4.5 REACTOR MATERIALS

4.5.1 CONTROL ELEMENT DRIVE STRUCTURAL MATERIALS

4.5.1.1 Material Specifications

a) The materials used in the control element drive mechanism (CEDM) reactor coolant pressure boundary components are as follows:

1. Motor housing assembly

SA 182, Type 348 (austenitic stainless steel)

→(EC-2800, R307)

Modified, Type 403, Conforming to Code Case N-4-12 Condition 2 (martensitic stainless steel)

←(EC-2800, R307)

SB 166 (nickel-chromium-iron alloy)

2. Upper pressure housing

SA 213, Type 316 (austenitic stainless steel)

→(EC-2800, R307)

←(EC-2800, R307)

SA 479, Type 316 (austenitic stainless steel)

ASTM A276, Type 440 (martensitic stainless steel with yield strength greater than 90,000 psi)

→(EC-2800, R307)

The above listed materials with the exception of the ASTM A276, Type 440 material are also listed in Appendix I of the 1998 Edition of Section III of the ASME Boiler and Pressure Vessel Code, including the 2000 Addenda. In addition, the materials comply with the 1998 Edition of Sections II and IX of the ASME Boiler and Pressure Vessel Code including the 2000 Addenda.

←(EC-2800, R307)

The functions of the above listed components are described in Subsection 3.9.4.1.1.1.

b) The materials in contact with the reactor coolant used in the CEDM motor assembly components are as follows:

1. Latch guide tubes

ASTM A269, Type 316 (austenitic stainless steel)

Chrome Oxide (plasma spray treatment)

2. Magnet and spacer

ASTM A276, Type 410 (martensitic stainless steel)

→(EC-2800, R307)

ASTM A240 Type 304 (Austenitic Stainless Steel)

←(EC-2800, R307)

3. Latch and magnet housing

ASTM A276, Type 316 (austenitic stainless steel)

→(EC-2800, R307)

QQ-C320, Class 2 (chrome plating)

←(EC-2800, R307)

4. Spacer

ASTM A240, Type 304 (austenitic stainless steel)

5. Alignment Button

→(EC-2800, R307)

AMS 5643 (martensitic stainless steel)

←(EC-2800, R307)

6. Spring

→(EC-2800, R307)

AMS 5698 (nickel base alloy)

←(EC-2800, R307)

7. Pin

→(EC-2800, R307)

AMS 5894 (cobalt base alloy)

←(EC-2800, R307)

8. Dowel pin

→(EC-2800, R307)

ASTM A276, Type 304 (Austenitic stainless steel)
ASTM A276 Type 410 (Martensitic stainless steel)

←(EC-2800, R307)

9. Spacer and screw

ASTM A276, Type 304 (austenitic stainless steel)

10. Stop

ASTM A276, Type 304 (austenitic stainless steel)

11. Latch and pin

Haynes Stellite No. 36 (cobalt base alloy)

→(EC-2800, R307)

ASTM A240 Type 304 (Austenitic stainless steel)
ASTM A193 Grade B8 (Austenitic stainless steel)
ASTM A276 Type 304 (Austenitic stainless steel)

←(EC-2800, R307)

12. Locking cup and screws

300 Series austenitic stainless steel

The functions of the CEDM motor assembly components are described in Subsection 3.9.4.1.1.2.

c) The materials in contact with the reactor coolant used in the extension shafts are listed below:

1. Shafts, rod, and plunger

→(EC-2800, R307)

ASTM A276 (austenitic stainless steel)

ASTM A269 (austenitic stainless steel)

←(EC-2800, R307)

2. Gripper

ASTM B446 (nickel-chromium-molybdenum-columbium alloy)

QQ-C-320a, Class 2B (chrome plating)

3. Spring

AMS 5699B, Inconel X-750 (nickel base alloy)

4. Pin

Type 304 austenitic stainless steel

The function of the extension shaft components are described in Subsection 3.9.4.1.1.5.

→(EC-2800, R307)

d) The weld rod filler materials used with the above listed components are 308 stainless steel, Type 316 stainless steel and Alloy 52M.

