316L
- **Core Plate and Top Guide Studs, Nuts, and Sleeves—**ASME SA-479/479M Type 316* or Type 316L and XM-19
- **Control Rod Drive Housing—**ASME SA-336/336M Grade F316* or ASME SA-312/312M TP316*

- **Control Rod Guide Tube—**ASME SA-312/312M Grade TP316* or Type 316L (Body), SA-479/479M Type XM-19 (Base), SA 312/312M Grade TPXM-19 (Sleeve)
- **Orificed Fuel Support—**ASME SA-351/351M Grade CF3

* The base material shall be qualified to assure that it is free from sensitization. Carbon content is specified to be 0.02% maximum.

Materials Employed in Shroud Head and Separator Assembly and Steam Dryer Assembly:
All materials are 316L stainless steel except castings, Steam Dryer Vanes, and Steam Dryer Seismic Blocks.

- **Plate, Sheet and Strip—**ASTM A240 Type 316L or ASME SA-240/240M Type 316L
- **Forgings—**ASTM A182 Grade F316L or A336 Grade F316L or ASME SA-182/182M Grade F316L or SA-336/336M Grade F316L
- **Bars—**ASTM A 479 Type 316L or ASME SA-479/479M Type 316L
- **Pipe—**ASTM A312 Grade TP316L or ASME SA-312/312M Grade TP 316L
- **Tube—**ASTM A269 Grade TP316L or ASME SA-312/312M Grade TP 316L or SA-403/403M WP 316L
- **Castings—**ASTM A351 Grade CF3 or ASME SA-351/351M Grade CF3
- **Steam Dryer Seismic Blocks**—ASTM A 240 Type XM-19 or ASME SA-240/240M Type XM-19
- **Steam Dryer Vanes**—ASTM A 240 Type 304L or 316L or ASME SA-240/240M Type 304L or 316L

All core support structures are fabricated from ASME specified materials, and designed in accordance with requirements of ASME Code Section III, Subsection NG. The other reactor internals are noncoded, and they are fabricated from ASTM or ASME specification materials or other equivalent specifications.

4.5.2.2 Controls on Welding

Core support structures are fabricated in accordance with requirements of ASME Code Section III, Subsection NG-4000, and the examination and acceptance criteria shown in NG-5000.

The internals, other than the core support structures, meet the requirements of the industry standards e.g., ASME or AWS, as applicable. ASME B&PV Code Section IX qualification

requirements are followed in fabrication of core support structures. All welds are made with controlled weld heat input.

4.5.2.3 Non-Destructive Examination of Wrought Seamless Tubular Products

The stainless steel CRD housing (CRDHs), which are partially core support structures (inside the reactor vessel), serve as the reactor coolant pressure boundary outside the reactor vessel. The CRD housing material is supplied in accordance with ASME Section III Class 1 requirements. The CRDHs are examined and hydrostatically tested to the ASME Section III Class 1 requirements as well as Class CS requirements.

Wrought seamless tubular products for other internals were supplied in accordance with the applicable ASTM or ASME material specifications. These specifications require a hydrostatic test on each length of tubing.

4.5.2.4 Fabrication and Processing of Austenitic Stainless Steel—Regulatory Guide Conformance

Significantly cold-worked stainless steels are not used in the reactor internals except for vanes in the steam dryers; cold work is controlled by applying limits on hardness, bend radii and surface finished on ground surfaces. Furnace sensitized material are not allowed. Electroslag welding is not applied for structural welds. The delta ferrite content for weld materials used in welding austenitic stainless steel assemblies is verified on undiluted weld deposits for each heat or lot of filler metal and electrodes. The delta ferrite content is defined for weld materials as a minimum average Ferrite Number (FN) of 8.0 with no individual reading less than 5 FN and 20FN maximum. This ferrite content is considered adequate to prevent any micro-fissuring (Hot Cracking) in austenitic stainless steel welds. This procedure complies with the requirements of Regulatory Guide 1.31.

The limitation placed upon the delta ferrite in austenitic stainless steel castings is 8% minimum and a maximum value of 20%. The maximum limit is used for those castings designed for a 60 year life such as the fuel support pieces, in order to limit the effects of thermal aging degradation. Short in-reactor lifetime components such as the fuel tie plates do not require such a limit.

Proper solution annealing of the 300 series austenitic stainless steel is verified by testing per ASTM-A262, “Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steels.” Welding of austenitic stainless steel parts is performed in accordance with Section IX (Welding and Brazing Qualification) and Section II Part C (Welding Rod Electrode and Filler Metals) of the ASME B&PV Code.

For the ABWR, the primary method used to comply with the intent of Regulatory Guide 1.44 is to require low carbon content (<0.020%) for all 300 series stainless steels exposed to high temperature reactor water. Alternately, material use is restricted to low temperature locations (T<93 deg C). These controls comply with the intent of Regulatory Guide 1.44.

Exposure to contaminants is avoided by carefully controlling all cleaning and processing materials which contact stainless steel during manufacture and construction. Any inadvertent surface contamination is removed to avoid potential detrimental effects.

Special care is exercised to insure removal of surface contaminants prior to any heating operation. Water quality for rinsing, flushing, and testing is controlled and monitored.

The degree of cleanliness obtained by these procedures meets the requirements of Regulatory Guide 1.37.

4.5.2.5 Other Materials

Hardenable martensitic stainless steel and precipitation hardening stainless steels are not used in the reactor internals.

Materials, other than Type-300 stainless steel, employed in reactor internals are:

(1) Type XM-19 stainless steel

(2) Niobium modified Alloy 600 per ASME Code Case No. N-580-2.

(3) ASTM B 637 or ASME SB-637, AMS 5542, AMS 5699 UNS N07750 (Alloy X-750) or equivalent

All Nb-modified Alloy 600 is used in the solution annealed condition.

Where maximum resistance to stress corrosion is required, Alloy X-750 is used in the high temperature (1093°C) annealed plus single aged condition.

A hard chromium plating surface is applied to the austenitic stainless steel HPCF couplings.

All materials used for reactor internals shall be selected for their compatibility with the reactor coolant as shown in ASME Code Section III, NG-2160 and NG-3120. The fabrication and cleaning controls will preclude contamination of nickel-based alloys by chloride ions, fluoride ions, sulfur, or lead.

All materials have been successfully used for at least 25 years in BWR applications. Extensive laboratory tests have demonstrated that XM-19 is a suitable material and that it is resistant to stress corrosion in a BWR environment.

4.5.3 COL License Information

4.5.3.1 CRD Inspection Program

The CRD inspection program shall include provisions to detect incipient defects before they become serious enough to cause operating problems. The CRD nozzle and bolting are included in the inservice inspection program (Table 5.2-8, System Number B11/B12). CRD bolting is

accessible for inservice examinations during normally scheduled CRD maintenance (Subsection 4.5.1.2(1)).