Proposed Resolution Plans for Tier 3 Recommendations 5.2 and 6

Reliable Hardened Vents for Other Containment Designs and Hydrogen Control and Mitigation Inside Containment and Other Buildings

Background

As described in SECY-11-0093, "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan," dated December 23 2011 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML11186A950), the U.S. Nuclear Regulatory Commission's (NRC's) Near-Term Task Force (NTTF) identified Recommendation 5.2, which recommended that the NRC assess the need to require the installation of reliable, hardened venting systems for containments with designs other than Mark I and II (which are addressed as part of Recommendation 5.1). The NTTF also recommended that the staff assess the need to further strengthen requirements associated with hydrogen control and mitigation inside and outside reactor containment buildings as part of NTTF Recommendation 6. In SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned," dated October 3, 2011 (ADAMS Accession No. ML11272A111), the staff prioritized these as Tier 3 activities because they required further staff study and the insights from implementation of Recommendation 5.1 and related international activities to support a regulatory decision.

In SECY-11-0137, the NRC staff described its proposals for immediate regulatory actions and longer-term evaluations to address the NTTF recommendations. Among the highest-priority Tier 1 actions that the NRC staff proposed was the issuance of orders to address Recommendation 5.1, requiring reliable hardened containment vents for those licensees of boiling water reactors (BWRs) with Mark I and II containment designs. Venting Mark I and II containments can help prevent the loss of, and facilitate recovery of, important safety functions, such as reactor core cooling, reactor coolant inventory control, containment cooling, and containment pressure control. The NRC issued Order EA-12-050 on March 12, 2012 (ADAMS Accession No. ML12054A694), requiring reliable, hardened vents for these plants. The NRC subsequently revised these requirements by Order EA-13-109, dated June 6, 2013 (ADAMS Accession No. ML13130A067), to make the venting systems for Mark I and II containments capable of operation during severe accident conditions.

The NRC staff has been actively participating in various international studies, including a working group studying hydrogen generation, transport, and risk management organized by the Organization for Economic Cooperation and Development (OECD)/Nuclear Energy Agency (NEA). The NRC staff has also gathered insights from other Fukushima-related activities, as well as probabilistic risk studies, previous evaluations of generic issues, operating experience, and other available information. These insights are being used to help assess whether the results of additional studies of containment performance and the control of hydrogen following potential severe reactor accidents would justify regulatory actions beyond those already taken for plants with Mark I and II containments.

Containment performance and the control of hydrogen have been the focus of a number of previous NRC studies and evaluations. In addition to the recent evaluations related specifically to Mark I and II containments, the NRC completed detailed assessments as part of the Containment Performance Improvement Program (CPIP) in the 1980s, resolved generic safety issues, and established requirements such as Section 50.44, "Combustible Gas Control for Nuclear Power Plants," in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." Containment performance and hydrogen-related issues have also been addressed in major studies, such as those documented in NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," issued December 1990, and NUREG-1935, "State-of-the-Art Reactor Consequence Analyses (SOARCA) Report," issued November 2012.

The NRC staff described the CPIP effort in SECY-88-147, "Integration Plan for Closure of Severe Accident Issues," dated May 25, 1988. This effort evaluated generic severe accident challenges for each light water reactor (LWR) containment type to determine whether additional regulatory guidance or requirements concerning containment features were warranted. Therefore, the CPIP is especially relevant to this evaluation. The CPIP was initiated to address uncertainties in the ability of LWR containments to successfully survive some severe accident challenges, as indicated by the results documented in NUREG-1150. All LWR containment types were assessed in the CPIP, but as in more recent evaluations, many of the activities were focused on Mark I and II containment designs. The CPIP identified potential improvements for Mark I and II designs that were provided to licensees for consideration in performing individual plant examinations and resulted in plant changes for Mark I plants as described in Generic Letter 89-16, "Installation of Hardened Wetwell Vent." Some of these features were further enhanced through the Tier 1 activities associated with Orders EA-12-049, "Mitigating Strategies for Beyond Design Basis External Events," dated March 12, 2012 (ADAMS Accession No. ML12054A735), and Order EA-13-109. As described in NUREG-0933, "Resolution of Generic Safety Issues," published December 2011, the NRC staff did not identify generic improvements that would apply to Mark III, ice condenser, or large dry containments. Rather, the staff requested that licensees with plants with these containment designs consider insights from the CPIP within the individual plant evaluations.