←(EC-2800, R307)

All of the material listed in the above listings, a through d, were used in an extensively tested CEDM assembly that exceeded lifetime requirements, as described in Subsection 3.9.4.4.1. Also, all of the materials have performed satisfactorily in service in the Main Yankee (Docket 50-309), Millstone II (Docket 50-336), Calvert Cliffs (Docket 50-317), in addition to other designed reactors.

4.5.1.2 Control of the Use of 90 ksi Yield Strength Material

The only control element drive structural material identified in Subsection 4.5.1.1 which has a yield strength greater than 90 ksi is ASTM A276, Type 440, martensitic stainless steel. Its usage is limited to the steel ball in the vent valve on the top of the CEDM. The ball is used as a seal and is not a primary load bearing member of the pressure boundary. This material was tested and exceeded lifetime requirements. Also, this material is presently being used in operating reactors such as Maine Yankee (Docket 50-309), Millstone II (Docket 50-336) and Calvert Cliffs (Docket 50-317) and has performed satisfactorily for the same application.

4.5.1.3 Control of the Use of Sensitized Austenitic Stainless Steel

Control of the use of sensitized austenitic stainless steel is consistent with the recommendations of Regulatory Guide 1.44 as described in Subsections 4.5.1.3.1 through 4.5.1.3.32, except for the criteria used to demonstrate freedom from sensitization. The ASTM A393 Strauss Test was used in lieu of the ASTM A262 Method E Modified Strauss Test to demonstrate freedom from sensitization in fabricated unstabilized austenitic stainless steel. The former test has shown, through experimentation, excellent correlation with the type of corrosion observed in severely sensitized austenitic stainless steel NSSS components.

→(EC-2800, R307)

The replacement CEDM used the ASTM A262 Practice E test.

←(EC-2800, R307)

4.5.1.3.1 Solution Heat Treatment Requirements

All raw austenitic stainless steel, both wrought and cast, employed in the fabrication of the control element drive system structural components is supplied in the solution annealed condition as described in Subsection 4.5.2.4.2.1.

4.5.1.3.2 Material Inspection Program

→(DRN 00-644)

Extensive testing on stainless steel mockups, fabricated using production techniques, was conducted to determine the effect of various welding procedures on the susceptibility of unstabilized 300 series stainless steels to sensitization-induced intergranular corrosion. Only those procedures or practices demonstrated not to produce a sensitized structure were used in the fabrication of control element drive system structural components. The ASTM Standard A393 (Strauss Test) is the criterion used to determine susceptibility to intergranular corrosion. This test has shown excellent correlation with a form of localized corrosion peculiar to sensitized stainless steels. As such, ASTM A393 is utilized as a go/no-go standard of acceptability.

←(DRN 00-644)

→(EC-2800, R307)

The replacement CEDM used the ASTM A262 Practice E test.

←(EC-2800, R307)

4.5.1.3.3 Avoidance of Sensitization

Homogeneous or localized heat treatment of unstabilized austenitic stainless steel in the temperature range 800-1500 F is prohibited.

Weld heat affected zone sensitized austenitic stainless steel (which will fail the Strauss Test, ASTM A-393) is avoided in control element drive system structural components by careful control of

→(EC-2800, R307)

For replacement CEDMs, the ASTM A262 Practice E test was used.

←(EC-2800, R307)

a) Weld heat input to less than 60 kJ/in.

b) Interpass temperature to 350 F maximum.

4.5.1.4 Control of Delta Ferrite in Austenitic Stainless Steel Welds

→(EC-2800, R307)

The austenitic stainless steel, primary pressure retaining welds in the control element drive system structural components are consistent with the recommendations of the Interim Position of Regulatory Guide 1.31, MTEB 5-1, as described in Subsection 4.5.2.4.3.

Replacement CEDMs conform to Reg. Guide 1.31 Rev. 3. Revision 3 supersedes earlier revisions and BTP MTEB 5-1. See Section 1.8.

