Draft Safety Evaluation
"AP1000 In-Containment Cables and Non-Metallic Insulation Debris Integrated Assessment"
WCAP-17938-P, Revision 2
Project No. 0811

1.0 INTRODUCTION

In September 2004, NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design" (FSER) (Reference 1) was issued by the staff of the U.S. Nuclear Regulatory Commission (NRC). The staff issued Supplement 1 to the FSER in December 2005 (Reference 2) to address details related to rulemaking, and it issued Supplement 2 to the FSER in September 2011 (Reference 3) to address changes proposed in the design certification amendment. The amendment included changes through Revision 19 to APP-GW-GL-700, "AP1000 Design Control Document" (DCD), dated June 2011 (Reference 4). NUREG-1793, Supplement 2, contains the staff's evaluation of how the amended AP1000 design addresses Generic Safety Issue 191, "Assessment of Debris Accumulation on Pressurized-Water Sump Performance," (GSI-191) (Reference 5), and Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design-Basis Accidents at Pressurized-Water Reactors" (GL 2004-02), dated September 13, 2004 (Reference 6).

Westinghouse Electric Company (Westinghouse) issued WCAP-17938, "AP1000 In-Containment Cables and Non-Metallic Insulation Debris Integrated Assessment," Revision 2, in June 2017 (Reference 7, hereinafter, "the WCAP").[1] It reevaluates the GSI-191 and GL 2004-02 debris assessment for the AP1000 as described in the DCD. Specifically, the WCAP assesses the potential for the generation of debris from nonmetallic insulation (NMI) (e.g., microporous insulation in the neutron shield blocks) in the reactor cavity and electrical cables in the containment. As discussed in the WCAP, the GSI-191 and GL 2004-02 debris assessment for the AP1000 showed that no fibrous debris is generated in a loss-of-coolant accident (LOCA). DCD Section 6.3.2.2.7.1, "General Screen Design Criteria," documents this, stating that, "a LOCA in the AP1000 does not generate fibrous debris due to damage to insulation or other materials included in the AP1000 design." This conclusion is based on the use of metal reflective insulation (MRI) or a suitable equivalent[2] and the lack of fibrous insulation and other sources of fiber located in the LOCA jet impingement zones. As discussed in the WCAP, the AP1000 plant design includes NMI in the reactor cavity that is designed to perform as a suitable equivalent to MRI. Additionally, the plant design includes in-containment electrical

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[1] Previous versions of the WCAP reviewed by the staff as part of this evaluation were submitted to NRC on March 12, 2015 (Reference 8), and November 20, 2015 (Reference 9).

[2] As described in the WCAP and the AP1000 DCD, a suitable equivalent insulation is one that is encapsulated in stainless steel that is seam welded, so that LOCA jet impingement does not damage the insulation and generate debris. Insulation that could be damaged by LOCA jet impingement is also a suitable equivalent if the resulting insulation debris is not transported to the containment recirculation screens, to the in-containment refueling water storage tank screens, or into a direct vessel injection (DVI) or a cold-leg LOCA break that becomes submerged during recirculation. In order to qualify as a suitable equivalent insulation, testing must be performed that subjects the insulation to conditions that bound the AP1000 plant conditions and demonstrates that debris would not be generated. If debris is generated, testing or analysis (or both) must be performed to demonstrate that the debris is not transported to an AP1000 plant screen or into the core through a flooded break. It would also have to be shown that the material used would not generate chemical debris.

cabling that may contain fibrous and other materials (jackets, wrappings, and filler materials) that may be directly impinged upon by a jet of water from a LOCA. Neither the applicant's DCD evaluation addressing GSI-191 and GL 2004-02 nor the staff's FSER considered encapsulated NMI or cabling.

To address these items, Westinghouse developed a program to evaluate any potential impacts to the current licensing basis from the exposure of cables to direct jet impingement by water from a LOCA and to qualify encapsulated NMI as a suitable equivalent to MRI. The purpose of the program was to define a zone of influence (ZOI) applicable to cables and to confirm that the encapsulated NMI met the requirements of suitable equivalency and may be used in place of MRI at discrete locations in the reactor cavity. The program included jet impingement testing of neutron shield blocks (e.g., encapsulated NMI) and cabling, and submergence testing of neutron shield blocks.

This safety evaluation (SE) describes the staff's review of the WCAP and responses to requests for additional information (RAI) issued by the staff.

The general approach followed in this SE, beginning with the introduction in Section 3.1.2, is to describe the applicant's evaluations and conclusions in a section of the WCAP, followed by the staff's evaluation of that section, as appropriate. Beginning with Section 3.2, the numbering system used in the technical evaluation section (Section 3) parallels the section numbering in the WCAP (e.g., Section 3.2 of the SE corresponds to Section 2 of the WCAP, Section 3.3 of the SE corresponds to Section 3 of the WCAP, and so on).

2.0 REGULATORY EVALUATION

The following Commission regulations pertain to the evaluation of the AP1000 and water sources for long-term recirculation cooling after a LOCA:

- General Design Criterion 35, "Emergency core cooling," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," as it relates to providing abundant emergency core cooling to transfer heat from the reactor core following a LOCA

- General Design Criterion 38, "Containment heat removal," as it relates to the ability of the containment heat removal system to rapidly reduce the containment pressure and temperature following a LOCA and to maintain these indicators at acceptably low levels

- 10 CFR 50.46(b)(5), as it relates to requirements for long-term cooling in the presence of LOCA-generated and latent debris

- Appendix D to Part 52-Design Certification Rule for the AP1000 Design

A specific area of the staff's review under these regulations is to confirm that adequate long-term cooling is available when considering debris resulting from a LOCA. The staff evaluated the AP1000 design against these regulations with regard to this issue. Because the applicant is reassessing debris resulting from a LOCA for the design, these regulations remain applicable for the staff's review of the WCAP.

3.0 TECHNICAL EVALUATION

3.1 GENERAL

3.1.1 AP1000 Description

The DCD Tier 2, Section 6.3.2.2.7, "IRWST and Containment Recirculation Screens," describes the evaluation of the water sources for long-term recirculation cooling following a LOCA, including the in-containment refueling water storage tank (IRWST). It considers debris resulting from a LOCA together with debris that exists before a LOCA (i.e., latent debris).

Item 3 in DCD Tier 2, Section 6.3.2.2.7.1 states that MRI or a suitable equivalent is used on the reactor vessel, each reactor coolant pump (RCP), the steam generators, the pressurizer, and all lines designated Class 1 under the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code). In addition, MRI is used inside containment where insulation would be subject to jet impingement. As a result, an AP1000 LOCA would not generate fibrous debris.

Item 10 of DCD Tier 2, Section 6.3.2.2.7.1, states that other potential sources of fibrous material, such as ventilation filters or fiber-producing fire barriers, are not located in jet impingement damage zones or below the maximum post-LOCA floodup water level.

Supplement 2 to the FSER, Section 6.2.1.8, "Adequacy of In-Containment Refueling Water Storage Tank and Containment Recirculation Screen Performance," evaluates DCD Tier 2, Section 6.3.2.2.7, and replaces the analysis documented in NUREG-1793.

Supplement 2 to the FSER, Section 6.2.1.8.2.1, "Break Selection," states the following:

> In the AP1000 design, there are only three sources of debris that transport with the recirculating water: latent or resident containment debris, debris from post-accident chemical effects, and debris from coatings located in the zone of influence (ZOI) of a LOCA jet.

Supplement 2 to the FSER, Section 6.2.1.8.2.2, "Zone of Influence/Debris Generation and Characterization (Excluding Coatings)," states the following:

> In the AP1000, metal reflective insulation (MRI) or a suitable equivalent is specifically required on the reactor vessel, RCPs, steam generators, pressurizer, and all ASME Code Class 1 lines. MRI is also required at any location within the insulation ZOI. . . .
>
> If insulation in the AP1000 ZOI is not MRI, it must meet the DCD definition of suitable equivalence, which requires that the insulation be tested at conditions that bound the AP1000 operation. . . . It also requires that the NRC approve the test applicability and any subsequent analysis. This is appropriate because there are no clearly defined protocols for jet impingement testing, and all previous submittals on this type of testing were subject to staff evaluation.

DCD Tier 2, Section 6.3.2.2.7.1, Item 10 prohibits other potential sources of fibrous material, such as ventilation filters or fiber producing fire barriers, in the insulation ZOI. The staff agrees that this design commitment, in combination with the previously discussed insulation commitments, excludes all potential sources of fibrous debris except latent debris from the ZOI.

3.1.2 Introduction

The WCAP summarizes the AP1000 licensing basis assessment of potential debris sources during design-basis accidents. DCD Tier 2, Section 6.3.2.2.7.1 documents this assessment and states that, “a LOCA in the AP1000 does not generate fibrous debris due to damage to insulation or other materials included in the AP1000 design.” In Section 1, the WCAP states, “This is based on the use of MRI or a suitable equivalent and the elimination of fibrous insulation and other sources of fiber.”

As stated in the WCAP, the AP1000 plant design includes encapsulated NMI in the reactor cavity that is designed to be a suitable equivalent to MRI. Additionally, the AP1000 plant design includes in-containment electrical cabling that may contain fibrous and other materials (jackets, wrappings, and filler materials) that may be directly impinged upon by a LOCA jet.

The WCAP assesses whether the encapsulated NMI contained in neutron shield blocks meets the definition of a suitable equivalent insulation through a test program that includes jet impingement and submergence testing. This test program identifies the material-specific performance (i.e., ZOI) of the AP1000 encapsulated NMI when exposed to representative LOCA conditions and assesses the chemical effects because of submergence.

The WCAP assesses the potential for cables to become a debris source through a test program that conducted jet impingement testing. The cable test program identifies the material-specific performance (i.e., ZOI) of the AP1000 plant cables when the cables are exposed to representative LOCA conditions. As noted in the WCAP, the potential for chemical effects due to cables had been addressed previously and is not impacted by the WCAP.

In conjunction with the test program, the WCAP also applies an evaluation methodology described in a guidance report prepared by the Nuclear Energy Institute (NEI). The guidance report, NEI 04-07, “PWR Sump Performance Evaluation Methodology,” Revision 0, issued December 2004 (Reference 10) was approved by the staff’s SE (Reference 11) with conditions and limitations. The WCAP applied an evaluation methodology described in Section 6, “Alternate Evaluation,” of NEI 04-07. Specifically, the WCAP defines a debris generation break size for the AP1000 plant. In addition, the WCAP applies more realistic analysis methods when assessing main coolant pipe breaks between the debris generation break size and a double-ended guillotine break (DEGB) of the largest pipe in the reactor coolant system (RCS).

As stated in its introduction, the purpose of the WCAP is to obtain NRC approval for the following items:

- A ZOI of four pipe diameters (4D) applicable to AP1000 plant in-containment cabling bounded by testing and analysis presented in this topical report.
- The NMI in the [ ] reactor vessel insulation system (RVIS) lower neutron shielding (LNS) and the water inlet doors, and the NMI in the neutron shield blocks of the refueling cavity floor module (CA31) is a suitable equivalent to MRI for the locations bounded by testing and analysis presented in this topical report.

- The use of NEI-04-07 [WCAP References 1-4 and 1-5]. . . alternative methodology for defining debris generation break size for postulated accidents in the AP1000 plant.

NRC Staff Evaluation

The staff reviewed the WCAP in terms of the request to approve a 4D ZOI for AP1000 in-containment cabling. The staff's review of an industry guidance report (NEI 04-07), the associated SE, and NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," (Reference 12) did not reveal any existing data on ZOIs associated with cabling. Section 3.3.3.3 of this SE discusses the staff's acceptance of an AP1000 in-containment cable ZOI of 4D.

The staff also reviewed the WCAP in terms of the request to approve that the NMI in the [ ] RVIS LNS, the RVIS water inlet doors, and the CA31 neutron shield blocks is a suitable equivalent to MRI for the locations bounded by testing and analysis. The staff's review of NEI 04-07, the associated SE, and NUREG/CR-6808 did not reveal any existing data from testing these types of components (e.g., neutron shield blocks). Sections 3.3.3.4, and 3.5 of this SE discuss the staff's acceptance of these items as suitable equivalents to MRI.

Finally, the staff reviewed the WCAP in terms of the request to use the alternate evaluation methodology as discussed in NEI 04-07 and the associated SE. The staff's investigation did not reveal any operating reactor licensee that has adopted the NEI 04-07 alternate evaluation methodology. Section 3.4 of this SE discusses the staff's acceptance of the use of the alternate evaluation methodology to determine debris generation break sizes for potential debris sources.

3.2 POTENTIAL SOURCES OF ADDITIONAL DEBRIS (WCAP-17938, SECTION 2)

Section 2 of the WCAP is divided into two subsections that describe cables and reactor vessel cavity NMI materials.

3.2.1 Cables

In Section 2.1, the WCAP states that the AP1000 plant design includes cabling that a LOCA jet may impinge upon directly. These cables may contain fibrous and other materials (jackets, wrappings, and filler materials) that were not considered in the initial GSI-191 debris source term evaluation.

To address the cabling issue, jet impingement testing and component characterizations were performed on AP1000 plant cables that may be directly impinged upon by a LOCA jet. The WCAP states that submergence testing of cables was not necessary because submerged cables have been a part of the AP1000 plant design since its inception and have been dispositioned as having negligible chemical effects.

The WCAP states that Westinghouse obtained several types of AP1000 plant cable for the jet impingement test program, including low-voltage, jacketed, insulated, single-conductor cables; low-voltage, jacketed, multiconductor cables; and medium-voltage, jacketed power cables. The cables used in the plant jet impingement test program were procured from among the cables produced for in-containment equipment qualification testing. These cables met all cable material design criteria and specifications for cables used in the AP1000 plant containment.

3.2.2 Reactor Vessel Cavity Nonmetallic Insulation

In Section 2.2, the WCAP states that the AP1000 evaluation addressing GSI-191 and GL 2004-02 accounts for zero fibrous LOCA-generated debris from insulation, based on the use of MRI or a suitable equivalent.

The WCAP states that NMI is used in the AP1000 RVIS and the CA31 reactor cavity floor structural module neutron shields. Radiation shielding is located in three areas in the reactor cavity with two areas containing NMI: the RVIS LNS and the CA31 module. The neutron shield blocks containing NMI are]. In addition, NMI is used in [ ] that comprise the RVIS water inlet doors.

The WCAP states that all NMI in the reactor cavity is located below the LOCA floodup level and has the potential to be fully submerged. The neutron shielding located in the CA31 module is in close proximity to the reactor coolant loop and piping for the DVI line. The WCAP identifies that the potential debris from the reactor cavity NMI was not considered in the licensing basis since only insulation that is a suitable equivalent to MRI is allowed in the containment.

The WCAP further describes the location, materials of construction, and arrangement of the nonmetallic materials in the reactor cavity (e.g., the RVIS water inlet doors, the RVIS LNS, and the CA31 neutron shielding). With regard to potential debris sources, the RVIS water inlet doors are made of . The RVIS LNS consists of [. The CA31 neutron shield blocks, including supplemental shield blocks, are . These blocks reduce the amount of radiation streaming upwards into containment. Each CA31 neutron shield block has .

NRC Staff Evaluation

The staff reviewed the descriptive information about AP1000 plant in-containment cables. The WCAP indicates that the design includes cabling that may be impacted by a LOCA and that these cables may contain fibrous and other materials that may impact GSI-191 debris source term evaluations. The WCAP states that cables were not considered in the initial GSI-191 debris source term. It discusses performing jet impingement testing to address the cabling debris source term and states that submergence testing is not needed.