The NRC has also addressed containment performance issues and the role of the containment in limiting the consequences of severe accidents in research programs, resolving generic safety issues, and evaluating regulatory actions that were ultimately not pursued because the possible action was found to provide only minimal safety benefits. Many of the NRC-sponsored research projects related to containment performance are described in NUREG/CR-6906, "Containment Integrity Research at Sandia National Laboratories," published in July 2006. NUREG-0933 describes the NRC's assessment and closure of various containment-related issues, including the activities within the CPIP. The NRC and licensees have also addressed containment performance issues through the development and revision of regulatory requirements within plant technical specifications and in the development of regulations such as 10 CFR 50.44. The NRC staff evaluated various issues and potential improvements to containment performance as part of internal initiatives (e.g., SOARCA) and in response to petitions for enforcement action or rulemaking. These activities have collectively added to the body of knowledge related to containment performance and the control of hydrogen following severe reactor accidents. The activities undertaken in response to the Fukushima accident provide additional insights and have resulted in regulatory actions, such as issuance of Orders EA-12-049 and EA-13-109, which further enhance safety.

Current Status

The staff has performed a preliminary analysis to determine if regulatory action associated with Recommendations 5.2 and 6 is warranted. The initial conclusion of this analysis is that further regulatory action or study beyond those completed for Mark I and II containments is not warranted. Details of this analysis are provided in this enclosure, along with the staff's plans to obtain stakeholder input, finalize its analysis, and complete its evaluation of these recommendations. In the absence of new information from external stakeholders, the staff expects these additional activities will support and provide further justification for its initial conclusion.

<u>BWR Mark I and II Containments</u>

In the March 19, 2013, staff requirements memorandum (SRM) (ADAMS Accession No. ML13078A017) to SECY-12-0157, "Consideration of Additional Requirements for Containment Venting Systems for Boiling-Water Reactors with Mark I and Mark II Containments," dated November 26, 2012, the Commission directed the NRC staff to: (1) issue a modification to Order EA-12-050 requiring BWR licensees with Mark I and II containments to upgrade or replace the reliable hardened vents required by Order EA-12-050 with a containment venting system designed and installed to remain functional during severe accident conditions, and (2) develop a technical basis and rulemaking for filtering strategies with drywell filtration and severe accident management for BWR Mark I and II containments. The staff subsequently issued Order EA-13-109[1], which rescinded the requirements imposed by Order EA-12-050 and replaced them with the following requirements for licensees of BWRs with Mark I and II containments:

- Phase 1: Upgrade the venting capabilities from the containment wetwell to provide reliable, severe accident capable hardened vents to assist in preventing core damage and, if necessary, to provide venting capability under severe accident conditions.

- Phase 2: Install a reliable, severe-accident-capable drywell vent, or develop a reliable containment venting strategy that makes it unlikely the site would need to vent from the containment drywell during a severe accident.

The NRC's interim staff guidance (ISG) for Phase 1 of the order was issued in November 2013, which endorsed the guidance developed by the Nuclear Energy Institute (NEI) and an industry working group, NEI 13-02, Revision 0 (ADAMS Accession No. ML13316A853). The NRC issued the ISG for Phase 2 requirements in April 2015. This ISG endorsed the updated industry guidance document, NEI 13-02, Revision 1 (ADAMS Accession No. ML15113B318). As required by Order EA-13-109, licensees with Mark I and II containments submitted their overall integrated plans (OIPs) for Phase 1 by June 30, 2014. The staff has completed its review of

[1] Order EA-13-109 states that the requirement to provide a reliable hardened containment vent system (HCVS) to prevent or limit core damage upon loss of heat removal capability is necessary to ensure reasonable assurance of adequate protection of public health and safety, while the requirement that the reliable HCVS remain functional during severe accident conditions is a cost-justified substantial safety improvement under 10 CFR 50.109(a)(3).

Phase 1 plans and has issued interim staff evaluations. Licensees are required to submit OIPs for Phase 2 of EA-13-109 by December 31, 2015.

Containment Protection and Release Reduction (CPRR) Rulemaking

As directed by the SRM for SECY-12-0157, the staff assessed possible additional requirements for containment pressure control and venting, to include measures to enhance the capability to maintain containment integrity and to cool core debris. These evaluations formed the draft regulatory basis prepared for the CPRR rulemaking. The main objective of the CPRR regulatory basis was to determine what, if any, additional requirements are warranted related to filtering strategies and severe accident management of BWRs with Mark I and II containments assuming the installation of severe-accident-capable hardened vents per Order EA-13-109. The staff interacted with external stakeholders and identified four major alternatives for possible courses of action related to filtering strategies and severe accident management for BWRs with Mark I and II containment designs. The CPRR alternatives were the following:

- Alternative 1 (the status quo): Take no additional action (Order EA-13-109 implemented without rulemaking).