←(EC-2800, R307)

4.5.1.5 Cleaning and Contamination Protection Procedures

The procedure and practice followed for cleaning and contamination protection of the control element drive system structural components are as described in Subsection 4.5.2.4.1.

4.5.2 REACTOR INTERNALS MATERIALS

4.5.2.1 Material Specifications

The materials used in fabrication of the reactor internal structures are primarily Type 304 stainless steel. The flow skirt is fabricated from Inconel. Welded connections are used where feasible; however, in locations where mechanical connections are required, structural fasteners are used which are designed to remain captured in the event of a single failure. Structural fastener material is typically a high strength austenitic stainless steel; however, in less critical applications Type 316 stainless steel is employed. Hardfacing of Stellite material is used at wear points. The effect of irradiation on the properties of the materials is considered in the design of the reactor internal structures. Work hardening properties of austenitic stainless steels are not used.

The following is a list of the major component of the reactor internals together with their material specifications:

a) Core support barrel assembly

1) Type 304 austenitic stainless steel to the following specifications:

(a) ASTM-A-182

(b) ASTM-A-240

(c) ASTM-A-479

2) Precipitation hardening stainless steel to the following specifications:

(a) ASTM-A-453, Grade 660

(b) ASTM-A-638, Grade 660

b) Upper guide structure assembly

1) Type 304 austenitic stainless steel to the following specifications:

(a) ASTM-A-182

(b) ASTM-A-240

(c) ASTM-A-269

(d) ASTM-A-312

(e) ASTM-A-451

(f) ASTM-A-479

2) Precipitation hardening stainless steel to the following specifications:

(a) ASTM-A-453, Grade 660

c) Core shroud assembly

1) Type 304 austenitic stainless steel to the following specifications:

(a) ASTM-A-182

(b) ASTM-A-240

d) Holddown ring

ASTM-A-182, Grade F-6, modified to ASME Code Case 1337-6 with exception to the temper temperature which shall be 1150F for 4 hours.

The ASTM-A-182, Grade F-6 used for the holddown ring is heat treated to a minimum yield strength of 90,000 psia. Under reactor operating conditions of low oxygen and slightly alkaline pH, a slightly higher (than austenitic stainless steel) but acceptable general corrosion rate is anticipated to occur. No localized corrosion is anticipated under these conditions. When heat treated in hardness with Code Case 1337, i.e., BHN 226-277 (HRC 21-29), Type 403 can be expected to be resistant to stress corrosion in the primary coolant. Stress corrosion failures in PWR environments have occurred only where the material has been heat treated to hardness levels higher than specified.[1]

e) In-core instrument support system

1) Type 304 austenitic stainless steel to the following specifications:

(a) ASTM-A-193

(b) ASTM-A-194

(c) ASTM-A-240

(d) ASTM-A-249

(e) ASTM-A-269

(f) ASTM-A-276

(g) ASTM-A-312

(h) ASTM-A-473

(i) ASTM-A-479

(j) ASTM-B-353

(k) ASTM-B-446

2) Zircaloy -4

(a) ASTM-B-353

→(EC-10453, R304)

(b) ASTM-B-351

←(EC-10453, R304)

f) Bolt and pin material

ASTM-A-453 and ASTM-A-638, Grade 660 material (trade name A-286) is used for bolting and pin applications. This alloy is heat treated to a minimum yield strength of 85,000 psia. Its corrosion properties are similar to those of the 300 series austenitic stainless steels. It is austenitic in all conditions of fabrication and heat treatment. This alloy was used for bolting in previous reactor systems and test facilities in contact with primary coolant and has proven completely satisfactory.

g) Chrome plating and hardfacing

→(DRN 00-644)

Chrome plating or hardfacing are employed in the reactor internals components or portions thereof where required by function. Chrome plating complies with Federal Specification No. QQ-C-320a. The hardfacing material employed is Stellite 25.

←(DRN 00-644)

All of the materials employed in the reactor internals and in-core instrument support system have performed satisfactorily in operating reactors such as Palisades (Docket 50-255), Fort Calhoun (Docket 50-285), Maine Yankee (Docket 50-309).

