Draft for Comment

U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD FOR NuScale SMR DESIGN

6.2.2 CONTAINMENT HEAT REMOVAL SYSTEMS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of containment integrity

Secondary - None

I. AREAS OF REVIEW

NuScale is an integral, pressurized-water, small modular reactor (SMR) with the reactor, steam generator, pressurizer, and control rod drives all located in a single pressure vessel. The NuScale reactor containment is a steel structure that is located below grade level. The Nuclear Steam Supply System (NSSS) is enclosed in a cylindrical containment. The cylindrical steel containment is partially submerged in a common reactor building pool. The common reactor building pool is designed to support twelve units where each NSSS module is located in its own bay. The containment vessel pressure is maintained at a deep vacuum under normal operating conditions.

The review includes the information in the application concerning containment heat removal under post-accident conditions to ensure conformance with the requirements of General Design Criteria (GDC) 5, 38, 39, and 40 of Appendix A to 10 CFR Part 50 and 10 CFR 50.46(b)(5). The ultimate heat sink (UHS) in the NuScale design includes the reactor building pool and the reactor building air space, including heat sinks in the reactor building, to the extent the pool, air space, or another heat sink in the reactor building is credited in the safety analysis to remove heat from the containment atmosphere. The UHS is further described in Standard Review Plan (SRP) 9.2.5 (Ultimate Heat Sink) and DSRS 9.4.2 (Reactor Building HVAC). This DSRS section will collectively refer to the portion of the UHS credited for containment cooling (i.e., the reactor building pool, the reactor building air space, other heat sinks in the reactor building, or some combination of them), as “the UHS.”

The NuScale application will include the classification of systems, structures, and components (SSCs), a list of risk-significant SSCs, and a list of Regulatory Treatment of Non-safety Systems (RTNSS) equipment. Based on this information, the staff will review the design according to Standard Review Plan (SRP) Sections 3.2.1, 3.2.2, 17.4 and 19.3 to confirm the determination of safety-related and risk-significant SSCs.

The specific areas of review are as follows:

1. Analyses of the consequences of single component malfunctions.

2. The potential for surface fouling of the inner and outer walls of the containment vessel and the effect on passive containment heat removal performance.

3. The design provisions and proposed program for periodic inservice inspection and operability testing of each system or component.

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4. The design of the UHS for containment heat removal.

5. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the structures, systems, and components (SSCs) related to this DSRS section in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this DSRS section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

6. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters). For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

Review Interfaces

Other SRP and DSRS sections interface with this section as follows:

1. Review of the sensing instrumentation provided for the containment heat removal systems is performed under Chapter 7 DSRS sections.

2. Review of the seismic qualification test program for the containment heat removal system, such as the UHS structures, liner, welds, restraints, pool syphon breakers, and anchorages, is performed under DSRS Section 3.7.2 and SRP Section 3.9.6.

3. Review of fission product control features is performed under SRP Section 6.5.3.

4. Review of the system seismic design and quality group classification of the containment heat removal systems is performed under SRP Sections 3.2.1 and 3.2.2.

5. Review of the capability of the active, nonsafety-related cooling system that transfers heat delivered to the reactor pool from the containment system to the heat sink (e.g., cooling tower) is performed under DSRS Section 9.1.3..

6. Review of the UHS-reactor building pool functional requirements (e.g., pool volume, level, temperature, filling options, and leakage specifications) is performed under Standard Review Plan (SRP) 9.2.5. Review of the UHS-reactor building air space functional requirements (e.g., air space volume, temperature and capability to passively transfer heat from containment and reactor building pool to the environment) is performed under DSRS Section 9.4.2.

7. Review of the containment vessel evacuation and vacuum retention system is performed under DSRS Section 9.3.6.

8. Review of the emergency core cooling system (ECCS) with the utilization of the reactor vent valves (RVVs) and reactor recirculation valves (RRVs) to allow recirculation from the containment sump is performed under DSRS Section 6.3.

9. Review of the proposed technical specifications for each system at the operating license stage of review is performed under DSRS Section 16.0.

10. Determination of structures, systems and components risk significance is performed under SRP Section19.3.

11. Review of containment performance is performed for design basis accidents (DBAs), including both loss-of-coolant accidents (LOCAs) and main steam line break accidents (MSLBs) in DSRS Section 6.2.1.1.A.