As part of the cable review, it was not clear to the staff that the cables selected for testing adequately represent all cables found within the AP1000 plant. In a letter dated May 11, 2016

(Reference 13), the staff issued RAI-ICC&NMI-008, asking the applicant to clarify in the WCAP whether the cables selected for testing bound the plant in-containment cables. In a response dated July 14, 2016 (Reference 14), the applicant proposed revisions to the WCAP reflecting the fact that the cables tested bound the specifications for cables that will be used in the containment. The staff finds the response acceptable as the applicant clarified that the tested cables adequately represent AP1000 in-containment cables. Because the tested cables bound the design criteria and specifications for cables used in the containment, the staff finds that the tested cables are an acceptable test article for use in establishing a cable's ZOI. The staff considers RAI-ICC&NMI-008 to be a closed item, based on a revision to the WCAP. Section 3.3.3.3 of this SE discusses the staff's review of cable testing.

During an Advisory Committee on Reactor Safeguards (ACRS) subcommittee meeting on February 7, 2018, discussing this topical report, questions were raised about the potential for cable replacement using different cables from those described in the WCAP. Discussion centered on how a different cable construction (e.g., jacket and filler) could impact cable ZOI performance. Because new or evolving cable designs may have a different cable construction that could exhibit a different ZOI, the staff agreed with the ACRS that licensees should evaluate cable design changes to ensure that new designs do not impact adequate long term cooling. Accordingly, the staff added a limitation to the topical report. This is discussed in the Limitations and Conditions section of this report (Section 4.0).

WCAP Section 2.1 states that chemical effects associated with the cable debris are small compared to other sources of chemical effects. The applicant based this on conclusions from a December 2010 letter to the NRC Chairman from the ACRS (Reference 15), a February 2009 phenomena identification and ranking table (PIRT) evaluation sponsored by the staff (Reference 16), and December 2006 chemical effects testing sponsored by the staff (Reference 17). The 2009 PIRT identified several potential chemical effects of organic materials that were uncertain and should be considered for further study. The ACRS letter noted that radiolysis of cable materials could form hydrochloric acid, which adds to the uncertainty about chemical effects. The chemical effects testing sponsored by the staff did not evaluate cable materials, but it did include chloride, which can be generated by radiolysis of cable materials. In a more recent (March 2011) PIRT report (Reference 18), the staff addressed the potential for chemical effects as a result of the radiolysis of electrical cable insulation. The report concluded that the strong acids generated by radiolysis would be neutralized by the pH[3] buffer in containment. The March 2011 report considered other potential effects of organic materials – location of organic sources, agglomeration, complexation, and release from coatings – and concluded no additional research was needed based on the potential effects probably being small, uncertain, short-lived, or even beneficial.

The AP1000 design basis, as modified by the WCAP, uses an approach to chemical effects based on WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," issued March 2008 (Reference 19), which the staff found acceptable. Based on the conservative assumptions in this approach, the staff found it unnecessary to consider cable insulation and jacket materials. In addition, the calculation of the required amount of pH buffer in containment includes the acid expected to be generated by the radiolysis of these materials. Therefore, the staff finds that the potential chemical effects from

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[3] pH is a scale that tells how acidic or alkaline a substance is. More acidic solutions have lower pH. More alkaline solutions have higher pH.

cable insulation and jacket materials have been adequately addressed, and no additional evaluation is necessary in the WCAP.

The staff reviewed the descriptive information provided on NMI in the reactor cavity. Because the WCAP indicates that all reactor cavity nonmetallic materials are located below the LOCA floodup level and some are in close proximity to reactor coolant loop and DVI piping, the staff considers that submergence testing and jet impingement testing are the appropriate tests to address debris sources. As part of the WCAP description, the staff expected to see a discussion of NMI testing, comparable to the testing discussion provided for cables. In a letter dated May 11, 2016, the staff issued RAI-ICC&NMI-009, asking the applicant to include a discussion about NMI testing. In a response dated July 5, 2016 (Reference 20), the applicant provided a markup of WCAP Section 2.2, in which the applicant stated that suitable equivalency for NMI is achieved through jet impingement testing and submergence testing. The staff finds the response acceptable because the applicant described the NMI tests in the WCAP. The staff considers RAI-ICC&NMI-009 to be a closed item, based on a revision to the WCAP. Sections 3.3.3 and 3.3.4 of this SE discuss the staff's review of NMI (e.g., neutron shield blocks) jet impingement and submergence testing, respectively.

3.3 GSI-191 TEST PROGRAM SUMMARY (WCAP-17938, SECTION 3)

Section 3 of the WCAP summarizes the tests that were performed to understand the effects of jet impingement and submergence on the reactor cavity NMI and the in-containment cabling. These tests include the following:

- cable jet impingement testing
- reactor vessel insulation jet impingement testing
- reactor vessel insulation submergence testing

In addition, Section 3 of the WCAP discusses the confined jet behavior in the AP1000 reactor vessel cavity and the applicability of the results of the free jet impingement testing performed at the National Technical Systems (NTS) facility.

3.3.1 Jet Impingement Test Background

Section 3.1 of the WCAP discusses a test program designed to establish the reactor cavity NMI as a suitable equivalent to MRI from a debris production standpoint and to establish a defensible cable ZOI.

For NMI, the WCAP states that testing that bounds the AP1000 plant conditions must be performed in order to show that an insulation type qualifies as a suitable equivalent to MRI. The WCAP elaborates that the only form of testing that could subject the reactor cavity NMI to conditions that bound the AP1000 plant is jet impingement testing performed at bounding conditions. Jet impingement testing focused on the RVIS type blocks, as this was the most limiting at the time of testing. The WCAP indicates that the results of jet impingement testing on test specimens are used to draw conclusions about the behavior of the LNS and the CA31 neutron shield blocks, and water inlet doors.

For cabling in containment, the WCAP discusses that testing is needed to establish a material-specific ZOI (the zone around a pipe break in which debris is generated for a given material) because no cable ZOI data was discovered in current GSI-191 documentation.

The WCAP discusses the initial development of ZOIs used to resolve GSI-191 and reflected in NEI 04-07 and the companion staff SE. The WCAP states that to address some of the uncertainties in formulating ZOIs for specific materials (as defined in NEI 04-07), a group of licensees within the Pressurized-Water Reactor Owners Group (PWROG) chose to pursue jet impingement testing using subcooled water at pressurized-water reactor (PWR) nominal temperature and pressure conditions.

The WCAP states that the results of the PWROG jet impingement testing, as documented in FAI/11-0497, "PWROG Model for the Two Dimensional Free Expansion of a Flashing, Two-Phase Critical Flow Jet," Revision 1, issued February 2012 (Reference 21), showed that the test facility was capable of producing a subcooled jet that was representative of the range of temperatures and pressures associated with a PWR large-break LOCA.

The WCAP states that the approach to qualifying NMI as a suitable equivalent considers acceptance criteria in the AP1000 certified design that allows for some damage to the target material. Specifically—

- A suitable equivalent insulation is one that is encapsulated in stainless steel that is seam welded, so that LOCA jet impingement does not damage the insulation and generate debris; or, if debris is generated, the resulting debris is not transported to the containment recirculation screens, to the IRWST screens, or into a DVI or a cold leg LOCA break that becomes submerged during recirculation. It would also have to be shown that the material used would not generate chemical debris.

Similarly, the WCAP's approach to ZOI development for cables considers acceptance criteria that allows for and accounts for some damage to the cable material. Specifically—

- determining incipient damage (the amount of damage that resulted in the generation of a negligible amount of debris)
- using an approach to measure the amount of debris generated or clearly define a no damage ZOI

The WCAP describes that, for both the neutron shield block and cable jet impingement test programs, a process was developed to demonstrate that the acceptance criteria were met. The process determined the amount of material lost during each test by [

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3.3.2 Jet Impingement Test Facility

Section 3.2 of the WCAP includes a schematic of the test facility. The WCAP states that the facility used for jet impingement testing is capable of simulating the conditions of a high-energy line break, representative of a cold leg break, within the AP1000 containment. The thermal-hydraulic conditions (e.g., pressure, temperature, and flow) were selected so that conditions associated with a postulated break in the primary piping were accurately simulated, and the data from the experiment will be directly applicable to and bounding of the AP1000 plant. The WCAP states that a cold leg break provides the highest potential for damage based on the thermal hydraulic conditions exhibited by the break, and that the parameters associated with the cold leg break in the test facility present a limiting break with respect to the NMI and cables.

3.3.2.1 Comparison of PWROG Facility with AP1000 Plant Facility

Section 3.2.1 of the WCAP contains figures that compare the PWROG test facility with the AP1000 plant test facility. The WCAP states that the major components of the two facilities are identical from a practical standpoint, and a review of the components ensures that the choke point of the facility is at the nozzle exit. The major difference between the facilities is the approach to [ ]. This difference, and the associated difference in instrumentation location, has the effect of slightly reducing recorded pressure at the reducer, where the diameter of the piping changes.

3.3.2.2 Comparison of PWROG Facility Data with AP1000 Facility Data

Section 3.2.2 of the WCAP contains figures (e.g., showing pressure, temperature, and flow versus time) that compare the AP1000 test facility data to the PWROG test facility data. The WCAP concludes that these comparisons ensure that the AP1000 test facility reproduces the same conditions and output as the PWROG test facility, and that both tests are conservative with respect to a full-scale LOCA in the AP1000.

3.3.2.3 Comparison of AP1000 Plant Licensing Basis with AP1000 Plant Facility Data

Section 3.2.3 of the WCAP compares the high-pressure subcooled jet generated at the experimental facility to a LOCA response in the AP1000 plant. The WCAP concludes that testing conducted at the facility is conservative with respect to the AP1000 plant licensing basis large-break LOCA.

NRC Staff Evaluation

The staff reviewed the goals of the jet impingement test program as stated in the WCAP—namely, to establish the NMI in the reactor cavity as suitable equivalent insulation and to establish a defensible ZOI for cables. Section 3.1 of the WCAP states that “the only form of testing that could subject the reactor cavity non-metallic materials to conditions that bound the AP1000 plant is jet impingement testing performed at bounding conditions.” In general, the staff agrees that a demonstration of testing performed at bounding conditions with no damage that could lead to debris generation would be necessary to establish NMI as a suitable equivalent. Section 3.3.3.4 of this SE gives the staff’s evaluation of the jet impingement testing, while Section 3.3.3.5 evaluates the bounding nature of the testing. The acceptance criteria for qualifying NMI as a suitable equivalent, as stated in the WCAP, is encapsulated in stainless steel that is seam welded and allows for damage as long as debris is not generated. The staff finds this acceptable, as long as fibrous debris generation is precluded entirely, as the impact of fiber in the AP1000 post-accident environment is more important than in traditional GSI-191 analyses because of the assumptions made about the low fiber total in the AP1000 plant.

Similarly, the acceptance criteria related to defining the ZOI for cables in containment uses the approach defined in NEI 04-07, which requires the applicant to define the ZOI for incipient damage (resulting in a negligible amount of debris) and either measure the amount of debris generated or clearly define a no-damage ZOI. The staff finds that this approach is appropriate for this particular application as the applicant has chosen to define a no-damage ZOI.

The staff reviewed the comparison of the test facility as it was used for the jet impingement tests to the PWROG blowdown test facility. The two series of tests occurred in the same facility, and the AP1000 tests modified the facility slightly to [

]. The NRC Office of Nuclear Regulatory Research reviewed the PWROG test facility and found it to be designed appropriately and capable of producing conditions representative of a PWR cold-leg break.[4] The staff visited the facility used for the AP1000 jet impingement testing as part of pre-application interactions with the applicant (Reference 22). The staff found that the differences between the PWROG facility and the AP1000 blowdown facility would have no impact on the test results, and that the AP1000 blowdown facility was appropriate for producing a jet simulating PWR LOCA conditions.

The staff reviewed the comparison in the WCAP of the PWROG facility data with the data from the AP1000 blowdown facility. Because the AP1000 facility targets were not instrumented, the validity of this comparison is important in determining whether the AP1000 facility produced a jet with representative pressure and mass flow. The staff found that the two facilities produced practically identical pressure distributions at the nozzle exit. The upstream pressure readings differed slightly because of the change in measurement location from] although the two data sets are consistent with one another when taking this change into account. The data sets show [ ]. The staff, therefore, concludes that the two facilities produce results that are consistent. The AP1000 blowdown facility target pressures can be expected to align with those measured for the PWROG facility, given that the upstream pressure and temperatures are consistent.

The applicant asserted in the WCAP that the test facility is conservative compared with a large-break LOCA under actual AP1000 plant conditions. The staff reviewed the data presented in Section 3.2.3 of the WCAP, comparing data from the two test facilities to the mass flux expected to result from a LOCA in the AP1000 based on the licensing basis accident analysis. With the exception of the the conditions produced by the test facility bound the conditions resulting from a full-scale LOCA for the duration of the blowdown. In an effort to understand the impact of [ ] L/D,[5] in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-002 and -003. In a response dated July 14, 2016 (Reference 14), the applicant clarified that

]. Thus, the staff finds the AP1000 blowdown test facility to be capable of producing a jet conservatively representative of an AP1000 LOCA blowdown jet. The applicant clarified this in a revision to the WCAP, and the staff finds the updated text acceptable. Therefore, the staff considers RAI-ICC&NMI-002 and -003 to be closed items.

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[4] “Technical Review of a Two-Dimensional Free Expansion of a Flashing, Two-Phase, Critical Flow Jet,” April 30, 2012 (ADAMS Accession Nos. ML121010457 and ML121010493).

[5] Test distances are expressed as X = L/D to maintain consistency between the scaled test values and the prototypic plant values.

3.3.3 Jet Impingement Tests

3.3.3.1 Jet Impingement Test Objectives

Section 3.3.1 of the WCAP discusses the jet impingement test objectives for AP1000 cables and the neutron shield blocks. The WCAP states that data and observations collected from the tests and test specimens were used to determine a ZOI for cables and suitable equivalency for encapsulated NMI.

3.3.3.2 Jet Impingement Test Specimens

Section 3.3.2 of the WCAP is divided into two subsections that describe the cable specimens and neutron shield block specimens.

In Section 3.3.2.1, “Cable Specimens,” the WCAP states that the applicant tested five types of electrical cables. Each cable type was tested with and without aging to bound cable conditions over 60 years of operation. The cable arrangement used in the tests placed the cables in the known jet field for defining the cable material destruction pressure and ZOI.

In Section 3.3.2.2, “Neutron Shield Block Specimens,” the WCAP states that three neutron shield block test specimen configurations (i.e., Types I, II, and III) were subjected to testing. The WCAP includes figures that show a typical neutron shield block construction and the variations among the three test specimen configurations.

3.3.3.3 Cable Jet Impingement Test Summary

Section 3.3.3 and associated subsections of the WCAP summarize the cable jet impingement testing. The WCAP states that the goal of the cable jet impingement testing was to define a ZOI outside of which cables exposed to a LOCA jet do not contribute to the AP1000 plant debris source term. The cable tests were separated into two groups, large and small, and tested at varying distances from the jet nozzle. Following a successful facility test (i.e., the AP1000 test facility produced a jet that bounds the licensing basis for the AP1000 plant), cables were evaluated for any damage. The damage evaluation was used to determine the cable ZOI. [

. WCAP Section 3.3.3.5, Table 3-5, “Cable Jet Impingement Test Results,” presents the cable test results. The WCAP states that the results of the cable jet impingement test program show that no damage and no loss of material was seen at 4 = L/D. Based on the results of the cable jet impingement test program, a ZOI of 4D is applied to the AP1000 plant in-containment cables that may be directly impinged upon by a LOCA jet. The WCAP also notes that there are cables that cannot be relocated outside of a 4D ZOI and that these cables are protected by a number of different protection schemes.