4.5.2.2 Controls on Welding

Welds employed on reactor internals and core support structures meet the acceptance standards delineated in article NG-5000 Section III, Division I - 1974 Edition, and control of welding has been performed in accordance with Sections III Division 1, and IX of the applicable ASME Code. In addition, consistency with the recommendations for Regulatory Guides 1.31 and 1.44 is described in Subsection 4.5.2.4.

4.5.2.3 Nondestructive Examination of Wrought Seamless Tubular Products and Fittings

Quality Group A components in the reactor internals which are wrought seamless tubular products or fittings are consistent with the recommendations of Regulatory Guide 1.66.

4.5.2.4 Fabrication and Processing of Austenitic Stainless Steel Components

The following information applies to unstabilized austenitic stainless steel as used in the reactor internals.

4.5.2.4.1 Cleaning and Contamination Protection Procedures

Specific requirements for cleanliness and contamination protection are included in the equipment specifications for components fabricated with austenitic stainless steel. The provisions described below indicate the type of procedures utilized for components to provide contamination control during fabrication, shipment, and storage.

Contamination of austenitic stainless steels of the 300 type by compounds that can alter the physical or metallurgical structure and/or properties of the material are avoided during all stages of fabrication. Painting of 300 series stainless steels is prohibited. Grinding is accomplished with resin or rubber-boned aluminum oxide or silicon carbide wheels that have not previously been used on materials other than 300 series stainless alloys.

Internal surfaces of completed components are cleaned to the extent that grit, scale, corrosion products, grease, oil, wax gum, adhered or embedded dirt, or extraneous material are not visible to the unaided eye.

Cleaning is effected by either solvents (acetone or isopropyl alcohol) or inhibited water (30-200 ppm hydrazine). Water will conform to the following requirements:

Halides	0.60
Chloride, ppm	< 0.60
Fluoride, ppm	< 0.40
Conductivity, µmhos/cm < 5.0	
pH	6.0-8.0
Visual clarity	No turbidity, oil or sediment

→ (DRN 00-644)

To prevent halide-induced, intergranular corrosion that could occur in an aqueous environment with significant quantities of dissolved oxygen, flushing water is inhibited via additions of hydrazine. Experiments have proven this inhibitor to be efective(2). Operational chemistry specificatiopns preclude halides and oxygen, (both prerequisites of intergranular attacks), and are shown in Subsection 9.3.4 and 16.3/4.

← (DRN 00-644)

4.5.2.4.2 Control of the Use of Sensitized Austenitic Stainless Steel

→ (DRN 00-644)

The recommendations of Regulatory Guide 1.44, as desribed in Subsections 4.5.2.4.2.1 through 4.5.2.4.2.5, were followed except for the criteria used to demonstrate freedom from sensitization. The ASTM A393 Strauss Test was used in lieu of the ASTM A262 Method E Modified E Modified Strauss Test to demonstrate freedom from sensitization in fabricated unstabilized austenitic stainless steel, since the former test has shown, through experimentation, excellent correlation with the type of corrosion observed in severely sensitized austenitic stainless steel NSSS components. Either ASTM A262 Method E or A393 were used as the acceptance criteria for raw austenitic stainless steel material, with the exception of tubing for the in-core instrument support system. Tubing for this application

← (DRN 00-644)

conforms to the requirements of ASTM-A 269, which includes provisions for rapid cooling subsequent to solution heat treatment.

4.5.2.4.2.1 Solution Heat Treatment Requirements

➔(DRN 00-644)
All raw austenitic stainless steel material, both wrought and cast, employed in the fabrication of the reactor internals is supplied in the solution annealed condition as specified by the pertinent ASTM or ASME B&PV Code material specification; viz, 1900 to 2050 F for 1/2 to one hr per in. of thickness and rapidly cooled to below 700 F. The time at temperature is determined by the size and type of component.

Solution heat treatment is not performed on completed or partially fabricated components. Rather, the extent of chromium carbide precipitation is controlled during all stages of fabrication as described in Subsection 4.5.2.4.2.4.

