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Pu-239, and Pu-241. To prepare multigroup cross sections, the applicant used the BUGLE-93 multigroup cross-section library, which includes 20 gamma groups and ~~46~~ neutron groups.

The staff notes that DORT is widely used in the nuclear industry to evaluate RPV neutron flux distributions. Although the applicant’s method does not employ the standard method of 3-D flux synthesis, it does use a conservative predicted axial power distribution and accounts for uncertainty in the methodology.

The staff reviewed the nuclide compositions of the modeled reactor materials, the fission spectra data, and the neutron source spectrum data provided in Tables 2-1 and 2-2 of APR1400-Z-A-NR-14015-P, Revision 0, respectively, by performing hand calculations and comparing the source spectrum with published independent data (Haghighat, Mahgerefteh, and Petrovic, "Evaluation of the Uncertainties in the Source Distribution for Pressure Vessel Neutron Fluence Calculations,” *Nuclear Technology*, Vol. 109, 54-75, January 1995, [Ref. 4.3-1]). The staff found no erroneous data but was not able to discern and confirm the nuclide fractions that the applicant used for mixing the fission source spectra. Therefore, on November 5, 2015, the staff issued RAI 293-8332 (ML15314A018), Question 04.03-6, and in Part (a), requested the applicant to state the fission nuclide fractions used in calculating the source spectrum.

In the April 28, 2016, response to RAI 293-8332, Question 04.03-6 (ML16119A442), part (a), the applicant provided a table listing the number of neutrons per fission and the cycle-averaged relative fission rates for the uranium and plutonium isotopes in its source spectrum. The staff found this data consistent with measurements from the ENDF/B-VII library. For this reason, the staff finds that the applicant used adequate nuclide fractions for calculating the source spectrum and considers Part (a) of Question 04.03-6 resolved.

To assess the adequacy of the 2-D meshing used in the applicant’s r-θ DORT calculations, the staff compared the applicant's meshing with the various meshing models evaluated in an independent published study (Petrovic and Haghighat, "“Effects of Sn Method Numerics on Pressure Vessel Neutron Fluence Calculations,” *Nuclear Science and Engineering*, Vol. 122, No. 2, 167-193, 1996, [Ref 4.3-2]). Based on this comparison, the staff confirmed that the applicant’s 2-D meshing is sufficiently detailed.

With regard to the choice of multigroup nuclear cross-section library, the applicant examined the effect of using the newer BUGLE-96 library in place of BUGLE-93 by performing calculations at the inner reactor vessel surface using each library. As shown in Figure 4-1 of APR1400-Z-A-NR-14015-P, Revision 0, the resulting fast neutron fluxes obtained from using the two libraries are nearly identical. Therefore, the staff concludes that the use of the older BUGLE-93 library is acceptable.

The staff noted that APR1400-Z-A-NR-14015-P, Revision 0 does not identify the numerical options (e.g., differencing schemes) the applicant used in its DORT calculations. Therefore, in Part (b) of RAI 293-8332, Question 04.03-6, the staff requested that the applicant indicate what DORT numerical options it used.

In the response to Part (b) of RAI 293-8332, Question 04.03-6 (ML16119A442), the applicant listed the major DORT calculation options it used. The staff notes that the applicant’s selected options are consistent with RG 1.190 and are, therefore, acceptable. Hence, Part (b) of RAI 293-8332, Question 04.03-6, is resolved.

- RG 1.31, "Control of Ferrite Content in Stainless Steel Weld Metal."
- RG 1.44 and RG 1.84.
- ASME NQA-1, 2008 Edition with 2009 Addenda.

4.5.1.4 Technical Evaluation

The staff reviewed and evaluated the information included in DCD Tier 2 Section 4.5.1 to ensure that the materials specifications, fabrication, processing and cleanliness controls are in accordance with the criteria of SRP Section 4.5.1.

Materials Specifications

The staff reviewed DCD Tier 2 Section 4.5.1 to determine the suitability for service of the materials selected for CRDM structural components. Section 4.5.1 provides information on the specifications, types, grades, heat treatments, and properties used for the materials of the CRDM components. The materials used for the pressure housing components include stabilized stainless steel (Grades 347 and 348), martensitic stainless steel (ASME Code Case N-4-13 modified Type 403), nickel-based alloy SB-166 (alloy 690, thermally treated) and austenitic stainless steel (SA-213, Type 316 and SA-479, Type 316). Welding filler materials Alloy 52/52M, Alloy 152, and Types 308 and 316 austenitic stainless steel will be used in the fabrication of the CRDM pressure housing. The staff reviewed the specifications and grades of the CRDM pressure housing materials and verified that the materials listed meet the requirements of ASME Code, Section III, Paragraph NB-2121, "Permitted Materials Specifications," which requires the use of materials listed in ASME Code, Section II, Part D, Subpart 1, Tables 2A and 2B. The staff also verified that modified Type 403 stainless steel per the ASME Code Case ~~N-14-3~~ is approved for use in RG 1.84, Revision 36, and is therefore acceptable for use.