NRC Staff Evaluation

The staff accepts that the test methodology applied to determine the destruction pressure of the cables represents a viable approach for evaluating cable performance following a postulated accident. The staff evaluated whether the documented testing in the WCAP met the stated goal to determine an appropriate, technically defensible, realistic ZOI for cables. The staff’s SE for NEI 04-07 notes that “the correlation between any prediction of jet pressure and an experimental observation of damage pressure depends on how the measurements were taken, how the debris was characterized, and what the thermodynamic conditions of the test actually were." As noted in Section 3.3.2.3 of this SE, the staff accepts that the facility used for the AP1000 testing is capable of producing relatively representative test conditions, so the primary concern in quantifying a ZOI for the cables lies in the experimental observation and debris characterization.

Cables were tested at varying distances L/D ranging from [ ]. With one exception, no damage was observed at distances of 4 = L/D or greater. The damage from the one test occurred because of [ ] that were not representative of plant conditions and were rectified in subsequent tests. The staff witnessed testing as part of pre-application activities (Reference 22), including the [ ]. The staff agreed with the WCAP's assessment that the [ ] was likely not representative of as-built cable installation, but that the issue would need to be corrected in future testing and appropriately dispositioned. Aside from the issue [ ], the staff also noted that temperature conditions for the cables were not necessarily at representative conditions when compared to the plant cables. The WCAP notes that the primary difference is the temperature of the cables, and that the cables reach temperatures similar to those in the plant within 2–3 seconds of test initiation. The staff recognizes that the minimal difference in temperature for such a short period is unlikely to impact the results of the jet impingement testing.

During the course of the review, the staff was unable to determine in the context of the WCAP whether restraining the cables in the test was representative of (or at least conservative when compared with) the in-plant cables. As such, in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-005, asking the applicant to justify in the WCAP that the testing configuration of the cables is conservative. In a response dated July 14, 2016 (Reference 14), the applicant noted that cables are unrestrained [

. The staff agrees that the facility restraints were needed to ensure the tested cables were exposed to jet pressure. The applicant revised the WCAP to clarify this, and the staff finds the updated text acceptable. Therefore, the staff considers RAI-ICC&NMI-005 to be a closed item.

While the staff found the test facility acceptable for producing a conservative jet with respect to the AP1000 (see Section 3.3.3.5 of this SE), test repeatability and verifiability are important in providing assurance that the testing was acceptable, given the lack of measurement at the target. The staff reviewed data from upstream of the jet nozzle, and testing for the cables shows that the pressure and temperature values are in good agreement, both with each other and with the previous instrumented testing carried out by the PWROG. In addition, [

]. The staff considers that the assertion that "no cables were damaged by the jet" when damage occurred because of [ ] does not adequately communicate the issue (WCAP Table 3-5), and, while auditing the test report (Reference 23), found that the test acceptance criteria were inconsistent with the description in the WCAP. As such, in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-004, asking the applicant to clarify the perceived discrepancy, which applies to both the cables and the neutron shield blocks. In a response dated July 14, 2016 (Reference 14), the applicant stated that [

. Ultimately, as testing was repeated at 4 = L/D with no damage to the cables, the staff views RAI-ICC&NMI-004 as closed. Testing showed [

. As such, the staff agrees that no debris is produced at 4 = L/D.

Because of the uncertainties inherent in evaluating the precise pressure at the target, the staff agrees with the WCAP's choice of 4 = L/D. At this distance, no damage occurred in successful tests. This is consistent with the more straightforward option identified by the staff in its SE of NEI 04-07, to define the ZOI at a distance where no jacketing is breached in any way. The staff does not entirely agree with the statement in the WCAP that [

]. The WCAP compares the production of debris fines from cables to that of k-wool and calcium silicate described in the SE for NEI 04-07 and states that similar fractions of fines production occurred for the cables. Because most cables [

in combination with the design-basis requirement of no additional debris production in the AP1000, the staff agrees that the use of 4 = L/D is most appropriate and finds that the WCAP request of a ZOI of 4D for cables is acceptable.

As part of the review, it was not clear to the staff that, in the context of the WCAP, the cables tested bounded all cables located within the AP1000 plant. As discussed in Section 3.2.2 of this SE, the staff issued RAI-ICC&NMI-008, asking the applicant to clarify in the WCAP the representative characteristics of the cables. In the response, the applicant proposed revisions to the WCAP reflecting the fact that the cables tested bound the specifications for those intended for use in the AP1000. Additionally, the staff notes that the performance of cables within the ZOI is outside the scope of the WCAP's request for staff review and approval (see Section 3.1.2 of this SE). The WCAP indicates that cables within the ZOI would produce debris in the absence of a suitable protective enclosure. Given the importance of the justification of the unprotected cable ZOI, the staff considers the suitability of the protection scheme used for cables inside the ZOI equally important. Therefore, a licensee that references this WCAP should assess whether the cable protection schemes incorporated into the design prevent the generation of debris from cables located within the 4D ZOI, and determine that the protection schemes, in and of themselves, do not introduce potential debris sources. The discussion of limitations and conditions in Section 4.0 of this SE addresses this topic.

3.3.3.4 Neutron Shield Block Jet Impingement Test Summary

Section 3.3.4 and associated subsections of the WCAP summarize the neutron shield block jet impingement testing. The WCAP states that the goal of the jet impingement testing is to assess whether the neutron shield block satisfies the definition of suitable equivalent insulation for the AP1000 plant encapsulated NMI. Following a successful facility test (i.e., AP1000 test facility produced a jet that bounds the licensing basis for the AP1000 plant), neutron shield blocks were evaluated for any damage. Overall, seven tests were conducted on three neutron shield block configurations, with the following results:

- The Type I neutron shield block design [

  ].

- The Type II neutron shield block designed [

  .

- The Type III neutron shield block

  ].

In addition, the Type III neutron shield block [

.

NRC Staff Evaluation

The staff reviewed the jet impingement testing summarized in the WCAP to qualify the neutron shield blocks encapsulated NMI as a suitable equivalent to MRI. The blocks were tested using three different configurations at varying distances.

]. In order to qualify the blocks as a suitable equivalent, the test pressure should bound the pressure the blocks will experience in the plant.

Because of the nature of the confined jet and the uncertainty associated with the pressure the blocks will be exposed to (see Section 3.3.3.5 of this SE), the staff felt that testing performed at [ ] was likely to bound the plant configuration but that this testing was not necessarily by itself justification of suitable equivalency. The applicant conducted additional testing at [

].

The staff witnessed the testing of the blocks [ ] as part of pre-application activities (Reference 24). [

] the staff concludes that the test

configuration [ ] was a reasonable representation of the blocks being subjected to a significantly greater force than would occur in the plant design.

In the test with [

. The staff views this test as merely highlighting the robust nature of the blocks.

, as discussed in Section 3.3.3.5 of this SE.

As was the case with cable testing, test repeatability and verifiability are important in providing assurance that the testing was acceptable to the staff. For the blocks, no testing on the Type III blocks was repeated, but testing took place at [ ] for all three types of blocks. Each test showed similar damage profiles to the bulk metal of the blocks, with the primary difference in the tests being the extent of the weld damage. Pressure and temperature data for these runs also show reasonable agreement with the PWROG data and between the tests themselves; thus, the staff agrees with the WCAP's assertion of repeatability when applied to the tests at [ ]. Temperature and pressure data for the tests at [ ] were also consistent, but interactions with the test fixture preclude direct comparison between the two tests. The WCAP describes those tests as measures of additional assurance that were performed under substantially more conservative conditions than the blocks installed in the plant would experience.

Based on the discussion in Section 3.3.3.5 of this SE, staff considers the testing performed at [ ] represents a reasonable approximation of the pressures that would be experienced by the blocks in the actual plant configuration. [ ], it is reasonable to assume that the blocks will not fail under loads experienced for the limiting break in the cavity region. Further margin is present in the testing because the tested blocks have a [ ] outer encapsulation thickness, while blocks in the plant will use thicker [ ] construction. For an additional measure of conservatism, testing was performed at

the testing demonstrated that the blocks were robust and could withstand substantially greater pressures than they would be expected to experience.

Therefore, the staff finds that the NMI blocks perform as a suitable equivalent for MRI from the perspective of debris generation when subjected to pressures associated with jet impingement forces from break distances of at least [ ] in the plant configuration. This finding is based on the combination of testing expected to be bounding given the analysis (see Section 3.3.3.5 of this SE) and the performance of the blocks during testing conducted at [ ] that is more conservative than would be experienced in the as-built design.

Finally, the staff's evaluation of NMI was limited to their qualification as performing as a suitable equivalent for MRI only from the perspective of debris generation. The staff did not evaluate other impacts on the AP1000 plant as a result of the changes in the reactor cavity associated with the installation of NMI (e.g., neutron shield blocks). For example, the staff's evaluation did not assess the shielding or insulation performance of the neutron shield blocks. Licensees should ensure that the impacts to the AP1000 design of structures, systems, and components as a result of the NMI changes have been fully evaluated. Licensees should also assess the need for a license amendment request in accordance with the requirements of Section VIII.B.5.b of Appendix D, “Design Certification Rule for the AP1000 Design,” to 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants.” The discussion of limitations and conditions in Section 4.0 of this SE addresses this topic.

3.3.3.5 Considerations Resulting from Confined Jet Behavior

The WCAP indicates that the reactor vessel cavity is a more confined space as compared to other regions of containment. The jet impingement testing performed at the NTS facility, as discussed in Section 3.3.3 of this SE, recreated a freely expanding jet. The freely expanding jet was allowed to expand into an approximately infinite volume, and there were no discharge volume constraints on the jet behavior. In WCAP Section 3.3.5 and associated subsections, the applicant discussed the implications of a jet discharging in a confined space and compared the confined jet behavior and characteristics to that of the jet impingement testing at the NTS facility. Specifically, the applicant surveyed the open literature (References 3-15, 3-17, 3-18, and 3-19 of the WCAP) for confined jet empirical data, related the data to the AP1000 plant configuration, related the derived confined jet considerations to develop a prediction of the NMI jet impingement pressure in the plant, and related that prediction to the NTS testing performed at [ ].

Figure 3-66 and Table 3-9 of the WCAP show key dimensions of the NMI pertaining to the cold-leg break location and the reactor vessel for assessing confined jet behavior in the AP1000 reactor vessel cavity. Dimension variable D is the cold-leg pipe diameter. Dimension variable X' is the distance from the outer boundary of the reactor vessel to the weld at the reactor vessel nozzle inlet. Dimension variable R is the vertical distance from the cold-leg weld at the reactor vessel inlet nozzle to the top of the NMI. The applicant used these dimensions to relate the test results contained in the cited open literature to the AP1000 plant geometry.

Reference 3-15 of the WCAP is a National Aeronautics and Space Administration technical note that is based, in part, on a survey of the literature on the effect on the flow field caused by impingement on a flat plate. Reference 3-15 used certain physical parameters to define the characteristics of the jet flow, including dividing the jet flow into distinct regions. Figure 3-64 of the WCAP, taken from its Reference 3-15, shows four jet flow regions resulting from a jet impinging on a flat plate. Region I of the jet flow field is the region defined as the jet core and extends from the nozzle exit to the apex of the potential core. It represents the region of flow establishment. Region II is the region of established flow in the direction of the jet beyond the apex of the potential jet core. Region III is the region in which the jet is deflected from the axial direction associated with impingement on the plate or surface. Region IV is the wall jet region, where the directed flow increases in thickness as the boundary layer builds up along the solid surface. This is a region characterized by boundary layer growth radially from the stagnation point (where the jet center line impinged on the surface). In addition, WCAP Reference 3-15 indicates that it was confirmed empirically that no change in jet surface characteristics occurred, such that the jet spreading rate, velocity profile, and pressure distribution were not impacted when the plate was spaced greater than or equal to two pipe diameters from the jet source.

Reference 3-17 of the WCAP describes an experimental and numerical study to investigate the flow field of a confined jet issuing from a nozzle from the lower surface (referred to as the confinement plate) and impinging normally on the upper surface (referred to as the impingement plate). Figure 3-67 of the WCAP includes a side-by-side comparison of the WCAP

Reference 3-17 confined jet facility apparatus to the AP1000 plant geometry. The comparison shows that the Reference 3-17 test apparatus is similar to the AP1000 plant configuration. The confinement plate simulates the reactor cavity wall; the impingement plate represents the reactor vessel. The traversing system of the testing apparatus allowed for motion in both the axial and radial directions. In this manner, the jet pressure on the impingement plate could be determined based on a range of confinements (defined as the impingement plate distance to nozzle diameter, X'/D) ranging from 0.2 to 6. From Table 3-9 of the WCAP, the AP1000 plant reactor vessel spacing to cold-leg diameter is X'/D of [ ], so the tested ranges encompassed the geometric confinement of the AP1000 plant configuration. The WCAP states that one observation from the Reference 3-17 testing is that the presence of the impingement plate causes the flow to deflect about one jet diameter above the impingement plate. Figure 3-68 of the WCAP shows the variability in pressure distribution associated with confined jet behavior taken from the results of the Reference 3-17 study. Specifically, it shows that the pressure distribution for the confinement at X'/D of 1 is very similar to that of the confinement at X'/D of 6, which corresponds to that of a free jet and indicates that at a value of X'/D of 1, the jet pressure field is nearly converged to that of the free jet pressure field. Therefore, the applicant concluded that for the AP1000 plant confinement ratio of [ ], which was encompassed by the test ranges of Reference 3-17 testing, the jet pressure field is analogous to that of the free jet.

Similar to WCAP Reference 3-17 discussed above, Reference 3-18 of the WCAP also investigated the behavior of a confined jet. Figure 3-69 of the WCAP shows the schematic test facility. The confining plate was mounted on a traversing mechanism that was used to change the distance between the nozzle exit on the top confining plate and the bottom impingement plate. Measurements were performed for jets with nozzle-to-plate distances of X'/D of 0.25 to 6 diameters. The effect of the confinement on the flow field was examined using measurements of the static and fluctuating wall pressures in these jets. Figure 3-70 of the WCAP shows the distributions of the static pressure from the stagnation point to an R/D of 4 for the top and the bottom plates (where R is the vertical distance from the centerline to the target). This figure was reproduced from the test results in WCAP Reference 3-18 for an unconfined free jet and confined jets with various confinement of X'/D of less than or equal to 1. The figure shows that static pressure decreased from the stagnation point and approaches atmospheric pressure at R/D of 1 for the unconfined jet. It also shows that confinement ratios of less than 1 could potentially result in a change in the jet behavior such that free jet analogies may not be applicable. This level of confinement may result in boundary layer detachment in Region IV (as depicted in Figure 3-64 of the WCAP), which is different than that of the free jet. The AP1000 plant value for an R/D of [ ] for NMI is denoted by a vertical red line in Figure 3-70 that is located in a region where the wall pressures for the top and bottom plates are analogous to the unconfined free jet. Furthermore, the WCAP also states that for a confinement of X'/D greater than 1, the effects of confinement are negligible and the wall pressure distributions are nearly identical, as substantiated by the Reference 3-17 testing.

Reference 3-19 of the WCAP is a confined jet study that focused on the static wall pressure distribution to help understand the impact of confinement ratio on pressure distribution. Figure 3-72 of the WCAP shows the experimental setup. It is similar to the other test apparatuses in that an impingement plate and a confinement plate are attached to a traversing system to allow for testing at different X'/D values. A pressure tap is used to determine the variability of R/D on pressure distribution. Figure 3-73 of the WCAP shows the results of confined jet impingement testing (with confinement ratio ranging from 0.25 to 4) as compared to the results of free jet testing. The AP1000 plant value of R/D of [ ] for NMI is denoted by the red vertical line shown in Figure 3-73. Figure 3-73 shows that at R/D of 2, the wall static pressure has converged to that of the free jet regardless of the confinement ratio.