4.5.2.4.2.2 Material Inspection Program

Extensive testing of stainless steel mockups, fabricated using production techniques, was conducted to determine the effect of various welding procedures on the susceptibility of unstabilized 300 series stainless steels to sensitization-induced intergranular corrosion. Only those procedures or practices demonstrated not to produce a sensitized structure were used in the fabrication of reactor internals components. The ASTM Standard A393 (Strauss Test) is the criterion used to determine susceptibility to intergranular corrosion. This test has shown excellent correlation with a form of localized corrosion peculiar to sensitized stainless steels. As such, ASTM A393 is utilized as a go/no-go standard for acceptability.
🡐(DRN 00-644)
As a result of the above tests, a relationship was established between the carbon content of Type 304 stainless steel and weld heat input. This relationship is used to avoid weld heat affected zone sensitization as described in Subsection 4.5.2.4.2.4.

➔(EC-2800, R307)
For replacement CEDMs, the ASTM A262 Practice E test was used.
🡐(EC-2800, R307)

4.5.2.4.2.3 Unstabilized Austenitic Stainless Steels

➔(DRN 03-2058, R14)
The unstabilized grade of austenitic stainless steel with a carbon content greater than 0.03 percent used for components of the reactor internals is Type 304. This material is furnished in the solution annealed condition. The acceptance criteria used for this material as furnished from the steel supplier is ASTM A262 Practice E or ASTM A393.

Exposure of completed or partially fabricated components to temperatures ranging from 800 to 1500F is prohibited except as described in Subsecvtion 4.5.2.4.2.5.

Duplex, austenitic stainless steels, containing >5 v/o delta ferrite (weld metal, cast metal, weld deposit overlay), are not considered unstabilized since these alloys do not sensitize; i.e., form a continuous network of chromium-iron carbides. Specifically, alloys in this category are:
🡐(DRN 03-2058, R14)

a) CF8M Cast stainless steels (delta ferrite controlled to 5-25 v/o

b) CF8

c) Type 308 Singly and combined

d) Type 309 Stainless steel weld filler metals. (Delta ferrite controlled to 5-18 v.o as deposited.)

e) Type 312

f) Type 316

In duplex austenitic/ferrite alloys, chromium-iron carbides are precipitated preferentially at the ferrite/austenitic interfaces during exposure to temperatures ranging from 1000-1500F. This precipitate morphology precludes intergranular penetrations associated with sensitized 300 series stainless steels exposed to oxygenated or otherwise faulted environments.

4.5.2.4.2.4 Avoidance of Sensitization

Exposure of unstabilized austenitic 300 stainless steels to temperatures ranging from 800 to 1600 F will result in carbide precipitation. The degree of carbide precipitation, or sensitization, depends on the temperature, the time at that temperature, and also the carbon content. Severe sensitization is defined as a continuous grain boundary chromium-iron carbide network. This condition induces susceptibility to intergranular corrosion in oxygenated aqueous environments, as well as those containing halides. Such a metallurgical structure will readily fail the Strauss Test, ASTM A393. Discontinuous precipitates (i.e., an intermittent grain foundary carbide network) are not susceptible to intergranular corrosion in a PWR environment.

→(EC-2800, R307)
For replacement CEDMs, the ASTM A262 Practice E test was used.
←(EC-2800, R307)

Weld heat affected zone sensitized austenitic stainless steels were avoided (which will fail the Strauss Test, ASTM A393) by careful control of:

a) Weld heat input

b) Interpass temperature

A weld heat input of less than 60kJ/in. is used during most fabrication stages of the Type 304 stainless steel core support structure. Higher heat inputs are used in some heavy section weld joints. Freedom from weld heat-affected zone sensitization in these higher heat input weldments is demonstrated with weld runoff samples produced at the time of component welding in material having a carbon content equal to or greater than the highest carbon content of those heats of steel being fabricated. Specimens so provided are subjected to the Strauss Test, ASTM A393.