N-4-13

The staff verified that the materials identified for each of the specific pressure boundary components are acceptable materials for use in ASME Code, Section III, Class 1 systems, as noted below.

In order for the staff to determine whether the APR1400 design meets these criteria in GDC 14 and GDC 26 with regard to pressure-retaining and internal components of its control rod drive (CRD) system, on November 10, 2015, the staff issued RAI 303-8391, Question 04.05.01-1 (ML15314A597) , requesting that the applicant determine if there are components of the APR1400 design that would be considered RCPB components, or components in contact with reactor coolant, which have been omitted, but which should be included in DCD Sections 4.5.1.1(a) and 4.5.1.2(b), along with their ASME Code material specifications. The staff noted, for example, that APR1400 DCD Figure 3.9-7 identified the housing nut and vent stem, which are reactor coolant pressure retaining components, but these were omitted from DCD Section 4.5.1.1(a). The staff also requested the applicant to revise DCD Sections 4.5.1.1(a) and 4.5.1.1(b) to include any omitted components and their ASME Code material specifications.

In the December 22, 2015, response to RAI 303-8391, Question 04.05.01-1 (ML15356A554), the applicant provided the revised DCD Subsection 4.5.1.1(a) to include all pressure retaining material specification for each part, emphasizing the staff's concern raised in RAI 303-8391, Question 04.05.01-2, above.

cup these parts , needs to be deleted

In the December 22, 2015, response to RAI 303-8391, Question 04.05.01-4 (ML15356A554), the applicant revised DCD Tier 2 Subsections 4.5.1.1(b)(9), 4.5.1.1(b)(13) and 4.5.1.1(c)(4) to include the material specifications and types, which included ASTM A276, Type 304; ASTM A479, Type 304; and ASTM A193, Grade B8. The functions for the CRD system dowel pin, locking ~~cap~~ and screws, and extension shaft pins are to provide anti-rotation of alignment taps, guiding moving parts, and positive locking for threaded parts and are exposed to reactor coolant. These parts are not considered RCPB and do not experience loading conditions conducive to SCC, and are common material used in operating plants. The staff finds these material specifications are identical to the ASME Code, Section II materials and are acceptable for use in non-pressure boundary applications exposed to reactor coolant. Incorporation of revised Subsections 4.5.1.1(b)(9), 4.5.1.1(b)(13) and 4.5.1.1(c)(4) into the next revision of the APR1400 DCD will be tracked as a **Confirmatory Item.**

Compliance with the requirements of GDC 26 as it relates to the CRD system materials ensures that the material selection and fabrication support reliable rod movement for reactivity control that preserves fuel and cladding integrity. Accordingly, components of the CRDM that do not perform a pressure retaining function must also be fabricated from ma
they function reliably in order to meet the requirements of GDC 26. N
CRDM component materials exposed to reactor coolant include:

; ASTM A240, Type 304;
ASTM A479, Type 304;
ASTM A193, Grade B8

- austenitic stainless steels (ASTM A269, Type 316; ASTM A276, Type 316; ASTM A276, Type 321; ASTM A276, Type 304; ASTM A269, Type 304),
- martensitic stainless steels (ASTM A276,Types 410, 410 condition T and 440C),
- nickel-based alloys (AMS 5698, Alloy X-750 and AMS 5699, Alloy X-750),
- nickel-chromium-molybdenum-columbium alloy (ASTM B446, Alloy 625),
- cobalt-based alloys (Haynes No. 36 and Stellite No. 6B),
- SAE AMS 2460 chrome plating, and
- chrome oxide plasma spray treatment.