12. Review of postulated pipe break sizes and locations within the reactor coolant pressure boundary is performed under DSRS Section 15.6.5.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

1. General Design Criteria (GDC) 5, Sharing of Structures, Systems, and Components.

2. GDC 38, Containment Heat Removal.

3. GDC 39, Inspection of Containment Heat Removal System.

4. GDC 4, Testing of Containment Heat Removal System 0

5. 10 CFR 50.46(b)(5), as it relates to requirements for long-term cooling, including adequate water level (head) margin above the reactor recirculation valves (RRVs), in the presence of LOCA-generated and latent debris.

DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are set forth below. The DSRS is not a substitute for the NRC's regulations, and compliance with it is not required. As an alternative, and as described in more detail below, an applicant may identify the differences between a DSRS section and the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and discuss how the proposed alternative provides an acceptable method of complying with the NRC regulations that underlie the DSRS acceptance criteria.

1. In meeting the requirements of GDC 5, the analyses for containment heat removal should account for the sharing of structures, systems, and components important to safety, such as the UHS among nuclear power units, and should demonstrate that such sharing will not significantly impair the ability of each unit to perform their containment heat removal safety functions, including, in the event of an accident in one unit, an orderly shutdown and cool down of the other units.

2. The containment heat removal systems should meet the redundancy and power source requirements for an engineered safety feature (i.e., the results of failure modes and effects analyses of each system should ensure that the system is capable of withstanding a single failure without loss of function). This conforms to the requirements of GDC 38.

3. In evaluating the heat removal capability of the containment heat removal system to satisfy GDC 38 and 10 CFR 50.46(b)(5), the analyses of its heat removal capability should account for the potential for surface fouling of the containment vessels exterior by the reactor building pool water over the life of the plant, and containment vessels interior by periodic exposure to reactor building pool water during maintenance activities (e.g., refueling). The effect of surface fouling on the heat removal capacity of the containment vessel should be evaluated. The application should discuss the results of the analysis. The results will be acceptable if they demonstrate that provisions are provided to prevent surface fouling or that surface fouling has been taken into account in the establishment of the heat removal capability of the containment vessel. In addition, the evaluation of the containment heat removal system should include analyses of the capability of the UHS to transfer heat passively from the containment vessel to the outside environment.

   NuScale plans to remove the core decay heat via natural circulation inside the containment and the UHS such that no residual heat removal heat exchanger and fan coolers are used. The analysis should involve natural-circulation based decay heat removal. This would potentially need a test program and simulation models to demonstrate the performance capabilities and transient response of the containment and the UHS under natural circulation conditions. NuScale design specific single-phase and two-phase heat transfer correlations may be needed to analyze natural circulation conditions within the containment and the UHS. Condensation calculations should also account for the effect of non-condensable gases. The impact of any surface coatings or fouling has to be assessed on boiling/condensation heat transfer from the surface.

   When tests are being performed on subscale mockups to develop the computer code model, a scaling analysis should identify important non-dimensional parameters related to geometry and key phenomena. Scaling distortions and their impact on the computer code model should be identified and evaluated in determining the effect of scale on the overall uncertainty of the computer code model.

4. In meeting the requirements of GDCs 39 and 40 regarding inspection and testing, the design of the containment heat removal systems should provide for periodic inspection and operability testing of the systems and system components.

5. To satisfy the requirements of GDC 38 and 10 CFR 50.46(b)(5) regarding long-term cooling, the containment emergency sump(s) should be designed to provide a reliable, long-term water source for ECCS. The containment and reactor vessel design should allow for the drainage of condensed water to the containment emergency sump and for recirculation of this water through the ECCS RRVs. The design of the containment emergency sump is a critical element in ensuring ECCS long-term recirculation cooling capability. Therefore, the design should reflect (1) adequate consideration of containment emergency sump pool hydraulic performance (such as water level (head) above RRV inlet), (2) evaluation of potential debris generation and associated effects (e.g., RRV blockage), and (3) impacts of debris on long-term coolability of the core (e.g.,

fuel blockage). Regulatory Guide 1.82, Revision 4, as modified and supplemented for PWRs by the Nuclear Energy Institute (NEI) Guidance Report (GR) (Ref. 6) and the associated NRC safety evaluation (SE) on the GR (Ref. 7), provide guidance for PWR debris evaluations.