The applicant stated that it has surveyed the above-referenced open literature to reach the conclusion that the NMI free-jet testing is representative of the jet behavior even in the confined configuration that exists in the reactor cavity. WCAP Reference 3-15 indicates that no change in jet surface characteristics occurred when the plate was spaced greater than or equal to 2D (i.e., two pipe diameters) from the jet source. WCAP Reference 3-17 declared a confinement X'/D greater than 6 to be analogous to the free jet, but Reference 3-18 actually performed experiments with and without the confinement plate to unequivocally ascertain the difference. Both tests showed that confinement ratios greater than about 1 yielded free jet behavior. Furthermore, for the AP1000 plant values of a confinement ratio of [ ] and an R/D value of [ ], the confined jet behavior is analogous to the free jet; thus, the results of the AP1000 plant free jet testing performed at the NTS facility are applicable for assessing the confined jet behavior in the reactor vessel cavity of the AP1000 plant configuration.

In WCAP Section 3.3.5.5, the applicant referenced NUREG/CR-2913, “Two-Phase Jet Loads,” issued January 1983 (Reference 3-16 of the WCAP), for assessing the jet impingement pressure at the AP1000 NMI. NUREG/CR-2913 was developed to predict the direct jet impingement on a target resulting from a jet source. Figure 3-79 of the WCAP reproduces Figure A.103 from NUREG/CR-2913. The applicant used the information in Figure 3-79, with the AP1000 plant value of R/D denoted by the red dot, along with the NMI data included in Table 3-10 of the WCAP to develop a prediction of the NMI target jet impingement pressure in the AP1000 plant. The applicant stated that this target pressure is conservatively assumed to be a constant pressure distribution along the top surface of the NMI with no radial degradation. Moreover, the applicant used the NTS jet testing rake data for [ ] to determine the facility-induced pressure distribution on the NMI top surface and concluded that the NTS jet impingement test at [ ] bounded the predicted NMI jet impingement pressure in the AP1000 plant. In addition, the applicant indicated that in the case of postulated break, the NMI could possibly experience a [

. Therefore, the applicant concluded that placing the NMI at the free jet centerline stagnation point of the NTS test facility resulted in a conservative test condition as compared to what the jet would actually experience in the plant configuration.

NRC Staff Evaluation

The staff reviewed the applicant’s approach to assessing the confined jet behavior in the reactor vessel cavity of the AP1000 plant. As described above, the applicant surveyed the open literature (WCAP References 3-15, 3-17, 3-18, and 3-19) for confined jet empirical data and related that data to the AP1000 plant configuration. The applicant described the respective study or testing performed in each of the open literature references. The applicant also included multiple figures in the WCAP to describe the test facility and show that the test apparatus is similar to the AP1000 plant configuration. The applicant then described the findings related to the effects on confined jet behavior for the various confinement tests described in these references. Moreover, the applicant discussed how these results could be used to address the confined jet behavior for the AP1000 reactor vessel cavity because the tested ranges encompassed the geometric configuration of the AP1000 plant with respect to jet confinement. Furthermore, the applicant related these confined jet considerations to develop a prediction of the NMI jet impingement pressure in the plant and showed that the predicted NMI jet impingement pressure would be bounded by the NTS facility jet testing performed at [ ].

Based on its review of the information provided in WCAP Section 3.3.5 and associated subsections as described above, the staff determined that it needed additional information and clarifications for the issues described below.

The staff found the applicant's statement on page 3-60 of revision 1 of the WCAP about the pressure coefficient to be unclear. Text at the top of this page states that the pressure is approximately unity for an AP1000 plant X'/D of [ ], while text at the bottom of the page states that the pressure coefficient is approximately zero for an AP10000 plant X'/D of [ ]. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-014, asking the applicant to clarify the perceived discrepancy. In a response dated July 14, 2016 (Reference 14), the applicant indicated that the discrepancy was the result of a typographical error and should be corrected. The applicant revised Item 4 on page 3-61 of the WCAP to state that the pressure coefficients are approximately unity at an H/D of zero (where H/D is referred to as r/D in Figure 3-68 of the WCAP). The staff found the applicant's WCAP revision acceptable because it clarifies the perceived discrepancy. The staff considers RAI-ICC&NMI-014 to be a closed item.

The applicant stated, on page 3-61 of the WCAP, that the testing results in Reference 3-17 of the WCAP indicate that the flow deflects about a jet diameter above the impingement plate for an X'/D of less than 2. The staff found that statement unclear. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI ICC&NMI-016, asking the applicant to clarify that statement. In a response dated July 14, 2016 (Reference 14), the applicant indicated that it would revise the WCAP to state that the presence of the impingement plate causes the flow to deflect about a jet diameter above the impingement plate. The staff found the applicant's revised WCAP statement acceptable because the revised statement clarifies the observation about the results in Reference 3-17 with regard to flow deflection as a result of the presence of the impingement plate. The staff considers RAI-ICC&NMI-016 to be a closed item.

The applicant's discussion about the jet flow region that the NMI would experience in the case of postulated break was not clear. As described above, the applicant stated that the NMI would probably experience [

. However, in order to technically justify the validity of that comparison, the applicant needed to provide additional information about the jet region for which the NMI would experience jet impingement in the case of a postulated pipe break. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-020, asking the applicant to clarify the flow region for which the NMI would experience jet impingement in the case of a postulated pipe break. In a response dated August 23, 2016 (Reference 25), the applicant stated that an evaluation was performed to substantiate the region of the jet impacting the NMI. Using Equation C-6 in American National Standards Institute (ANSI)/American Nuclear Society (ANS) 58.2-1988, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture" (Reference 4-4 of the WCAP), the applicant determined that the region of the jet impacting the NMI is outside Region I (as depicted in Figure 3-64 of the WCAP); that is, it is outside the jet core. The applicant further stated that ANSI/ANS 58.2-1988 may conservatively over predict the asymptotic plane and the jet area, and the jet could experience a Region IV jet instead. The applicant, therefore, concluded that the use of Figure 3-78 in the WCAP to predict the jet velocity and the associated comparison result is valid. The staff found the applicant's response acceptable because the applicant provided sufficient information to substantiate the jet flow region to which the NMI would be subjected in the case of a postulated break. Furthermore, the response demonstrated that placing the NMI at the jet centerline stagnation point of the test facility resulted in a conservative test condition as compared to the conditions the NMI would actually experience in the plant configuration. The applicant revised the WCAP to include a discussion to this effect at the beginning of Section 3.3.5. The staff considers RAI-ICC&NMI-020 to be a closed item.

In summary, the staff determined that the applicant provided adequate information to substantiate its conclusion that, for the AP1000 plant values of a confinement ratio of [ ] and an R/D value of [ ], the confined jet behavior in the reactor vessel cavity is analogous to the free jet. Thus, the results of the AP1000 plant free jet testing performed at the NTS facility are applicable for assessing the confined jet behavior in the reactor vessel cavity of the AP1000 plant configuration. Specifically, the WCAP addresses which data were used and where the data came from, and it demonstrates the applicability of the results contained in the tests referenced from the open literature to the AP1000 plant geometric configuration. In addition, as described above, the applicant has shown that the NTS jet impingement test at [ ] bounded the predicted NMI jet impingement pressure in the AP1000 plant. The applicant also demonstrated that placing the NMI at the jet centerline stagnation point of the NTS test facility resulted in a conservative test condition as compared to the potential jet from the AP1000 plant configuration. Therefore, as discussed above, the staff finds the applicant's approach to assess the confined jet behavior in the AP1000 reactor cavity acceptable.

3.3.4 Neutron Shield Block Submergence Test Summary and Objectives

Section 3.4 and associated subsections of the WCAP discuss submergence tests to evaluate the potential chemical effects of the materials and design features of the neutron shield blocks. The tests were designed to determine whether elements were released and chemical precipitates formed from NMI and materials with different levels of encapsulation.

3.3.4.1 Neutron Shield Blocks Submergence Test Summary

The WCAP proposes the use of NMI in the RVIS water inlet doors, neutron shield blocks (LNS), and in the CA31 module, each at a different elevation. Since all of these elevations would be submerged following a LOCA, Section 3.4.1 of the WCAP explains that all of the materials in the doors and blocks were tested to understand their individual potential to produce chemical precipitates and potentially contribute to the AP1000 chemical effects analysis. The materials were tested in simulated PWR water with prototypical post-LOCA temperature, pressure, and pH buffering.

3.3.4.2 Submergence Test Specimens

Section 3.4.2 of the WCAP describes the seven specimens used in the submergence testing program and how they relate to the different locations in the RVIS and the CA31 module. Five of the samples were a single material; four of these samples had no encapsulation and one was encapsulated in stainless steel with an edge exposed. The four fully exposed samples were [ ].
The fifth single-material sample was [

]. The sixth and seventh specimens were simulated shield blocks that included neutron absorber material, [ ], enclosed in a [ ] case. These two specimens differed in that they incorporated [ ] materials from two different manufacturers. One sample had no foil encapsulating the internal components ([ ]). No specimens represented the proposed design with a [ ] stainless steel case. Testing a [ ] sample would yield no information about chemical effects from the internal components.

3.3.4.2.1 Acceptance Criteria

The acceptance criterion for each submergence test was confirmation that the test was performed according to the test procedure and conditions. In this context, meeting the acceptance criterion did not involve the interpretation of the meaning or acceptability of the test results. The applicant concluded that the test conditions were maintained as specified and, therefore, met the acceptance criterion. On that basis, the applicant found the test results valid for evaluation.

3.3.4.2.2 Test Conditions

Each sample was exposed in a separate pressure vessel in a solution representing the AP1000 post-LOCA sump fluid, including boric acid, a pH buffer of trisodium phosphate, and a specified temperature and pressure profile. Each vessel was equipped with

]. The submergence test conditions were specified to bound the design basis accident conditions with additional margin added to both temperature and pressure. In addition to temperature, pressure, and water chemistry, the mass of each vessel was monitored to determine when fluid would be added to maintain its level.

3.3.4.2.3 Sampling Procedure

[The samples were used for chemical analysis and the detection of chemical precipitates. [

]

3.3.4.2.4 Submergence Test Results

[

] During its audit (Reference 23), the applicant explained the information in the table. The WCAP notes that [

].

Section 3.4.2.4 of the WCAP makes several observations about the test results. [

3.3.4.2.5 Impact on Chemical Effects

[

Therefore, the WCAP concludes, chemical effects do not have to be considered for the NMI blocks to meet the AP1000 licensing basis that a suitable equivalent to MRI generates no chemical effects.

NRC Staff Evaluation

The chemical effects design-basis methodology for the AP1000 is the staff-approved WCAP-16530-NP-A base model, which calculates the release of elements that could contribute to chemical precipitates in containment. The proposed neutron shield blocks are not a standard material class in the WCAP-16530-NP-A methodology, and they contain materials not evaluated for WCAP-16530-NP-A. Therefore, considering the materials and configurations, the effect of the neutron shield blocks without intact encapsulation on the AP1000 design-basis chemical debris quantity cannot be determined directly by the submergence tests. The applicant used the submergence test results to obtain solution chemistry values that could be entered into the calculation given in WCAP-16530-NP-A. The program also included a test designed to detect chemical precipitates that may [ ]. For intact stainless steel encapsulation, the blocks would contribute no chemical effects, given the negligible corrosion of stainless steel in reactor coolant and buffered post-LOCA fluid.

The staff evaluated the submergence testing with respect to how the testing was used to prevent the neutron shield blocks and water inlet doors from generating chemical effects. Acceptance is based on one of the requirements in AP1000 DCD, Section 6.3.2.2.7.1, for a suitable equivalent to MRI. This requirement states that “it would also have to be shown that the material used would not generate chemical debris.” Although the submergence testing was used to quantify the effect of incomplete encapsulation in a chemical effects calculation (WCAP Section 5.1.4), the testing was used mainly to show that complete encapsulation was necessary to prevent the release of elements that could generate chemical effects.

The staff did not evaluate the submergence testing methodology as a way to conservatively or realistically determine the presence, composition, or quantity of chemical precipitates. The staff considered this unnecessary because the applicant’s approach to chemical effects was to isolate the neutron shielding and insulation materials through design.

The staff determined that the submergence test specimens were representative of the materials to be used in the plant design. The test specimens included [. However, in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-029, asking the applicant to clarify the type of NMI used in the neutron absorber blocks, water inlet doors, submergence testing, and the WCAP-16530-NP-A chemical effects analysis. In a response dated July 14, 2016 (Reference 14), the applicant stated that [ ] was used in the submergence testing and was the material specified for the neutron absorber blocks and water inlet doors. The staff finds this acceptable because the response clarifies that the insulation material used in the submergence testing is the same material used in the plant design. The response also stated that Temp-Mat insulation was used in a WCAP-16530-NP-A analysis instead of], as discussed further in the evaluation of WCAP Section 5.1.4 (Section 3.5.1.4 of this SE). Based on the discussion above, the staff considers RAI ICC&NMI-029 to be a closed item.

In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-030, asking the applicant to explain how the test conditions were “limiting” with respect to post-LOCA conditions. In its response dated July 5, 2016 (Reference 20), the applicant explained that the testing temperature, pressure, and water chemistry ranges were selected to promote higher rates of corrosion and dissolution than compared to plant conditions following a design-basis-accident LOCA. The test temperature and pressure were equivalent to the equipment qualification requirements, which are higher than the containment pressure and temperature responses given in AP1000 DCD Section 6.2, “Containment Systems.” The water chemistry (boron and pH) was meant to represent plant conditions. The response also proposed corresponding changes to WCAP Section 3.4.2.2 to reflect the explanation. The staff finds this explanation acceptable because it clarifies that the testing was designed to produce higher chemical release rates than prototypical conditions. The staff did not verify the temperature and pH dependence of the release rates for all of the tested materials as the tests results showed that elements were released into solution if the encapsulations are not sealed. The staff notes that in the tests used to develop the methodology in WCAP-16530-NP-A, higher temperature caused higher release rates for microporous insulation and aluminum at constant pH. The applicant revised the WCAP as shown in the response; therefore, the staff considers RAI-ICC&NMI-030 to be a closed item.

The staff did not evaluate the capability of the chemical analyses and filtering tests to characterize the chemistry of the solutions or the ability to detect chemical precipitates. Some of the results described in the WCAP were unexpected. For example, according to WCAP Table 3-12,

. The methodology in WCAP-16530-NP-A, which is the design basis for the AP1000, would likely predict more precipitates from this sample than from any other because it conservatively assumes that aluminum is completely insoluble and therefore, will form a precipitate that causes head loss. [

]

The staff considered a more detailed level of review of the test results and interpretations to be unnecessary because the applicant designed the neutron shield blocks and inlet doors to isolate the internal materials from the external environment. From that perspective, the staff found that the information about submergence testing in Section 3.4 of the WCAP is acceptable because it describes the testing and results in sufficient detail to determine that without intact encapsulation, the materials in the neutron shield blocks may introduce elements into solution that contribute to chemical effects.

The staff determined that it needed additional information to clarify or correct the interpretation of results. Specifically, the staff had difficulty understanding [

. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-031, asking the applicant to clarify how [

. In a response dated August 23, 2016 (Reference 25), the applicant indicated that [

. The staff finds the response acceptable because it clarifies the applicant's interpretation of the results in the WCAP. The applicant revised the WCAP as shown in the response; therefore, the staff considers RAI-ICC&NMI-031 to be a closed item. The response to RAI-ICC&NMI-031 considers [

.

In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-032, asking for clarification about a reference (WCAP Reference 3-29) that is included in the reference list in WCAP Section 3.6 but is not discussed in the text. In a response dated July 5, 2016 (Reference 20), the applicant stated that the reference was not used in the WCAP and would be deleted. The applicant deleted the unused document reference in Rev. 2 of the WCAP; therefore, the staff considers RAI-ICC&NMI-032 to be a closed item.

3.3.5 Characterization of CA31 Neutron Shielding Material

Section 3.5 of the WCAP and associated subsections describe the CA31 neutron shielding material, which is

Section 3.5 explains that [

].