APR1400 DCD Tier 2 Subsection 4.5.1.3 specifies a cobalt-based alloy (Stellite No. 6B) for the pins and another cobalt-based alloy (Haynes No. 36) for the latch and links. The staff understands that these materials will be used as structural materials for the fabrication of these components (not hardfacing material). Therefore, on November 10, 2015, the staff issued RAI 303-8391, Question 04.05.01-5 (ML15314A597), requesting that the applicant provide the following additional information to ensure that the material properties of these components (e.g., toughness, etc.) will be appropriate for these applications:

- Revise APR1400 DCD Subsection 4.5.1.3 to specify the applicable material specifications, including heat treatment to be applied, etc., which will ensure appropriate component material properties when utilizing Haynes No.36 or Stellite No. 6B material.

There is no low ally steel material used in the RVIs of the APR1400.

stainless steels, ~~low alloy steel~~, and nickel-based superalloy. Cold-worked austenitic stainless steel is only to be used in bolting or pin applications. Chrome plating and hardfacing is specified in several locations, as clearly stated in DCD markup provided in the supplemental letter. The applicant stated, in DCD markup provided in the November 12, 2015, response to RAIs (ML15316A780), that the materials used in RVI and core support structures were selected for compatibility with the reactor coolant, consistent with ASME Code, Section III, Subsubarticles NG-2160 and NG-3120.

Controls on Welding

The DCD requires that welds in RVIs and core support structures be fabricated in accordance with the criteria of ASME Code, Section III, Article NG-4000, and the examination and acceptance criteria included in Article NG-5000. The control of welding is performed in accordance with ASME Code, Sections III and IX as appropriate. Welding is to be conducted consistent with NRC RGs 1.31 and 1.44 as well.

Nondestructive Examination

The DCD requires that NDE of RVI and core support structure materials be in accordance with the requirements of ASME Section III, Subsection NG. ~~For any materials not defined as ASME Code, Section III NG materials, NDE examinations are to be performed in accordance with the applied material specification.~~

DCD will be revised per RAI 291-8347(6).

Fabrication and Processing of Austenitic Stainless Steel Components

The DCD requires that the recommendations of RG 1.44 be applied to control sensitized austenitic stainless steel. Processes demonstrated not to produce sensitized structures are to be used in the fabrication of RVIs and core support structures. The DCD references DCD Tier 2, Subsection 5.2.3.4 for additional information pertaining to the use of austenitic stainless steel. The DCD specifies that raw austenitic stainless steel, both wrought and cast, is to be supplied in the solution-annealed condition as specified by the material specification. Solution treatment is not to be performed on completed or partially-fabricated components, rather chromium carbide precipitation is to be controlled during all stages of fabrication.

5.2.3.4 and 5.2.3.3

The DCD then requires conformance with RGs 1.31; 1.28, and 1.71, "Welder Qualification for Areas of Limited Accessibility;" by citing DCD Tier 2 Subsections 5.2.3.4.4, ~~5.2.3.3, and 5.2.3.4~~, respectively. Conformance with these RGs covers ferrite control for RVI and core support materials; welder qualification for areas of limited accessibility; and quality assurance requirements for cleaning fluid systems and associated components of water-cooled nuclear plants.

Other Materials

The DCD Tier 2 Subsection 4.5.2.5 states that the precipitation-hardened stainless steel used in the RVIs and core support structures is to be ~~SA-453 Grade 660 or~~ SA-638 Grade 660. The DCD states that SA-479, S21800 material is to be supplied in the annealed condition. The DCD identifies that SA-182 F6NM is to be solution heat treated at a specified temperature and then air cooled. Finally, the DCD identifies thermally-trea[DCD will be revised per RAI 291-8347(4).] 690 and Alloys accordance with ASME Code, Section III, Subsection NG. Because using ASME Code Section III meets the acceptance criteria for GDC 1 and 10 CFR 50.55a, the staff finds this acceptable.

4.5.2.4.4 Fabrication and Processing of Austenitic Stainless Steel Components

The staff reviewed DCD Tier 2, Revision 0, Subsection 4.5.2.4 for its conformance to regulatory requirements. The staff confirmed that environmental conditions are controlled and welding procedures are developed such that the probability of sensitization and microfissuring are minimized. This is achieved by following the guidance of RGs 1.44 and 1.31, respectively. The staff confirmed the RVI and core support material compatibility with coolant through a review of the selection of materials for each component; commitment to RGs and ASME Code requirements; the topics detailed in DCD Tier 2 Subsections 4.5.2.4 and 4.5.2.6 and 5.2.3.4; and the water chemistry requirements regarding oxygen content in DCD Tier 2, Section 5.2, Table 5.2-5. The oxygen concentration requirement of 0-0.1 parts per million (ppm) ($T_{coolant}$ > 121.1 degrees C [250 degrees F]) is known to inhibit SCC in particular. The staff reviewed the fabrication and cleaning controls imposed on stainless steel components. These controls are principally enforced through adherence to RG 1.28 and ASME Code NQA-1 in addition to the extended discussion referenced in DCD Tier 2 Subsection 5.2.3.4 concerning cleaning chemicals, cleaning water chemistry, and halides. Because the fabrication and cleaning controls conform to the recommendations of RGs 1.31 and 1.44, staff concludes they are acceptable.