6. To satisfy the system design requirements of GDC 38, instrumentation should be provided to monitor the performance of the containment heat removal system and its components under normal and accident conditions. The instrumentation should determine whether a system is performing its intended function or whether a system train or component is malfunctioning. The containment heat removal system for normal operation is the non-safety-related containment evacuation system, the reactor building pool, the non-safety-related reactor building pool cooling system, and the non-safety related reactor building HVAC; and the systems for accident conditions are the UHS (i.e., the reactor building pool, the reactor building air space, other heat sinks in the reactor building, or some combination of them).

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this DSRS section is discussed in the following paragraphs:

1. GDC 5, as it relates to providing assurance that sharing of SSCs important to safety among nuclear power units will not significantly impair their ability to perform their safety functions.

   GDC 5 applies to this DSRS section because the multiple reactors share systems, structures, and components important to safety. For example, the UHS, which is shared by all reactor modules, must have sufficient inventory and heat sink capacity/capability to serve as the UHS (and spent fuel pool cooling) for all reactor modules during commonly-affecting events.

2. Compliance with GDC 38 requires that systems be provided to remove heat from the reactor containment. The system safety function is to rapidly reduce containment pressure and temperature after any DBA and to maintain these indicators at acceptably low levels.

   Meeting the requirements of GDC 38 regarding the characteristics and designs of containment heat removal systems provides assurance that containment pressure and temperature will be reduced to and maintained at acceptably low levels after any DBA, thereby protecting the safety function of the containment as an engineered safety feature.

3. Compliance with GDC 39 requires that the designs of containment heat removal systems allow for appropriate periodic inspection of important components, such as the UHS, and that the design account for fouling of containment surfaces to ensure the integrity and capability of this system.

   This DSRS section describes staff positions related to the inspection of containment heat removal systems, indicating that provisions should be made for periodic inspection of system components.

Meeting the requirements of GDC 39 with regard to periodic inspection of containment heat removal systems provides assurance that containment pressure and temperature will be reduced to and maintained at acceptably low levels after any DBA, thereby protecting the safety function of the containment as an engineered safety feature.

4. Compliance with GDC 40 requires that the design of containment heat removal systems permits periodic pressure and functional testing to ensure leaktight integrity of components, such as the UHS (e.g., reactor building pool), as well as overall system availability and functionality for passive performance of safety-related functions.

   This DSRS section describes staff positions related to the testing of containment heat removal systems. Provisions should be made for startup and periodic operability testing of these systems and their components such as testing to confirm that the containment vessel's heat transfer performance is consistent with the safety analysis.

   Meeting the requirements of GDC 40 with regard to testing of containment heat removal systems provides assurance that containment pressure and temperature are reduced to and maintained at acceptably low levels after any DBA, thereby protecting the safety function of the containment as an engineered safety feature.

5. 10 CFR 50.46(b)(5) requires that systems be provided to ensure long-term cooling after any initial operation of the ECCS. The containment heat removal system safety function in support of long-term cooling, in addition to heat removal, is to maintain adequate water level margin above the RRVs to support the ECCS function to maintain the core temperature at acceptably low levels after any LOCA.

   This DSRS section describes staff positions and is intended to ensure that systems are provided to maintain adequate core cooling.

   Meeting the requirements of 10 CFR 50.46(b)(5) with regard to long-term cooling provides assurance that core temperature will be maintained at acceptably low levels after any LOCA.

III. REVIEW PROCEDURES

These review procedures are based on the identified DSRS acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

The procedures described below provide guidance for the review of containment heat removal systems. The reviewer selects and emphasizes material from the review procedures as may be appropriate for a particular case.

1. Selected Programs and Guidance - In accordance with the guidance in NUREG-0800, "Introduction - Part 2: Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: Integral Pressurized Water Reactor Edition" (NUREG-0800 Intro Part 2) as applied to this DSRS Section, the staff will review the information proposed by the applicant to evaluate whether it meets the acceptance criteria described in Subsection II of this DSRS. As noted in NUREG-0800 Intro Part 2, the NRC requirements that must be met by an SSC do not change under the SMR framework. Using the graded approach described in NUREG-0800 Intro Part 2, the NRC staff may determine that, for certain structures, systems, and components (SSCs), the applicant's

basis for compliance with other selected NRC requirements may help demonstrate satisfaction of the applicable acceptance criteria for that SSC in lieu of detailed independent analyses. The design-basis capabilities of specific SSCs would be verified where applicable as part of completion of the applicable ITAAC. The use of the selected programs to augment or replace traditional review procedures is described in Figure 1 of NUREG-0800, Introduction - Part 2. Examples of such programs that may be relevant to the graded approach for these SSCs include:

- 10 CFR Part 50, Appendix A, General Design Criteria (GDC), Overall Requirements, Criteria 1 through 5
- 10 CFR Part 50, Appendix B, Quality Assurance (QA) Program
- 10 CFR 50.49, Environmental Qualification of Electrical Equipment (EQ) Program
- 10 CFR 50.55a, Code Design, Inservice Inspection and Inservice Testing (ISI/IST) Programs
- 10 CFR 50.65, Maintenance Rule requirements
- Reliability Assurance Program (RAP)
- 10 CFR 50.36, Technical Specifications
- Availability Controls for SSCs Subject to Regulatory Treatment of Non-Safety Systems (RTNSS)
- Initial Test Program (ITP)
- Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)

This list of examples is not intended to be all-inclusive. It is the responsibility of the technical reviewers to determine whether the information in the application, including the degree to which the applicant seeks to rely on such selected programs and guidance, demonstrates that all acceptance criteria have been met to support the safety finding for a particular SSC.

2. In accordance with 10 CFR 52.47(a)(8),(21), and (22), and 10 CFR 52.79(a)(17), (20) and (37), for design certification or combined license applications submitted under Part 52, the applicant is required to (1) address the proposed technical resolution of unresolved safety issues and medium- and high-priority generic safety issues which are identified in the version of NUREG-0933 current on the date up to 6 months before the docket date of the application and which are technically relevant to the design; (2) demonstrate how the operating experience insights have been incorporated into the plant design; and, (3) provide information necessary to demonstrate compliance with any technically relevant portions of the Three Mile Island requirements set forth in 10 CFR 50.34(f), except paragraphs (f)(1)(xii), (f)(2)(ix), and (f)(3)(v) for a DC application, and except paragraphs (f)(1)(xii), (f)(2)(ix), (f)(2)(xxv), and (f)(3)(v) for a COL application. These cross-cutting review areas should be addressed by the reviewer for each technical subsection and relevant conclusions documented in the corresponding safety evaluation report (SER) section.

3. Upon request from the primary review organization, the review organizations with review interface responsibilities, as noted in Subsection I, will provide input for the areas of review, as stated in Subsection I of this DSRS section. The input obtained will ensure that the review is complete. The primary review organization ensures that the design and functional capability of the containment heat removal system conforms to the requirements of 10 CFR 50.46(b)(5) and GDC 5, 38, 39, and 40.

4. The acceptability of the containment heat removal system design is determined by reviewing the system to ensure the following:

   A. All potential single failures have been identified in accordance with GDC 38, and no single failure could incapacitate the entire system.

   B. Engineered safety feature design standards have been applied.

   C. The system design provisions for periodic inservice inspection and functionality or operability testing ensure that the system and components are accessible for inspection and all active components can be tested.

   D. The capability exists to monitor system performance from the control room.

5. The primary review organization evaluates the containment water height in relation to the RRVs and ensures that the applicant's analyses for the containment recirculation phase are done in accordance with the guidelines of Regulatory Guide 1.82, Revision 4 to include whether the containment interior allows drainage of condensate to the sump.

6. The primary review organization evaluates the post-LOCA time-dependent containment temperature and pressures analysis to ensure it accounts for: (a) in-containment recirculation from the containment sump through the RRVs into the reactor vessel; (b) the condensation of reactor coolant released through the RVVs onto the containment vessel walls; (c) the heat transfer through the containment vessel walls into the UHS.

7. The primary review organization reviews the potential for debris formation in the containment vessel during a LOCA and the potential for blockage of RRVs. Regulatory Guide 1.82 Revision 4 provides guidelines for the acceptability of the design of debris screens, if they are necessary. The applicant's analyses of core cooling in the presence of predicted debris loading are also reviewed.

8. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

   For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable), as augmented by the application of programmatic requirements in accordance with the staff's technical review approach in the DSRS Introduction, support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

1. Containment Heat Removal Systems

The scope of review of the containment heat removal systems for the NuScale design included system drawings and descriptive information. The review included the applicant's proposed design bases for the containment heat removal systems and analyses of the functional capability of the systems. The review included the design of the UHS for containment heat removal.

The staff concludes that the design of the containment heat removal system is acceptable and meets the requirements of 10 CFR 50.46(b)(5) and GDC 5, 38, 39, and 40.