3.3.5.1 Impact of CA31 Neutron Shielding Material on Chemical Effects

Section 3.5.1 states that no chemical effects are expected from] in the RVIS and CA31 components. This is based on the construction of the shield blocks [ ] preventing contact of the [ ] with the post-LOCA fluid, and on the [ ] being considered non-reactive in the expected environment.

3.3.5.2 Impact on Containment Recirculation Screens

Section 3.5.2 describes the reasoning that no transport of the [ ] is expected for this design. This section begins with a summary of the screen design for the PXS, which includes IRWST screens, recirculation screens, trash racks, and debris curbs. The transport analysis considers the location of [

]

This section also addresses the potential for transport of [ ] particles (assumed to be released from the encapsulation) by describing Westinghouse settlement testing of [ ] performed for the WCAP, and previous NRC-sponsored testing of debris transport along a floor. The previous testing is documented in NUREG/CR-6808. The WCAP describes the flow velocities identified in NUREG/CR-6808 for moving the debris along the floor and for lifting the debris over obstructions. The Westinghouse settling tests concluded that

]

NRC Staff Evaluation

The WCAP proposes using [ ] in the CA31 module neutron shield blocks because of its thermal stability and neutron shielding capability. The material is being specified according to an ASTM standard that defines physical and chemical requirements for [ ] in various nuclear applications. It has been used in applications such as [ ]. The high thermal stability makes it suitable for use as a [ ] is well within its range of stability.

The average particle diameter of the

]. During audit interactions (Reference 26), the applicant proposed changing the average particle diameter from a single number to the range detailed in the procurement specification. The staff finds the proposed changes (Reference 27) acceptable because they are consistent with procurement specifications and the staff considers the proposed changes to be a **confirmatory item**, pending an update to the WCAP.

A goal of the design is to prevent debris generation and transport, primarily with [

. The staff determined from a regulatory audit (Reference 26) that

] was subjected to jet impingement testing, as discussed in Section 3.3.3.4 of this SE. Therefore, the characterization of the CA31 module neutron shielding material described in Section 3.5 of the WCAP applies mainly to an unexpected failure of the shield blocks to contain the shielding material in a LOCA, as well as to chemical reactivity in the normal operating environment.

The staff considered potential chemical effects from the [ ] under normal operating conditions and in the anticipated post-LOCA environment. Research conducted on [ ] under conditions like the operating conditions for the shield blocks (hot and humid air) indicates [

Therefore, the staff finds it acceptable to neglect any effect of normal operation on the chemical effects analysis.

If the [ ] gets out of the box in a LOCA, no chemical effects are expected because of [

]

With respect to settling and transport of [ ], the WCAP concludes that [

the staff finds it reasonable to postulate that most of the [ ] would settle in the reactor cavity. However, since material released from the blocks could settle in the reactor cavity, nozzle gallery, or a steam generator compartment, the staff evaluated the potential transport.

The staff compared material size, density, and flow velocity to the NRC reports on coating debris transport. NUREG/CR-6916 documents transport testing of coating chips with density in the range 1.15 g/cm^3 (0.042 lb/in^3) to 2.5 g/cm^3 (0.09 lb/in^3), and three size ranges between 0.4 mm (0.016 inches) and 50.8 mm (2.00 inches). The density of 2.5 g/cm^3 (0.09 lb/in^3), corresponding to an epoxy/inorganic zinc coating system, is approximately the same as [ ] The WCAP states that for the AP1000, [ ]

The staff's consideration of the CA31 neutron shielding material described in WCAP Section 3.5 indicate that if [ ] particles get out of the shield blocks, they will settle and not transport to the screen or generate chemical effects. The staff finds that this provides additional conservatism in meeting the design of a suitable equivalent insulation.

3.4 DEBRIS GENERATION BREAK SIZE DETERMINATION (WCAP-17938, SECTION 4)

Section 4 of the WCAP discusses documents (WCAP References 4-1 and 4-2) that provide guidance for resolving GSI-191. In particular, these documents provide an alternate evaluation methodology that may be used to demonstrate acceptable containment sump performance.

The WCAP indicates that the alternate evaluation methodology allows for an alternate design-basis break size in conjunction with the baseline methodology for the RCS and attached piping. It also allows for the use of realistic analysis assumptions and credit for nonsafety systems and operator actions when evaluating up to a full DEGB of the RCS main loop piping.

The WCAP states that the alternate evaluation methodology consists of three main components: debris generation break size, Region I analysis, and Region II analysis. The WCAP discusses each of these components and their application to the AP1000 plant as described below.

3.4.1 Debris Generation Break Size

Section 4.1 of the WCAP defines the debris generation break sizes as follows:

- For all ASME Code Class 1 auxiliary piping (attached to the AP1000 plant RCS main loop piping) up to and including a DEGB of any of these lines, the GSI-191 design-basis rules apply.
- For breaks in the AP1000 plant RCS main loop piping (hot leg and cold leg piping) up to a size of equivalent break diameter to that of a 14-inch (35.56 cm) Schedule 160 pipe (approximately 11.188 inches (28.418 cm)), the GSI-191 design-basis rules apply (applicable to Region I).
- For breaks in the AP1000 plant RCS main loop piping (hot leg and cold leg piping) with equivalent diameter greater than that of a 14-inch (35.56 cm) Schedule 160 pipe (approximately 11.188 inches (28.418 cm)) and up to the DEGB, mitigative capability must be demonstrated, but GSI-191 design-basis rules may not necessarily apply (applicable to Region II).

The WCAP states that the AP1000 plant RCS piping is fabricated of forged seamless stainless steel without longitudinal or electroslag welds or cast fittings. In addition, the piping complies with the requirements of the ASME Code, Section II (Parts A and C), Section III, and Section IX, and adheres to the requirements of Regulatory Guide 1.44, “Control of the Processing and Use of Stainless Steel,” issued March 2011 (Reference 31), for the use of Series 300 stainless steel materials. The WCAP claims that these fabrication techniques minimize the risk of primary water stress-corrosion cracking failure throughout the RCS piping system.

The WCAP states that the staff found the pipe break spectrum listed above for evaluating debris generation to be acceptable (Reference 11) and that licensees could use the debris generation break size for distinguishing between Region I and Region II analyses when using the alternate evaluation methodology. The WCAP states that these conclusions are applicable to the AP1000 plant RCS loop piping and the associated RCS main loop branch piping.

NRC Staff Evaluation

The staff reviewed the debris generation break size discussion as described in the WCAP. Because the approach (pipe break spectrum listed above) discussed in the WCAP is consistent with an approach previously reviewed and approved by the staff (Reference 11), the staff finds the WCAP approach to debris generation break size acceptable.

In addition, although the WCAP mentions that the alternate evaluation methodology allows for the use of nonsafety structures, systems, or components or operator actions when evaluating up to a full DEGB of the RCS main loop piping, the WCAP does not propose to credit the use of nonsafety systems or operator actions when evaluating up to a full DEGB of the RCS main loop piping. As such, the staff’s review does not include credit for nonsafety systems or operator actions when evaluating up to a full DEGB of the primary system piping. If a licensee or applicant seeks to credit operator actions or nonsafety systems to demonstrate mitigative capability for postulated pipe breaks consistent with the alternate evaluation methodology, then the staff would need additional information in order to reach a conclusion on the acceptability of the applicant’s approach. Therefore, Section 4.0 of this SE includes a limitation and condition to clarify that the staff's review of the acceptability of the alternate evaluation methodology for the AP1000 design excludes the use of nonsafety systems and operator actions.

Furthermore, in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-033, asking the applicant to confirm the description of the RCS piping and how these features were used in determining the debris generation break size. In a letter dated July 5, 2016 (Reference 20), the applicant clarified that the WCAP describes the piping features to indicate a low failure susceptibility of the RCS piping, and that the alternate evaluation methodology did not consider these features for determining the debris generation break size. The response also proposed a corresponding revision to the WCAP stating that the break size determination did not credit the RCS piping features. The proposed WCAP revision also corrects a statement that the piping has no dissimilar welds, replacing it with a statement that there are no cast fittings or Alloy 600 weld metals. The staff finds this acceptable because the revised description of the RCS piping is consistent with that in the AP1000 DCD, Revision 19, and the applicant did not credit these RCS piping features in determining the debris generation break size. Therefore, the staff considers RAI-ICC&NMI-033 to be a closed item, based on the WCAP revision.

3.4.2 Region I Analysis

Section 4.2 of the WCAP describes the Region I analysis as an evaluation of the RCS main loop piping and every branch line connected to the RCS main loop piping. For the Region I analysis, all lines are evaluated for debris generation and transport using the baseline methods defined in NEI 04-07 and as modified by the SE on NEI 04-07.

The Region I analysis includes an evaluation of all break sizes up to and including the debris generation break size (i.e., 14-inch pipe (35.56 cm)) of the main loop piping. A DEGB of the main loop branch piping is assumed, as described in WCAP Section 4.1.

The WCAP states that while the SE for NEI 04-07 allows for the use of a volume-equivalent ZOI radius for the calculation of the ZOI volume, this method is not employed for the AP1000 analyses. The ZOI radius proposed in WCAP Section 3 (i.e., cables and neutron shielding) is based on jet impingement testing with the target material placed on the jet centerline. The ZOI radius for the material as determined from testing is equal to the centerline distance from the break location to the target at which the material did not fail.

WCAP Table 4-1 compares the volume-equivalent spherical ZOI approach to the WCAP's approach to ZOI. The results in WCAP Table 4-1 illustrate that the volume-equivalent spherical ZOI radii are bounded by spherical radii that use the centerline target distance determined from jet impingement testing. The WCAP concludes that the approach taken for calculating the ZOI dimensions for the AP1000 plant is conservative since the proposed WCAP ZOI is based on centerline target distance rather than the volume-equivalent model.

NRC Staff Evaluation

The staff reviewed the Region I analysis as described in WCAP Section 4.2. The staff finds the WCAP approach to Region I analysis is acceptable because the approach is consistent with the Region I approach in NEI 04-07 as previously reviewed and approved by the staff's SE (Reference 11), with the exception of the calculation of ZOI for NMI and cables.

For the calculation of ZOI for NMI and cables, WCAP Section 4.2 discusses two models. The first model is the approved spherical model defined by NEI 04-07 (i.e., volume-equivalent). The second model is a spherical model with a defined radius equal to the centerline distance from the break location to the target material at which the material did not fail. The WCAP employs the second model for assessing NMI and cables. The WCAP also states that the spherical model from NEI 04-07 is not employed for the AP1000 plant analysis. The statement that "this method [ ] is not employed for the AP1000 plant analyses" pertains only to NMI and cable materials.

The ZOI radii for the materials discussed in the WCAP (i.e., cable and NMI) are based on the centerline distance from the break location to the target at which the material did not fail (see Section 3.3.3 and associated subsections of this SE). As shown in WCAP Table 4-1, the WCAP ZOI approach increases the resultant ZOI as compared to the NEI 04-07 approved approach. The staff finds the WCAP approach to ZOI is acceptable due to the increase in ZOI (greater volume about the break in which the fluid escaping from the break has sufficient energy to generate debris) when compared to the ZOI model approved by the staff in the review of NEI 04-07.

3.4.3 Region II Analysis

Section 4.3 of the WCAP describes the Region II analysis. The Region II analysis includes evaluations of break sizes in the RCS main loop piping (hot and cold) greater than the debris generation break size defined in the Region I analysis and up to the DEGB of the largest pipe in the RCS. The WCAP states that the Region II analysis only considers the RCS main loop piping because all primary-side attached auxiliary piping is fully addressed as part of the Region I analysis.

The WCAP states that the Region II analysis is performed in the same manner and with the same methods used in the baseline analyses with respect to ZOI models and assumptions. However, the Region II analysis allows for more realistic analytical methods and assumptions such as limited pipe displacement. Crediting limited pipe displacement requires the application of results from pipe break analyses that may be used to limit the maximum break size to be evaluated. The WCAP proposes that if analyses show that limited (main coolant) pipe displacement (i.e., a limited separation break) will occur, then an equivalent break diameter for the limited separation break may be used to determine the ZOI for the Region II analyses.

NRC Staff Evaluation

The staff reviewed the WCAP's approach to the Region II analysis. The WCAP approach is to credit limited pipe displacement in the Region II analysis. Credit for limited pipe displacement is consistent with the provisions of the Region II analysis in NEI 04-07 previously reviewed and approved by the staff (Reference 11) and is therefore acceptable. Sections 3.4.3.1 and 3.4.3.2 of this SE provide the staff's review and evaluation of the WCAP's approach to and definitions for limited pipe displacement.

The WCAP description of the Region II analysis allows for crediting operator actions. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI ICC&NMI-022, asking the applicant to explain assumptions which may be employed in the analysis. In a response to RAI-ICC&NMI-022 dated August 23, 2016 (Reference 25), the applicant included a markup to the WCAP clarifying that no credit was taken for better estimate assumptions or operator actions as part of the Region II analysis. The staff finds this revision to the WCAP acceptable because it clarifies the applicant's position on the credit taken for operator actions in the Region II analysis. Therefore, the staff considers RAI-ICC&NMI-022 to be a closed item.

3.4.3.1 Full Separation Break

Section 4.3.1 of the WCAP describes the methodology for determining the ZOI for a full separation break used in the Region II analysis. It states that if a pipe displacement or structural analysis is not performed, or if the analysis results in a break with lateral pipe displacement greater than 1 diameter and axial displacement greater than 0.5 diameter, then a full separation DEGB of the RCS main loop piping must be assumed. The radius of the spherical ZOI used in a Region II analysis is defined using the inner diameter of the RCS main loop piping multiplied by a scaling factor determined for the specific material to be evaluated. The spherical ZOI is modeled with the defined radius applied to the axial centerline of the pipe.

NRC Staff Evaluation

The staff reviewed the applicant's methodology for determining the ZOI for a full separation break used in the Region II analysis. The staff finds the applicant's methodology acceptable because it is consistent with the provisions of the Region II analysis for assessing full separation break in NEI 04-07 previously reviewed and approved by the staff (Reference 11).

3.4.3.2 Limited Separation Breaks

Section 4.3.2 and the associated subsections of the WCAP describe the methodology for determining the ZOI for limited separation break used in the Region II analysis. The WCAP states that if a structural or pipe displacement analysis results in a lateral displacement of less than one diameter and an axial displacement of less than or equal to 0.5 diameter, then the Region II analysis may use a limited separation break in determining the alternate break size. The WCAP states that one of the key parameters of the circumferential break with limited separation is the value of the axial displacement. Similar to the inner diameter of the pipe for a full separation break, the axial displacement acts as the characteristic length for the simplified expanding jet model included in Appendix C to ANSI/ANS 58.2-1988 (Reference 4-4 of the WCAP).

WCAP Sections 4.3.2.1 and 4.3.2.2 describe the equations for determining the equivalent diameter for a limited separation break with lateral displacement of less than or equal to the pipe wall thickness, as well as a limited separation break with lateral displacement greater than the pipe wall thickness and less than 1 diameter. For a limited separation break with lateral displacement of less than or equal to the pipe wall thickness, the equivalent diameter is defined by the axial displacement. For a limited separation break with lateral displacement greater than the pipe wall thickness and less than 1 diameter, both the axial and lateral displacements are considered in the equivalent break diameter. The applicant stated that for those cases in which the method in WCAP Section 4.3.2.2 results in an equivalent diameter larger than the pipe diameter, the pipe diameter is to be used to calculate the radius of the spherical ZOI. Moreover, the equivalent diameter multiplied by a scaling factor determined for the specific material to be evaluated is used in determining the spherical ZOI used in the Region II analysis for the AP1000 plant.