4.5.2.4.5 Other Materials

DCD Tier 2, ~~Revision 0,~~ Subsection 4.5.2.5 lists several materials as “Other Materials.” Precipitation-hardened stainless steels ~~SA-453 Grade 660 and~~ SA-638 Grade 660 are identified with corresponding heat treatment requirements. In addition SA-479, S21800, a chromium-manganese-nickel type stainless steel, and SA-182, Grade F6NM, a martensitic stainless steel, are listed with heat treatm[illegible]y 690, 52/52M, and 152 superalloys are listed along with a supporting di[illegible]nt nature of these alloys regarding SCC. The staff evaluated the identifi[illegible]ciated heat treatments and found the discussion of “Other Materials” acceptable as they are consistent with precedent and regulatory requirements, specifically those of 10 CFR 50.55a.

DCD will be revised per RAI 291-8347(4).

4.5.2.4.6 Other Degradation Mechanisms

DCD Tier 2, Revision 0, Subsection 4.5.2.6 addresses “Other Degradation Mechanisms,” specifically IASCC and void swelling. The staff confirmed that the criteria used by the applicant for evaluating the internals with regards to IASCC and void swelling were appropriate. The staff issued RAI 291-8347, Question 04.05.02-5, dated November 4, 2015 (ML15316A780), requesting that the licensee provide the detailed report upon which Subsection 4.5.2.6 was based on. In the March 14, 2016, revised response to RAI 291-8347, Question 04.05.02-5 (ML16096A274), the applicant provided the Technical Report APR1400-Z-M-NR-14017-P, Revision 0, “Evaluation of Irradiation Assisted Stress Corrosion Cracking and Void Swelling on Reactor Vessel Internals.” This report provides substantial detail regarding the susceptibility determination process and results used by the applicant to ensure that IASCC and void swelling had been adequately accounted for. The staff reviewed both the process and the results in detail to confirm that the applicant had followed good practices and performed calculations of sufficient depth and quality to ensure that application of the above noted criteria would be adequate. The applicant performed radiation transport analysis, computational fluid dynamics required for DBE mitigation, the applicant stated that the CVCS provides redundancy and enhances the reliability of the reactivity control systems.

The CEDMs and the digital rod control system (DRCS) comprise the CRD system. The safety-related function of the CRD system is to insert the CEAs into the reactor core via gravity when a reactor trip causes removal of motive power from the CEDM power bus. DCD Tier 2, Section 3.9.4, "Control Element Drive Mechanisms," provides the CEDM component descriptions, characteristics, and a diagram. DCD Tier 2, Section 7.7, "Control Systems Not Required for Safety," provides the functions and description of the ~~DCRS~~. DCD Tier 2, Subsection 3.9.4.4, "CEDM Operability Assurance Program," discusses the testing and verification of the CRDMs. Finally, DCD Tier 2, Section 14.2, "Initial Plant Test Program," addresses the initial startup testing for the CEDMs.

DRCS

DCD Tier 2, Table 4.6-1, "Design Basis Events," identifies all DBEs in DCD Tier 2, Chapter 15, "Transient and Accident Analyses," that require reactivity control system operation to prevent or mitigate each event as well as the associated system(s). DCD Tier 2 Chapter 15 describes the analyses for postulated accidents that assume actuation of the CRD system and/or SIS.

The SIS and CVCS are discussed in more detail in DCD Tier 2, Sections 6.3, "Safety Injection System," and 9.3.4, "Chemical and Volume Control System," respectively.

ITAAC: ITAAC associated with DCD Tier 2 Section 4.6 are given in DCD Tier 1, Table 2.4.1-4, "Reactor Coolant System ITAAC"; Table 2.4.3-4, "Safety Injection System ITAAC"; and Table 2.7.3.6-1, "Reactor Containment Building HVAC System and Reactor Containment Building Purge System ITAAC."