The conclusion is based on the following:

A. The staff review documented above indicates that the applicant complied with GDC 5 by demonstrating that the shared UHS will not significantly impair the containment heat removal safety function, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

B. The staff review documented above indicates that the applicant complied with GDC 38 by providing containment heat removal systems consisting of (list systems). The applicant designed the containment heat removal systems according to the guidance provided in Regulatory Guide 1.82, Revision 4, as well as the additional guidance in (list appropriate). The staff review indicates that the systems will be capable of performing their intended safety function, which is to rapidly reduce containment pressure and temperature and to maintain these indicators at acceptably low levels after any DBA. Suitable redundancy in components and features and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished in the event of a single failure.

C. The staff's review indicates that the applicant complied with GDC 39 by designing the containment heat removal systems to permit appropriate periodic inspection of risk-significant components of the system such as the containment sump and the UHS.

D. The staff's review indicates that the applicant complied with GDC 40 by designing the containment heat removal system to permit appropriate periodic pressure and functional testing to ensure the structural and leaktight integrity of their components; the operability and performance of the active components of the systems such as the UHS. Testing will be conducted to ensure the performance of the full operational sequence that brings the systems into operation under conditions as close to design as practical, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of associated systems.

E. The staff's review indicates that the applicant has demonstrated adequate long-term core cooling in accordance with 10 CFR 50.46(b)(5) in the presence of post-LOCA debris, as appropriate.

For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this DSRS section.

V. IMPLEMENTATION

The regulations in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), and 10 CFR 52.79(a)(41) establish requirements for applications for ESPs, DCs, and COLs, respectively. These regulations require the application to include an evaluation of the site (ESP), standard plant design (DC), or facility (COL) against the Standard Review Plan (SRP) revision in effect six months before the docket date of the application. While the SRP provides generic guidance, the staff developed the SRP guidance based on the staff's experience in reviewing applications for construction permits and operating licenses for large light-water nuclear power reactors. The proposed small modular reactor (SMR) designs, however, differ significantly from large light-water nuclear reactor power plant designs.

In view of the differences between the designs of SMRs and the designs of large light-water power reactors, the Commission issued SRM- COMGBJ-10-0004/COMGEA-10-0001, "Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," dated August 31, 2010 (ML102510405) (SRM). In the SRM, the Commission directed the staff to develop risk-informed licensing review plans for each of the SMR design reviews, including plans for the associated pre-application activities. Accordingly, the staff has developed the content of the DSRS as an alternative method for the evaluation of a NuScale-specific application submitted pursuant to 10 CFR Part 52, and the staff has determined that each application may address the DSRS in lieu of addressing the SRP, with specified exceptions. These exceptions include particular review areas in which the DSRS directs reviewers to consult the SRP and others in which the SRP is used for the review. If an applicant chooses to address the DSRS, the application should identify and describe all differences between the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and the guidance of the applicable DSRS section (or SRP section as specified in the DSRS), and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria.

The staff has accepted the content of the DSRS as an alternative method for evaluating whether an application complies with NRC regulations for NuScale SMR applications, provided that the application does not deviate significantly from the design and siting assumptions made by the NRC staff while preparing the DSRS. If the design or siting assumptions in a NuScale application deviate significantly from the design and siting assumptions the staff used in preparing the DSRS, the staff will use the more general guidance in the SRP as specified in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), or 10 CFR 52.79(a)(41), depending on the type of application. Alternatively, the staff may supplement the DSRS section by adding appropriate criteria in order to address new design or siting assumptions.

VI. REFERENCES

1. Regulatory Guide 1.68, "Initial Test Programs for Water-Cooled Nuclear Power Plants."

2. Regulatory Guide 1.82, Rev. 4, "Water Sources for Long Term Recirculation Cooling Following a Loss of Coolant Accident," March 2012.

3. Regulatory Guide 1.160, "Monitoring the Effectiveness of Maintenance."

4. Regulatory Guide 1.206. "Combined License Applications for Nuclear Power Plants (LWR Edition)."

5. Regulatory Guide 1.215, "Guidance for ITAAC Closure Under 10 CFR Part 52"

6. Guidance Report by the Nuclear Energy Institute, Pressurized Water Reactor Sump Performance Evaluation Methodology, including Appendices A and B, NEI 04-07, May 28, 2004.

7. NRC Safety Evaluation of NEI GR, Pressurized Water Reactor Containment Sump Evaluation Methodology, December 6, 2004.