NRC Staff Evaluation

The staff reviewed the applicant's methodology for determining the ZOI for limited separation break used in the Region II analysis. The staff found that the method used by the applicant to define the break size is conservative compared to the method presented in ANSI/ANS 58.2-1988 for limited separation breaks, as discussed in Section 4.3.2 of the WCAP. Whereas the ANSI/ANS 58.2-1988 methodology defines a limited separation break as having an axial displacement of less than or equal to 0.5 diameter and a lateral displacement of less than or equal to the pipe wall thickness, the applicant's approach extends the ANSI/ANS 58.2-1988 methodology to include an axial displacement of less than or equal to 0.5 diameter and a lateral displacement greater than the pipe wall thickness and up to 1 pipe inner diameter. Using this extended method, the equivalent diameter of such a limited separation break is more conservative because both the axial and lateral displacements are considered in the equivalent break diameter, which yields a larger ZOI volume for the limited separation break in the Region II analysis. Therefore, the staff found the applicant's methodology as described in WCAP Section 4.3.2 acceptable because the methodology conservatively determines the ZOI for limited separation break in the Region II analysis, as described above.

3.4.4 Reactor Coolant System Main Loop Piping Displacement Analysis

3.4.4.1 Analysis Overview

Section 4.4 and associated subsections of the WCAP provide information related to the RCS main loop piping displacement analysis performed by the applicant in support of the Region II analyses. The applicant stated that a structural evaluation of the AP1000 RCS main loop piping was performed using ANSYS LS-DYNA to evaluate pipe whip and displacement in the RCS main loop piping. This analysis, documented in APP-PL01-P0C-003 (Reference 4-7 of the WCAP), used finite element models run on ANSYS LS-DYNA to demonstrate that the hot legs and cold legs do not fully separate as a result of a LOCA. The LOCA pipe reaction forces assumed for each DEGB scenario were calculated in APP-PL01-P0C-002 (Reference 4-6 of the WCAP). The applicant stated that five break scenarios shown in Figure 4-3 of the WCAP were analyzed. The applicant also discussed how the five postulated break scenarios and locations were strategically chosen to bound breaks at all locations along the hot-leg and cold-leg piping. In addition, Figures 4-4, 4-5, 4-6, and 4-7 of the WCAP show the respective thrust force vectors and the associated moment arms for each of the postulated break scenarios. Table 4-3 of the WCAP gives the results of these pipe displacement analyses.

NRC Staff Evaluation

The staff reviewed the applicant's RCS main loop piping displacement analyses described above. To support the review of the applicant's piping displacement analyses, the staff conducted an audit (Reference 23) of the applicant's RCS main loop piping displacement analyses. Two key documents included in this audit, which took place March 16–17, 2016, were two non-docketed Westinghouse calculation notes (References 4-6 and 4-7 of the WCAP).

WCAP Reference 4-6 documents Westinghouse's methodology for calculating the pipe reaction forces for the AP1000 loop piping resulting from a DEGB of the hot-leg and cold-leg loop piping. The calculations of the pipe reaction forces were then provided as inputs to a nonlinear structural analysis described in Reference 4-7 of the WCAP to mechanistically determine the magnitude of the pipe displacement that would occur as a result of a DEGB of AP1000 RCS loop piping. Reference 4-7 of the WCAP presents the methodologies and results for determining the pipe movement for five postulated RCS DEGBs as identified in Section 4.3 of the WCAP. Based on its review of the information provided in Section 4.4.1 and References 4-6 and 4-7 of the WCAP, the staff found that the applicant's RCS main loop piping displacement analyses are acceptable because the applicant's analysis strategies and methodologies are consistent with the pertinent engineering practices for determining the potential pipe displacement and are technically justified. Specifically, the applicant properly determined the force vector and the associated length of moment arm for the respective postulated break locations. The applicant then calculated the resultant moment by taking the product of the force vector and the moment arm and generated the associated potential pipe displacement for the respective postulated break locations. In addition, the applicant has provided sufficient information to substantiate its conclusion that the five postulated break scenarios and locations chosen are representative and bound breaks at all locations along the hot-leg and cold-leg piping.

3.4.4.2 Pipe Displacement Results

Table 4-3 in Section 4.4.2 of the WCAP gives the results of the hot-leg and cold-leg pipe displacement analyses for the five break locations of the AP1000 RCS main loop piping described in Reference 4-7 of the WCAP.

NRC Staff Evaluation

The staff reviewed the results of the hot-leg and cold-leg pipe displacement analyses presented in Table 4-3 of the WCAP. The staff finds these results acceptable because they are consistent with those shown in Reference 4-7 of the WCAP, which the staff assessed during the March 16-17, 2016 audit (Reference 23) and found it acceptable as discussed in Section 3.4.4.1 of this SE.

3.4.4.3 Application of Results to Region II Analyses

Section 4.4.3 and the associated subsections of the WCAP describe how the results of the piping displacement presented in Table 4-3 of the WCAP were used to support the AP1000 plant Region II analyses. The applicant stated that, following the methodology described in WCAP Section 4.3, the equivalent break diameter was determined for each of the five DEGB scenarios and was compared to the 14-inch (35.56 cm) Schedule 160 break size already used as the basis for the Region I analysis. To ensure the validity and conservatism of the use of a spherical ZOI model based on a 14-inch (35.56 cm) Schedule 160 break diameter, the representative geometry of each limited separation break was also determined. The geometries of the limited separation breaks were determined using anticipated operating and boundary conditions during the AP1000 plant LOCA transient and compared to the geometry of a fully separated DEGB. The applicant stated that this comparison relied on the staff's SE to NEI 04-07 (Reference 4-2 of the WCAP) in conjunction with the expanding jet models provided in Appendix C to ANSI/ANS 58.2-1988.

Moreover, the applicant indicated that a simplified volumetric comparison was proposed as a qualitative method of comparing the circumferential break jet expansion geometries with limited separation to the full separation DEGB jet expansion geometry. Appendix C to ANSI/ANS 58.2-1988 describes two regions of a jet that will occur following a LOCA. Using the methodology described in the WCAP, the Region 1 and 2 volumes (as shown in Figure (A) of Figure 4-8) of the expanding jet for each of the five limited separation break scenarios were compared to the volumes of Region 1 and 2 (as shown in Figure (B) of Figure 4-8) of the expanding jet for both ends of a DEGB with full separation for a 14-inch (35.56 cm) Schedule 160 pipe. This method was chosen as a simplified alternative to the calculation and comparison of jet isobars using the circumferential limited separation jet model and the full separation jet model. WCAP Sections 4.4.3.1 and 4.4.3.2 discuss the results of the equivalent break diameter calculations and expanding jet geometry comparisons.

NRC Staff Evaluation

The staff reviewed the applicant's approach for applying the results of piping displacement presented in Table 4-3 of the WCAP to support the AP1000 plant Region II analyses as described above. The staff found that the applicant's approach followed the staff SE on NEI 04-07 and the expanding jet models in Appendix C to ANSI/ANS 58.2-1988 in its comparison of the spherical ZOI model based on a 14-inch (35.56 cm) Schedule 160 break size to the representative geometry of each limited separation break. Therefore, the applicant's approach is acceptable.

3.4.4.3.1 Hot-Leg Break Evaluations

3.4.4.3.1.1 Hot-Leg Double-Ended Guillotine Break at the Reactor Vessel Nozzle

Section 4.4.3.1.1 of the WCAP discusses the evaluation of a hot-leg DEGB at the reactor vessel nozzle. Table 4-3 of the WCAP shows that the hot-leg break at the reactor vessel nozzle resulted in an axial displacement of [

The applicant then concluded that a spherical ZOI based on the [ ] would also conservatively bound this limited separation break of the hot-leg break at the reactor vessel nozzle.

Given that the ZOI for a fully separated break of a

], the applicant concluded that the Region I analysis bounds the Region II analysis modeling a hot-leg DEGB at the reactor vessel nozzle.

NRC Staff Evaluation

The staff reviewed the applicant's evaluation of hot-leg DEGB at the reactor vessel nozzle as described above. The staff finds the applicant's evaluation and the conclusion acceptable because the evaluation followed the methodology described in Section 4.4.3 of the WCAP, which the staff found acceptable as described in Section 3.4.4.3 of this SE. Consequently, the applicant has adequately substantiated its conclusion that the Region I analysis bounds the Region II analysis modeling [ ].

3.4.4.3.1.2 Hot-Leg Double-Ended Guillotine Break at the Steam Generator

Section 4.4.3.1.2 of the WCAP discusses the evaluation of a hot-leg DEGB at the steam generator. Table 4-3 of the WCAP shows that the hot-leg break at the steam generator resulted in an axial displacement [ ] The applicant then concluded that a spherical ZOI based on [ ] would also conservatively bound this limited separation break of the hot-leg break at the steam generator.

Given that the ZOI for], the applicant concluded that the Region I analysis bounds the Region II analysis modeling [ ].

NRC Staff Evaluation

The staff reviewed the applicant's evaluation of a hot-leg DEGB at the steam generator as described above. The staff found that some statements in the WCAP contain discrepancies in defining the core length and the distance from the break plane to the asymptotic plane for the limited separation model. In a letter dated May 11, 2016 (Reference 13), the staff issued RAI ICC&NMI-026, asking the applicant to clarify the perceived discrepancies. In a response dated August 23, 2016 (Reference 25), the applicant indicated that those statements were unclear because of a typographical error and inadequate explanation. The applicant proposed revisions to Sections 4.4.3.1.2, 4.4.3.2.2, and 4.4.3.2.3 of the WCAP to clearly define the core length and the distance from the break plane to the asymptotic plane for those limited separation models. The staff found the applicant's revisions acceptable because the revised WCAP clarified the perceived discrepancies. Therefore, the staff considers RAI ICC&NMI-026 to be a closed item.

In summary, the staff finds the applicant's evaluation and conclusion acceptable because the evaluation followed the methodology described in Section 4.4.3 of the WCAP, which was found acceptable by the staff as described in Section 3.4.4.3 of this SE. Consequently, the applicant has adequately substantiated its conclusion that the Region I analysis bounds the Region II analysis modeling [ ].

3.4.4.3.1.3 Hot-Leg Break Region II Results

Section 4.4.3.1.3 of the WCAP summarizes the results of the AP1000 hot-leg break Region II analysis. The applicant stated that for the Region I hot-leg break analysis, a debris generation break size was defined as that of a 14-inch (35.56 cm) Schedule 160 pipe. The applicant stated that, as shown by the results of the analyses presented in Sections 4.3.1.1 and 4.3.1.2 of the WCAP, the worst possible mechanical break displacement results in a ZOI that is smaller than that assumed in the Region I analysis. This ZOI is considered at all points along the RCS hot leg to determine the location that will produce the maximum debris. The resultant debris generation, with no other best estimate assumptions considered, cannot be greater than the debris generation from the Region I analysis.

NRC Staff Evaluation

The staff reviewed the applicant's summary of the results of the AP1000 hot-leg break Region II analysis presented in Section 4.4.3.1.3 of the WCAP. The staff finds the summary acceptable because it is consistent with the results of the analyses presented in Sections 4.3.1.1 and 4.3.1.2 of the WCAP, which was found acceptable by the staff as described in Sections 3.4.4.3.1.1 and 3.4.4.3.1.2 of this SE.

3.4.4.3.2 Cold-Leg Break Evaluations

3.4.4.3.2.1 Cold-Leg Double-Ended Guillotine Break at the Reactor Vessel Nozzle

Section 4.4.3.2.1 of the WCAP discusses the evaluation of a cold-leg DEGB at the reactor vessel nozzle. Table 4-3 of the WCAP shows that the cold-leg break at the reactor vessel nozzle resulted in an axial displacement

As described in WCAP Section 4.3.2.2, the equivalent diameter cannot exceed the pipe diameter. For those cases in which the WCAP Section 4.3.2.2 method results in an equivalent diameter larger than the pipe diameter, the pipe diameter will be used to calculate the radius of the spherical ZOI and the break will be considered a DEGB with full separation. Therefore, the applicant concluded that a

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NRC Staff Evaluation

The staff reviewed the applicant's evaluation of a cold-leg DEGB at the reactor vessel nozzle as described above. The staff finds the applicant's evaluation and conclusion acceptable because the evaluation followed the methodology described in Section 4.3.2 of the WCAP, which the staff found acceptable as described in Section 3.4.3.2 of this SE. Consequently, the applicant has adequately substantiated its conclusion that a spherical ZOI based on

].

3.4.4.3.2.2 Cold-Leg Double-Ended Guillotine Break at the Reactor Coolant Pump

Section 4.4.3.2.2 of the WCAP discusses the evaluation of a cold-leg DEGB at the RCP. Table 4-3 of the WCAP shows that the cold-leg break at the RCP resulted in an axial displacement of [

would also conservatively bound this limited separation break of the cold-leg break at the RCP.

Furthermore, the applicant stated that the ZOI for a fully separated break of a 14-inch (35.56 cm) Schedule 160 pipe would bound the parameters of the limited separation; however, the calculated equivalent break diameter was found to be greater than the inner diameter of the 14-inch (35.56 cm) Schedule 160 pipe (11.188 inches (28.418 cm)). As a result, a Region II analysis is to be assessed for

.

NRC Staff Evaluation

The staff reviewed the applicant's evaluation of a cold-leg DEGB at the RCP as described above. The staff finds the applicant's evaluation and conclusion acceptable because the evaluation followed the methodology described in Section 4.4.3 of the WCAP, which the staff found acceptable as described in Section 3.4.4.3 of this SE. Consequently, the applicant has adequately substantiated its conclusion that a Region II analysis is to be assessed [

].

3.4.4.3.2.3 Cold-Leg Double-Ended Guillotine Break at the CA01 Module Penetration

Section 4.4.3.2.3 of the WCAP discusses the evaluation of a cold-leg DEGB at the CA01 module penetration. Table 4-3 of the WCAP shows that the cold-leg break at the reactor vessel nozzle resulted in an axial displacement [

Furthermore, the applicant stated that based on the break results for the cold leg at the reactor vessel nozzle and the RCP presented in WCAP Sections 4.4.3.2.1 and 4.4.3.2.2, respectively, a Region II analysis is to be performed for the cold-leg break with a spherical ZOI based on a diameter of [ ] from the reactor vessel nozzle to the CA01 module penetration, and a spherical ZOI based on an equivalent diameter of [ ] from the CA01 module penetration to the RCP.

NRC Staff Evaluation

The staff reviewed the applicant's evaluation of a cold-leg DEGB at the CA01 module penetration as described above. The staff finds the applicant's evaluation and conclusion acceptable because the evaluation followed the methodology described in Section 4.4.3 of the WCAP, which the staff found acceptable as described in Section 3.4.4.3 of this SE. Consequently, the applicant has adequately substantiated its conclusion that a Region II analysis is to be performed for the cold leg with a spherical ZOI based on a diameter of [ ] from the reactor vessel nozzle to the CA01 module penetration, and a spherical ZOI based on an equivalent diameter of [ ] from the CA01 module penetration to the RCP.

3.4.4.3.2.4 Cold-Leg Break Region II Results

Section 4.4.3.2.4 of the WCAP summarizes the results of the AP1000 cold-leg break Region II analysis. The applicant stated that for the Region I cold-leg break analysis, a debris generation break size was defined as that of a 14-inch (35.56 cm) Schedule 160 pipe. The applicant stated that the AP1000 plant RCS cold leg is divided into two primary segments: (1) the cold-leg segment located inside the steam generator compartment, extending from the RCP through the CA01 module penetration, and (2) the cold-leg segment located inside the nozzle gallery, extending from the CA01 module penetration to the reactor vessel nozzle. The applicant further stated that, as shown by the results of the analyses presented in Sections 4.3.2.2 and 4.3.2.3 of the WCAP, the worst possible mechanical break displacement for all possible break locations inside the steam generator compartment and through the CA01 module penetration results in a ZOI that is smaller than that assumed in the Region I analysis. This ZOI is considered at all points along the RCS cold leg to determine the location that will produce the maximum debris. The resultant debris generation, with no other best estimate assumptions considered, cannot be greater than the debris generation from the Region I analysis.