TS: The TS associated with DCD Tier 2 Section 4.6 are given in DCD Tier 2, Chapter 16, and in Sections 3.1, "Reactivity Control Systems," and 3.5, "Emergency Core Cooling System (ECCS)."

4.6.3 Regulatory Basis

The relevant requirements of NRC regulations for the functional design of reactivity control systems, and the associated acceptance criteria, are in NUREG-0800, Section 4.6, "Functional Design of Control Rod Drive System," and are summarized below. Review interfaces with other SRP sections can be found in NUREG-0800, Section 4.6. The requirements governing ITAAC related to the reactivity control systems are provided in NUREG-0800, Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria."

- 10 CFR 50, Appendix A, GDC 4, "Environmental and dynamic effects design bases," as it relates to the structures, systems, and components important to safety that shall be designed to accommodate the effects of and to be compatible with the environmental conditions during normal plant operation as well as during postulated accidents

- GDC 23, "Protection system failure modes," as it relates to the protection system failing into a safe state or into a state demonstrated to be acceptable on some other defined basis

The markup of DCD Subsection 14.2.12.1.36 is not incorporated in the response to RAI 136-8081 Q 04.06-2.

RAI 136-8081, Question 04.06-2 is being tracked as a **Confirmatory Item,** pending incorporation of the proposed markup into DCD Subsections 14.2.12.1.27, ~~14.2.12.1.36,~~ 14.2.12.1.54, and 14.2.12.2.4.

According to SRP Section 4.6, the test program for the CRD system should include experimental verification of system operation where a single failure, such as a stuck rod, has been assumed. This was not addressed in the DCD; therefore, on August 7, 2015, the staff issued RAI 136-8081, Question 04.06-3 (ML15227A013), requesting that the applicant show how system operation is experimentally verified in the event of a single failure. In the September 14, 2015, response to RAI 136-8081, Question 04.06-3 (ML15257A308), the applicant stated that an electrical malfunction in the DRC system would not disturb the reactor trip function, and a mechanical failure of a CEDM would not affect the others because they operate independently. In addition, the applicant noted that the surveillance requirements (SR) in TS 3.1.5, “Control Element Assembly (CEA) Alignment,” can detect a stuck rod. The applicant also committed to insert text into DCD Tier 2 Section 4.6.3 to reference this SR. Although the applicant does not propose tests with imposed single failures, the staff concludes that this test is not necessary because the previously discussed FMEA shows that possible single failures would not prevent the reactor trip function, and operators can identify single failures through TS SR or other indications, such as control room alarms. Therefore, the staff considers RAI 136-8081, Question 04.06-3 resolved, and RAI 136-8081, Question 04.06-3 is being tracked as a **Confirmatory Item**, pending incorporation of the provided markup into DCD Section 4.6.3.

DCD Tier 1 Section 2.4.1 includes an ITAAC on reactor scram time that requires a maximum drop time of 4.0 seconds for a 90-percent CEA insertion. In addition, TS SR 3.1.5.5 requires verification of this specific drop time for each CEA after reactor vessel head removal and prior to criticality. This specific drop time, also specified in DCD Tier 2, Subsection 3.9.4.1, “Descriptive Information of Control Element Drive Mechanism,” ensures the appropriateness and conservatism of the drop times used in the safety analyses, as described in DCD Tier 2, Subsection 15.0.0.2.4, “CEA Insertion Characteristics.”

The staff concludes that the CRD system meets the requirements of GDC 29 because the tests addressed above, along with the design of the CRD system previously discussed, ensure an extremely high probability that the CRD system will accomplish its safety function in the event of an AOO.

4.6.4.4 Information for Combined Performance of the Reactivity Control Systems

The reactivity control systems for the APR1400 design include the CEDMs, the SIS, and the CVCS. Only the CEDMs and SIS are required to prevent or mitigate DBEs, as identified in DCD Tier 2, Table 4.6-1. The CVCS is a nonsafety-related system that is not required for any accident mitigation or safe shutdown function. The CEDMs and SIS are completely independent systems based on different design principles and methods of reactivity control and are protected from missiles, pipe breaks, and their effects. Therefore, the staff finds that the systems are not subject to common-mode failures.

DCD Tier 2, Section 4.6.5, “Evaluation of Combined Performance of the Reactivity Control Systems,” states that the CVCS is designed for a high degree of redundancy and reliability. However, DCD Tier 2 Section 4.6 does not explain how the CVCS or the other reactivity control