4.5.2.4.2.5 Retesting Unstabilized Austenitic Stainless Steels Exposed to Sensitizing Temperature

Sensitization which may be susceptible to intergranular corrosion, is avoided during welding as described in Subsection 4.5.2.4.2.4. Homogeneous or localized heat treatment of unstabilized stainless steels in the temperature range 800 to 1500 F is prohibited except in the case of the core support structure. This complex substructure is thermally stabilized at 900 ±25 F for seven hours after fabrication and prior to final machining. Such treatment produces only minor, discontinuous precipitates. In addition to thermocouple records during this heat treatment, a sample of Type 304 stainless steel having a carbon content equal to or greater than the highest carbon heat of material present in the structure is included as a monitor sample. After heat treatment, the monitor sample is subject to the Strauss Test, ASTM A393, as well as a metallographic examination to verify freedom from sensitization.

4.5.2.4.3 Control of Delta Ferrite in Welds

The recommendations of the Interim Position on Regulatory Guide 1.31, MTEB 5-1 were followed in the following manner:

a) The delta ferrite content of A-7 austenitic stainless steel filler metal used in the fabrication of major components of the reactor internals, was controlled to 5-20 v/o (FN5-23). Delta ferrite content was predicted either by chemical analysis performed on undiluted weld deposits using the Schaeffler or McKay diagram or by a calibrated magnetic measuring instrument. In the case of metal used with a nonconsumable electrode process, the delta ferrite content may be predicted by chemical analysis of the rod, wire, or consumable insert in conjunction with the stainless steel constitution diagram. The ferrite recommendations are met for each heat, lot, or heat/lot combination of weld filler material.

b) The average minimum delta ferrite content of production welds is three percent (FN3) as measured on an audit the basis.

→(EC-2800, R307)
For the replacement CEDMs, the recommendations of Reg. Guide 1.31 Revision 3 were followed. Revision 3 supersedes earlier revisions and BTP MTEB 5-1. See Section 1.8.
←(EC-2800, R307)

4.5.2.4.4 Control of Electroslag Weld Properties

The electroslag process was not utilized to fabricate reactor internal components.

4.5.2.4.5 Welder Qualification for Areas of Limited Accessibility

The specific recommendations of Regulatory Guide 1.71 were not followed. However, performance qualifications, for personnel welding under conditions of limited accessibility, are conducted and maintained in accordance with the requirements of ASME BPV Code Sections III an IX. A requalification is required when:

a) Any of the essential variables of Section IX are changed.

b) When authorized personnel have reason to question the ability of the welder to satisfactorily perform to the applicable requirements.

Production welding is monitored for compliance with the procedure parameters and welding qualification requirements are certified in accordance with Sections III and IX. Further

assurance of acceptable welds of limited accessibility is afforded by the welding supervisor assigning only the most highly skilled personnel to these tasks. Finally, weld quality, regardless of accessibility, is verified by the performance of the required nondestructive examination.

4.5.2.4.6 Non-Metallic Thermal Insulation

Non-metallic thermal insulation is not used on the reactor internals.

4.5.2.5 Contamination Protection and Cleaning of Austenitic Stainless Steel

→ (DRN 00-644)

Waterford 3 is consistent with the recommendations of Regulatory Guide 1.37. The QA program for safety-related items during onsite cleaning and layup of components, cleanliness control, and preoperational cleaning and layup of nuclear fluid systems was in accordance with ANSI-N-45.2.1-1973 as interpreted by Regulatory Guide 1.37.

← (DRN 00-644)

SECTION 4.5: REFERENCES

1. Bush, S.H. and Dillon, R.L., Stress Corrosion in Nuclear Systems, Pacific Northwest Laboratories, Battelle Memorial Institute, Richland, Washington, March 1973.

2. Habicht, P.R. and Bryant, P.E.C., Fluoride Induced Intergranular Corrosion of Sensitized Austenitic and Austenoferritic Stainless Steel, presented at the International Atomic Energy Authority Workshop on Stress Corrosion Cracking, San Francisco, California, March 1976.