Moreover, the applicant stated that, as shown by the results of the analyses presented in Sections 4.3.2.1 and 4.3.2.3 of the WCAP, the worst possible mechanical break displacement for all possible break locations inside the reactor nozzle gallery from the reactor nozzle to the CA01 module wall was determined to occur at the cold-leg reactor nozzle, and this displacement is greater than the debris generation break size used in the Region I analysis. Therefore, the applicant applied this maximum break size to the locations along the RCS cold leg from the reactor nozzle to the CA01 module wall. In addition, the applicant stated that the limiting break size for each segment is to be applied to any location on the corresponding cold-leg segment that results in the maximum debris generation.

NRC Staff Evaluation

The staff reviewed the applicant's summary of the results of AP1000 cold-leg break Region II analysis presented in Section 4.4.3.2.4 of the WCAP. The staff finds it acceptable because the summary as presented is consistent with the results of the analyses described in Sections 4.4.3.2.1, 4.4.3.2.2, and 4.4.3.2.3 of the WCAP, which the staff found acceptable as described in Sections 3.4.4.3.2.1, 3.4.4.3.2.2, and 3.4.4.3.2.3 of this SE.

3.5 NONMETALLIC INSULATION SUITABLE EQUIVALENCY (WCAP-17938, SECTION 5)

Section 5 of the WCAP states that the encapsulated NMI contained in the RVIS LNS blocks, the CA31 neutron shield blocks, and the RVIS water inlet doors, [ ], is a suitable equivalent to MRI for the locations bounded by testing and analysis.

NRC Staff Evaluation

Based on the WCAP NMI testing information and associated staff evaluations (i.e., Sections 3.3.3 and 3.3.4 of this SE) and the analysis in the remainder of Section 3.5 of this SE, the staff finds that the RVIS LNS blocks, the CA31 neutron shield blocks, and the RVIS water inlet doors, [ ], are a suitable equivalent to MRI for their locations bounded by testing and analysis and evaluated in the WCAP.

3.5.1.1 Debris Generation

Section 5.1.1 of the WCAP states that there is no debris production from the NMI contained within the neutron shield blocks (i.e., LNS and CA31) or the RVIS water inlet doors.

NRC Staff Evaluation

Based on the WCAP NMI testing information and associated staff evaluations (i.e., Sections 3.3.3 and 3.3.4 of this SE) and the analyses in the Subsections of 3.5.1.1 of this SE, the staff finds that there is no debris production from the neutron shield blocks or water inlet doors.

3.5.1.1.1 Jet Impingement Debris

Section 5.1.1.1 of the WCAP states that jet impingement testing was used to determine the ZOI for the RVIS LNS, the CA31 neutron shielding, and the water inlet doors. With the material ZOI defined through testing, it was possible to verify that debris would not be generated in the plant from a break of the hot-leg, cold-leg, or DVI piping.

NRC Staff Evaluation

Based on the information in the WCAP and the associated staff evaluation in Section 3.3.3.4 of this SE, the staff finds that the jet impingement testing used to determine the ZOI is acceptable.

3.5.1.1.1.1 Establishing the Zone of Influence

Section 5.1.1.1.1 of the WCAP defines ZOI as the spherical volume about a break in which the fluid escaping from the break has sufficient energy to generate debris from insulation, coatings, or other materials within the zone. The WCAP states that jet impingement testing was conducted on a [ ] neutron shield block test specimen, and the block maintained its encapsulation integrity and did not generate debris at a [ ] ZOI. The WCAP provides a calculation describing how the [ ] ZOI was determined by testing.

The WCAP states that the jet impingement test results can be applied to the CA31 neutron shielding, water inlet doors, and the RVIS Upper Neutron Shield (UNS) and LNS.

The WCAP indicates that the CA31 module uses [ ]. The UNS and LNS blocks use [. The construction of the installed blocks is more robust than that of the tested shield block.

The WCAP indicates that the RVIS water inlet doors are located much farther from a potential pipe break than the tested ZOI, and, because of the intervening structures and components, a LOCA jet has no direct path to the water inlet doors.

NRC Staff Evaluation

The staff finds that jet impingement test results can be applied to assess the CA31 neutron shielding, RVIS LNS, and the water inlet doors because testing demonstrated that the shield block maintained its integrity and did not generate debris at a [ ] ZOI. For the CA31 shield blocks, this finding is supported by its enhanced construction as compared to that of the test article. Similarly, for the LNS, the staff finding is supported by the LNS's enhanced construction as compared to that of the test article and because the RVIS LNS is located far from a potential pipe break (near the bottom of the reactor vessel), with many intervening structures and components between the break and RVIS LNS. For the water inlet doors, this finding is supported because the RVIS water inlet doors are located far from a potential pipe break (below the bottom of the reactor vessel), with many intervening structures and components between the break and the RVIS water inlet doors. The staff evaluation for suitable equivalency did not include the UNS because the UNS is not subject to the approval items identified in WCAP Section 1.1, "Purpose."

3.5.1.1.1.2 NEI 04-07 Approach to Determining the Zone of Influence

Section 5.1.1.1.2 of the WCAP compares the staff-approved methods (Reference 11) used to determine ZOI versus the WCAP's determination of ZOI. The WCAP provides information to demonstrate the conservatism in selecting a [ ] ZOI based on jet impingement testing.

NRC Staff Evaluation

The staff reviewed the ZOI discussion in WCAP Section 5.1.1.1.2. The staff agrees that the WCAP approach to determining a ZOI for NMI, based upon jet impingement testing, demonstrates conservatism in comparison with the staff-approved ZOI approach (Reference 11) and is therefore acceptable.

3.5.1.1.1.3 Debris Generation Assessment

Section 5.1.1.1.3 of the WCAP states that a debris generation assessment was performed for each potential pipe break in the reactor vessel cavity for the RVIS and the CA31 neutron shielding. The WCAP states that the RVIS LNS and water inlet doors are far enough away from the potential pipe breaks that they are not within the ZOI and do not generate debris from a LOCA jet. The WCAP provides figures that show the plan view and elevation views of the nozzle gallery area.

NRC Staff Evaluation

The staff reviewed the debris generation assessment for the RVIS LNS and water inlet doors (located in the bottom region of the reactor vessel cavity). Based on WCAP Section 2.2 location information and Figures 5-3 through 5-15, the staff agrees that the RVIS LNS and water inlet doors are located far from the potential pipe breaks and are not within the [ ] ZOI. Because of the construction of the RVIS LNS and water inlet doors and their distance from any potential break location (much greater than the 3D ZOI established by testing similarly constructed items), the staff finds it reasonable to conclude that the RVIS LNS and water inlet doors do not generate debris from a LOCA jet.

3.5.1.1.1.3.1 Direct Vessel Injection Pipe Break

Section 5.1.1.1.3.1 of the WCAP provides the debris generation assessment for the DVI piping. The ZOI was calculated using the full inner diameter of the DVI pipe of [ ]. The result is that the CA31 neutron shielding is outside the ZOI.

NRC Staff Evaluation

The staff reviewed the debris generation assessment for the DVI line break in the reactor vessel cavity region, including WCAP Figures 5-7 and 5-8 (elevation and plan views, respectively). Based on the figures, the application of a [ ] ZOI reveals that the CA31 neutron shielding is outside the ZOI sphere. Because the WCAP applied the appropriate ZOI to assess the debris generation potential of the DVI line break in the reactor cavity region, the staff considers the results acceptable. Therefore, the staff finds that the CA31 neutron shielding would not generate debris from a DEGB of the DVI line in the reactor cavity.

3.5.1.1.1.4 Hot-Leg Pipe Break

Section 5.1.1.1.4 of the WCAP analyzes a hot-leg pipe break for the AP1000 plant using the Region I and Region II analysis (i.e., alternate evaluation methodology) discussed in Section 3.4 of this SE.

Section 5.1.1.1.4.1 of the WCAP provides the Region I analysis of the hot-leg piping. The resulting spherical ZOI is small enough that the CA31 neutron shielding is outside the ZOI. Therefore, the Region I analysis determined that a break in the hot-leg piping in the reactor cavity would generate no debris from encapsulated NMI.

Section 5.1.1.1.4.2 of the WCAP provides the Region II analysis of the hot-leg piping. A pipe break analysis was performed for a break at the hot-leg nozzle to determine the pipe movement and resulting break area. The analysis showed that the resulting pipe break area was less than the break area used in the Region I analysis. Because the break size used in the Region I analysis is greater than the break size used in the Region II analysis, the Region I analysis is more conservative.

NRC Staff Evaluation

The staff reviewed the debris generation assessment for the hot-leg pipe break in the reactor vessel cavity region discussed above and depicted in WCAP Figures 5-9 and 5-10 (elevation and plan views, respectively), in conjunction with the pipe break analysis assessed in Section 3.4.4 of this SE. Based on the figures and the realistic pipe break analysis, the application of a 3D ZOI on the hot-leg reveals that the CA31 neutron shielding is outside the ZOI sphere. Because the WCAP appropriately applied the alternate evaluation methodology and ZOI to assess the debris generation potential of the hot-leg break in the reactor cavity region, the staff considers the results acceptable. Therefore, the staff finds that the CA31 neutron shielding would not generate debris from encapsulated NMI due to a hot-leg break in the reactor cavity.

3.5.1.1.1.5 Cold-Leg Pipe Break

Section 5.1.1.1.5 of the WCAP provides an analysis of a cold-leg pipe break for the AP1000 plant using the Region I and Region II analysis (i.e., alternate evaluation methodology) discussed in Section 3.4 of this SE.

Section 5.1.1.1.5.1 of the WCAP provides the Region I analysis of the cold-leg piping. The resulting spherical ZOI is small enough that the CA31 neutron shielding are outside the ZOI. Therefore, the Region I analysis determined that no debris would be generated from a break in the cold-leg piping in the reactor cavity.

Section 5.1.1.1.5.2 of the WCAP provides the Region II analysis of the cold-leg piping. A pipe break analysis was performed for a break at the cold-leg nozzle to determine the pipe movement and resulting break area. The analysis showed that the resulting pipe break area was greater than the break area used in the Region I analysis. The amount of movement indicated that

The WCAP states that the Region II analysis allows realistic assumptions to be used in the debris generation assessment, such as taking credit for intervening robust structures. The WCAP indicates that staff approved industry guidance (Reference 11) permits truncating a ZOI if there are robust barriers. At the cold-leg nozzle break location, the CA31 neutron shield blocks are located within the CA31 structural floor module. The module separates the refueling cavity and the nozzle gallery. The WCAP states that the CA31 module is a robust structure that would prevent impingement of the CA31 neutron shielding by a LOCA jet. For the Region II analysis, the ZOI was truncated by the CA31 module.

NRC Staff Evaluation

The staff reviewed the debris generation assessment for the cold-leg pipe break in the reactor vessel cavity region discussed above and depicted in WCAP Figures 5-11 through 5-15 (elevation, top, and plan views), in conjunction with the pipe break analysis assessed in Section 3.4.4 of this SE.

Based on pipe break analysis, the application of a [ ] ZOI to the cold leg reveals that the CA31 neutron shield blocks are outside the ZOI sphere or behind robust barriers. Because the WCAP appropriately applied the alternate evaluation methodology and ZOI to assess the debris generation potential of NMI for a cold-leg break in the reactor cavity region, the staff considers the results acceptable. Therefore, the staff finds that the CA31 neutron shielding would not generate debris from a cold-leg break in the reactor cavity.

3.5.1.1.2 Submergence Debris

The principal design feature to prevent chemical effects from the shield blocks and water inlet doors is the seam welding of the stainless steel encapsulation. Since each shield block also has a [

] WCAP Section 5.1.1.2 closes with two similar statements that the seam-welded stainless steel design does not produce debris and, therefore, no additional chemical effects have to be considered with respect to the RVIS. Chemical effects from the [ ] neutron absorber material in the CA31 module and UNS is addressed in WCAP Section 3.5.1.

NRC Staff Evaluation

Based on its review of the jet impingement testing and submergence test results, the staff determined that the

, there is a potential for chemical effects from contact between the shield block internal materials (insulation and shielding) and the post-LOCA fluid. However, by limiting application of the WCAP to plants with the amount of aluminum evaluated in WCAP Section 5.1.4, there is significant margin between the calculated chemical effects and the amount tested for strainer and in-vessel head loss in the AP1000 design.

[

]

According to the chemical effects methodology in WCAP-16530-NP-A, [

] If these materials contain aluminum, it would be possible for additional precipitates if the solution reaches the encapsulated material and aluminum is released and then diffuses outside the block. As suggested in WCAP Section 3.6.2.4, and has not required licensees and applicants to account for precipitates from lead. One reason for this is the conservative assumptions in the WCAP-16530-NP-A methodology, such as the immediate precipitation of all released aluminum, without regard to solubility or the time dependence of precipitation. The staff finds it reasonable to neglect precipitates from lead given the small amount that could reach the post-LOCA fluid.]

The staff finds it acceptable to state that no additional chemical effects have to be considered from the RVIS. This is based mainly on the isolation from the post-LOCA recirculating fluid provided by the seam-welded design as required by the AP1000 DCD.

the LNS, only if internal wrappers are not intact.

The WCAP-16530-NP-A methodology is conservative, and the actual amount of aluminum being used inside AP1000 containments provides substantial margin. The aluminum quantity is discussed in the staff's evaluation of WCAP Section 5.1.4. Chemical effects from the [ ] neutron absorber material in the CA31 module shield blocks are addressed in Section 3.3.5 of this SE.

3.5.1.2 Aging Effects

The neutron shield blocks and RVIS water inlet doors are fabricated from a combination of [ ]. As described in WCAP Section 2.2, not all of these materials are included in the blocks in all locations. Section 5.1.2 of the WCAP describes the potential aging effects for these materials and how the design addresses the aging effects that are expected to be significant. The WCAP considers [

The WCAP identifies

Of these aging effects, the WCAP indicates [

]

As part of audit interactions, the applicant submitted a letter (Reference 27) proposing a new WCAP Section 5.1.2.1. WCAP Section 5.1.2.1 is an assessment of potential aging effects for the [ ] neutron absorber material used in the CA31 shield blocks, including oxidation, gas generation, and swelling. This section also included an assessment of thermal expansion.

(Thermal expansion of the LNS [ ] is addressed in WCAP Section 5.1.3. Potential chemical effects from the [ ] are addressed in SE Section 3.5.1). The staff considers the revisions proposed in the letter to be a **confirmatory item** pending an update to the WCAP.

Based on tests performed [

]

NRC Staff Evaluation

For [ ], the staff finds the WCAP's discussion of aging effects acceptable with respect to qualification of the radiation shield blocks and insulation doors. The blocks are normally dry, so corrosion and stress-corrosion cracking of austenitic stainless steel are not concerns during normal operations. Following a LOCA, corrosion and stress-corrosion cracking of austenitic stainless steel are also not concerns because the pH of the post-LOCA fluid is buffered to neutral and alkaline pH values. Branch Technical Position 6-1 states that the pH of post-LOCA fluid in PWRs should be maintained above 7.0 in order to prevent stress-corrosion cracking of austenitic stainless steel. The resistance to degradation of austenitic stainless steel under normal operating and post-LOCA conditions is a reason that the AP1000 DCD specifies it for the encapsulation of NMI.

Comparing these aging effects to those described in the WCAP, the staff determined that the WCAP accurately identifies the aging mechanisms and effects. The staff concluded that the WCAP correctly identifies [ ] as the only aging effect that the design needs to address from the standpoint of debris generation. The other main effects—[ ]—are not sources of debris generation because the material is contained in the foil and sealed box.

In a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-034 and asked the applicant to indicate [

.

In a response dated July 14, 2016 (Reference 14), the applicant

] and considers RAI-ICC&NMI-034 closed.

In a letter dated August 22, 2016 (Reference 34), the staff issued RAI-ICC&NMI-036 asking the applicant to assess the types and amounts of gases released, the temperature and pressure corresponding to the quantities of gas, and the potential impact of the gases on structures, systems, and components in any part of the containment or containment system. In its response dated November 16, 2016 (Reference 35), the applicant assessed the normal operational impact of the gases on structures, systems, and components by assuming that all the released gas was hydrogen, adjusted for containment conditions, and all the released gas was retained within the containment during one full fuel cycle (i.e., 24 months). Assuming that the containment was not purged during the fuel cycle, the applicant’s analysis indicated that the global containment hydrogen concentration would be 0.092 volume percent at the end of a 24-month fuel cycle; well below the AP1000 containment hydrogen alarm setpoint (3 percent) and hydrogen lower flammability limit (4 percent). Additionally, the applicant discussed that the areas where the shield blocks are located are serviced by ventilation air from the containment ventilation system that provides cooling air and functions to mix the containment building atmosphere, preventing higher local concentrations. The staff finds the applicant's response acceptable with respect to the impacts on structures, systems, and components during normal operations because the applicant conservatively assessed the types of gases (i.e., assumed all gas was hydrogen) and the released quantities (i.e., buildup over a 24-month fuel cycle, with no purging) and showed that there was significant margin to hydrogen flammability limits. In addition, the applicant's ventilation air discussion provided reasonable assurance that localized concentrations of hydrogen were unlikely to form in the reactor cavity and nozzle gallery. Furthermore, the applicant's containment air filtration system is designed to purge the containment at regular intervals during the fuel cycle, which would decrease hydrogen concentration and further contribute to mixing. The applicant also indicated that passive autocatalytic recombiners, installed in containment, would prevent hydrogen concentration from reaching flammability limits. With respect to beyond-design-basis events, the applicant assessed the amount of gas produced by the neutron shield blocks in a typical fuel cycle. The staff finds that the assessment in the RAI response is acceptable because the applicant reviewed the impact of combustible gas on the safety analysis and confirmed the amount of gas produced by the neutron shield blocks is negligible in comparison to the overall amount of hydrogen gas generated via clad oxidation. In the response the applicant also provides a proposed markup to DCD Tier 2, Section 9.5.1.2.1.1, under the "Control of Combustible Materials" subheading (the final changes to the FSAR will be made by the licensee). The staff finds the proposed markup acceptable because the markup describes the off-gassing from the neutron shield blocks in the containment during normal operation. Based on the discussion above and a revision to the WCAP that incorporates the proposed markup, the staff considers RAI-ICC&NMI-036 to be a closed item.

The only other aging mechanism that would be a concern in this application is the higher solubility of Boraflex over time, which is described in EPRI TR-103300. WCAP Section 5.1.2 identifies this phenomenon, but the WCAP does not consider it applicable because the design [ ]. However, WCAP Section 5.1.4 addresses the increased solubility for the hypothetical case of failed encapsulation that allows [ ].

With respect to aging of [ ], the staff reviewed Section 5.1.2.1 submitted in the applicant's September 25, 2017, supplement to the WCAP (Reference 27). Section 5.1.2.1 addresses oxidation, gas generation, and swelling as potential aging effects. The staff evaluated the significance of [ ] as part of chemical effects in Section 3.3.5 of this SE. As described in that section, the staff concluded that the [

WCAP Section 5.1.2.1 on aging includes a discussion of thermal expansion resulting from the difference between plant operating and shutdown conditions. As part of the regulatory audit, the staff confirmed that the applicant evaluated thermal expansion using the full temperature range and conservative thermal expansion coefficient (relative to [ ] supplier data sheets).

Based on its evaluation of proposed WCAP Section 5.1.2.1, the staff agrees with the applicant's conclusion that potential aging effects of the [ ] will not adversely impact its design functions in this application. The staff considers inclusion of proposed Section 5.1.2.1 in the WCAP is a **confirmatory item** pending an update to the WCAP.

The staff finds the information in WCAP Section 5.1.2 acceptable because it accurately identifies the aging mechanisms as they relate to the design of the NMI and doors and the resulting prevention of chemical effects.

3.5.1.3 Thermal Expansion of Lower Neutron Shield Neutron Shielding Material

Section 5.1.3 of the WCAP describes thermal analysis and testing associated with the LNS blocks. Testing conducted at the LNS neutron shielding material temperature limits found [

]

NRC Staff Evaluation

[

] Based on the provided analysis in conjunction with the substantial margin between the maximum expected temperature and the maximum acceptable temperature for the material, staff agrees with the assessment stated in the WCAP that the LNS blocks will not generate debris as a result of thermal conditions during all design basis accident scenarios.

3.5.1.4 Additional Conservatisms

Section 5.1.4 of the WCAP describes circumstances that the applicant considers as contributors to the overall conservatism of the suitable equivalency analysis (e.g., chemical effects assessment, jet impingement testing and submergence testing).

NRC Staff Evaluation

Chemical Effects Assessment

Section 5.1.4 of WCAP-17938 provides insights into how certain factors are sources of conservatism. One such factor is the inventory during construction of aluminum parts in plant components. The staff found from its regulatory audit (Reference 23) that [ ] Maintaining the amount of margin in the calculation depends on the aluminum inventory remaining below the allowable amount, and on the assumptions used for incorporating the submergence test results.

The staff considers the submergence testing useful for providing insights into the potential chemical effects from the proposed RVIS changes. The staff also recognizes that the testing was not designed to directly support calculations of the amount of chemical debris the blocks would produce under prototypical plant conditions. Neither the design of the test specimens nor the ratio of material surface area or volume to liquid volume was prototypical. Studying the sensitivity to limited communication between the block internals and post-LOCA fluid requires assumptions about how much of the material in the blocks would be exposed to the solution and contribute to chemical effects.

The staff determined how the applicant performed these analyses through a regulatory audit in March and April 2016 (Reference 23). The audit included the aluminum inventory and the chemical effects calculations. The audit enabled the staff to understand how the applicant calculated the approximate mass and surface area of aluminum from the inventory. The chemical effects calculation explained how [ ] The staff also followed the calculations from the starting point through the chemical effects spreadsheet in WCAP-16530-NP-A to confirm its understanding of the applicant's analysis. The calculations demonstrate the difficulty of, and judgment required in, specifying the quantity of material to include in the chemical effects sensitivity calculation, but the staff found the approach reasonable for that purpose.

However, without any change to the amount of submerged aluminum allowed in containment, there is no margin for the small amount of chemical effects from unexpected conditions. Although the chemical effects methodology in WCAP-16530-NP-A does not predict additional chemical precipitation from [ ], it does predict additional precipitation from silicon in the presence of aluminum-containing materials, such as the [ ]. Therefore, in a letter dated May 11, 2016 (Reference 13), the staff issued RAI-ICC&NMI-035, asking the applicant to specify a condition on the use of the WCAP that sets a quantitative limit on the amount of aluminum permitted in containment such that adequate margin will be maintained to accommodate the use of the neutron shield blocks. In a response dated July 14, 2016 (Reference 14), the applicant stated that a quantitative limit on aluminum does not need to be a condition for use of the WCAP because the neutron shield blocks will not contribute any chemical debris, and because AP1000 licensees are reducing the aluminum limit through a licensing basis departure.

The staff does not agree with this assertion. The staff finds the WCAP acceptable to use only when the allowable amount of aluminum is limited as described because neither the aluminum inventory nor the licensing basis departures are controlled by the WCAP approval. The current licensing basis allows 60 pounds (27 kg) of aluminum, and conditions leading to a small amount of additional chemical effects cannot be ruled out. For the applicant's aluminum assumption of 40 pounds (18 kg) and 13.3 ft^2 (1.24 m^2), and [ ], the amount of chemical precipitate calculated using WCAP-16530-NP-A is approximately 14 pounds (6.4 kg). As discussed in WCAP Section 5.1.4, [

. These results represent significant margin below the licensing basis of 57 pounds (26 kg), and the staff considers this margin adequate to accommodate the use of the neutron shield blocks. Therefore, the staff's approval of the WCAP is limited to plants that have no more than 13.3 ft^2 (1.24 m^2) of aluminum submerged in containment following a LOCA. The discussion of limitations and conditions in Section 4.0 of this SE addresses this topic. Therefore, the staff considers RAI-ICC&NMI-035 to be a closed item, based on the aluminum limitation and condition discussed in Section 4.0 of this SE.

Jet Impingement Testing

The WCAP discusses that jet impingement testing on the **[**] neutron shield blocks was performed at [ ] on fully exposed blocks and blocks with a replicate reactor cavity cover plate. [

The staff finds that the proximity of the test article to the jet, test configuration, and the overall plant geometry provide useful information that supports the suitable equivalency of the NMI blocks.

Submergence Testing

The WCAP describes submergence test procedures that are interpreted as conservative compared to plant conditions. These relate to pressurization of the test specimens or actual shield blocks and the corresponding potential for exchange between the internal materials and external fluid.

]

3.6 REGULATORY IMPACTS

3.6.1 Licensing Basis Changes

Section 6.1 of the WCAP proposes the following changes to AP1000 DCD/UFSAR Tier 2:

- In DCD/UFSAR Subsection 6.3.2.2.7.1, item 3, this WCAP is added as a reference that demonstrates suitable equivalency for AP1000 reactor vessel neutron shield blocks. The shielding locations that were considered in this report are detailed in Section 2.2 of the WCAP.

- In DCD/UFSAR Subsection 6.3.2.2.7.1, item 12, it is noted that D [diameter] can be determined using DEGB of primary system piping or an alternate debris generation size from the alternate evaluation approach of NEI 04-07 ([WCAP] Reference 6-3). The usage of the alternate evaluation approach used is detailed in Section 4 of this WCAP.

- In DCD/UFSAR Subsection 6.3.2.2.7.1, item 12, this WCAP is added as a reference that supports a 4D ZOI radius for AP1000 plant in-containment cables.

- In DCD/UFSAR subsection 6.3.9, this WCAP and NEI 04-07 are included in the Section 6.3 references subsection.

- In DCD/UFSAR subsection 9.5.1.2.1.1, a statement is added related to off-gassing from neutron shield blocks.

NRC Staff Evaluation

The proposed changes to Tier 2 are consistent with the staff's evaluation of the WCAP and, therefore, are acceptable.

3.7 CONCLUSIONS

Section 7.0 of the WCAP summarizes the tests and analysis that determine (1) a ZOI for AP1000 plant in-containment cabling, (2) suitable equivalency to MRI for AP1000 plant reactor vessel cavity NMI, and (3) use of the alternate evaluation methodology to determine the ZOI radius for Region I and II analyses for an integrated debris assessment.

NRC Staff Evaluation

The staff finds acceptable, subject to the limitations and conditions described in Section 4.0 below, the application of a 4D ZOI radius for AP1000 plant in-containment cables based upon the testing and analysis described in the WCAP. Section 3.3.3.3 of this SE discusses the basis for this conclusion.

The staff finds acceptable, subject to the limitations and conditions described in Section 4.0 below, the determination that NMI located in the reactor vessel cavity of the AP1000 plant is a suitable equivalent under the AP1000 licensing basis for the locations that were bounded by testing and analysis. Section 3.5 and associated subsections of this SE discuss the basis for this conclusion.

The staff finds acceptable, subject to the limitations and conditions described in Section 4.0 below, the application of the alternate evaluation methodology to determine the ZOI radius for Region I and II analyses for an integrated debris assessment. Section 3.4 and associated subsections of this SE discuss the basis for this conclusion.

3.8 APPENDIX A - AP1000 DCD REVISION 19 MARKUPS

Appendix A to the WCAP provides markups to the AP1000 DCD that address the licensing basis changes discussed in Section 3.6.1 of this SE. In addition, in a letter dated March 5, 2018, the applicant provided an additional markup to WCAP Appendix A. This markup clarified that the cable ZOI radius is applicable to the AP1000 in-containment cables bounded by testing and analysis (Reference 36).

NRC Staff Evaluation

The proposed changes to AP1000 DCD Tier 2, Revision 19, Sections 6.3.2.2.7.1, 6.3.9, and 9.5.1.2.1.1 contained in WCAP Appendix A are consistent with the staff's evaluation of the WCAP (Revision 2) and, therefore, are acceptable. The staff also finds that the proposed change to WCAP Appendix A (Reference 36) is acceptable because the change is consistent with a stated purpose of the WCAP (WCAP Section 1) related to the ZOI for cables. The staff considers the proposed change to be a **confirmatory item**, pending an update to the WCAP.

4.0 LIMITATIONS AND CONDITIONS

The staff makes the following limitations and conditions with regard to the WCAP:

- As presented in the WCAP, a 4D ZOI is applicable to all AP1000 plant in-containment cabling bounded by testing and analysis. Because new or evolving cable designs may have a different cable construction that could exhibit a different ZOI, licensees or applicants must evaluate cable design changes to ensure that new designs do not impact adequate long term cooling (Section 3.2 of this SE).

- The performance of cables within the ZOI is outside the scope of the WCAP's request for staff review and approval (see Section 3.1.2 of this SE). Therefore, an AP1000 licensee or applicant that references this WCAP must assess that the cable protection schemes incorporated into the design function to prevent the generation of debris from cables located within the 4D ZOI and that the protection schemes, in and of themselves, do not introduce potential debris sources (see Section 3.3.3.3 of this SE).

- The staff's review of the acceptability of the alternate evaluation methodology (i.e., NEI 04-07) for the AP1000 design excludes the use of nonsafety systems and operator actions (see Sections 3.4.1 and 3.4.3 of this SE).

- The staff's evaluation of NMI was limited to NMI functioning as a suitable equivalent for MRI in the reactor cavity region only from the perspective of debris generation. The staff did not evaluate other impacts on the AP1000 plant due to changes in the reactor cavity associated with the installation of neutron shield blocks. For example, the staff's evaluation did not assess the shielding or insulation performance of the neutron shield blocks. Licensees or applicants are responsible to ensure that the impacts to the AP1000 design of structures, systems, and components resulting from these changes have been fully evaluated. Licensees are responsible to also assess the need for a license amendment request in accordance with the requirements of 10 CFR Part 52, Appendix D, Section VIII.B.5.b (see Section 3.3.3.4 of this SE).

- The staff's approval of the WCAP is limited to plants that have no more than 13.3 ft^2 (1.24 m^2) of submerged aluminum submerged in containment following a LOCA (see Section 3.5.1.4 of this SE).

5.0 CONCLUSION

The staff reviewed the WCAP, which determined that encapsulated NMI in the reactor cavity is a suitable equivalent to MRI. The encapsulated NMI is contained within the RVIS lower neutron shield blocks, water inlet doors, and the refueling cavity floor module (CA31) neutron shield blocks. Additionally, the WCAP establishes an AP1000 plant in-containment electrical cable ZOI based upon the potential for electrical cables to be directly impinged upon by a LOCA jet and become a debris source. Furthermore, the WCAP applies the alternate evaluation methodology (References 10 and 11) to the AP1000 plant to determine debris generation break sizes for potential debris sources. Based on this review, the staff finds that the approach described in the WCAP, qualified by the limitations and conditions stated in Section 4.0 of this SE and by **confirmatory items**, provides an acceptable AP1000 plant-specific evaluation that demonstrates the following:

- Encapsulated NMI contained within the reactor vessel cavity region is a suitable equivalent to MRI.

- The AP1000 plant in-containment electrical cables will not generate debris outside a ZOI defined by a radius of 4D.

- The alternate evaluation methodology for determining debris generation break size is applied appropriately in the WCAP, consistent with NEI 04-07 and the associated SE.

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