- Alternative 2: Pursue rulemaking to make Order EA-13-109 generically applicable for protection of BWR Mark I and II containments against over-pressurization.

- Alternative 3: Pursue rulemaking to address overall BWR Mark I and II containment protection against multiple failure modes by making Order EA-13-109 generically applicable and requiring external water addition points that would allow for water addition into the reactor pressure vessel or drywell.

- Alternative 4: Pursue rulemaking to address both containment protection against multiple failure modes and release reduction measures for controlling releases through the containment venting systems. This alternative would include making Order EA-13-109 generically applicable, requiring external water addition into the reactor pressure vessel or drywell, and requiring that licensees implement a strategy for managing the wetwell and drywell vents to limit releases of fission products and/or the addition of an engineered filter.

The draft regulatory basis document was provided to the Commission in SECY-15-0085, "Evaluation of the Containment Protection and Release Reduction for Mark I and Mark II Boiling Water Reactors Rulemaking Activities," dated June 25, 2015 (ADAMS Accession No. ML15022A218). In the SRM to SECY-15-0085, dated August 19, 2015 (ADAMS Accession No. ML15231A471), the Commission directed the staff to take no further action beyond those associated with implementation of Order EA-13-109 (Alternative 1). The addition of engineered filters would not provide a substantial additional safety benefit and the safety benefits of severe accident water addition are being provided by licensees for compliance with the Order. In addition, the SRM directed the staff to leverage the draft regulatory basis to the extent applicable to support resolution of the post-Fukushima Tier 3 item related to containments of other designs (i.e., Recommendation 5.2).

International Activities

The NRC staff has participated in various international meetings and working groups related to reactor containment performance and has used insights from these activities to identify and evaluate technical and regulatory issues. For example, in “Staff Requirements – Briefing of the Status of Lessons Learned from the Fukushima Dai-ichi Accident,” dated August 24, 2012 (ADAMS Accession No. ML122400033), the Commission directed the staff to compare practices for hydrogen control for plants in other countries with those of U.S. plants. The staff from the NRC Office of Nuclear Regulatory Research participated as members of an OEDC/NEA working group conducting a study of hydrogen generation, transport, and risk management. The working group issued a report entitled, “Status Report on Hydrogen Management and Related Computer Codes,” in June 2014. The report describes various containment designs, national requirements, and actions addressing lessons learned from the Fukushima accident. Measures to control hydrogen during severe accidents, including the use of passive autocatalytic recombiners, have been taken or are being pursued for many foreign plants. Currently, some countries are assessing the need for hydrogen mitigation measures outside containment, but no specific requirements have been imposed in most countries for such measures. The OECD/NEA report provides a comparison of various designs and practices for plants in the United States and other countries.

Discussion

The staff has used the insights from the technical evaluations discussed above in developing its initial assessment of Recommendations 5.2 and 6. The staff has also considered previous Commission decisions on post-Fukushima matters, regulatory analysis, and longstanding policies related to safety goals and treatment of severe accidents for operating reactors. These decisions are provided in SRMs related to a number of papers, such as the following:

- SECY-12-0110, “Consideration of Economic Consequences within the U.S. Nuclear Regulatory Commission’s Regulatory Framework,” dated August 21, 2012 (ADAMS Accession No. ML12173A478)

- SECY-12-0157, “Consideration of Additional Requirements for Containment Venting Systems for Boiling Water Reactors with Mark I and Mark II Containments,” dated November 26, 2012

- COMSECY-13-0030, “Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel,” dated November 25, 2013 (ADAMS Accession No. ML13329A918)

- SECY-15-0065, “Mitigation of Beyond-Design-Basis Events,” dated May 15, 2015 (ADAMS Accession No. ML15049A201)

- SECY-15-0085, “Evaluation of the Containment Protection and Release Reduction for Mark I and Mark II Boiling Water Reactors Rulemaking Activities,” dated June 18, 2015 (ADAMS Accession No. ML15022A218)

These decisions provide continuity between current assessments and previous evaluations of containment-related safety issues and maintain the relevance of previous regulatory and backfit analyses and the associated decisions.

Table 1 provides a summary of key functional areas related to these two recommendations and how they have been addressed for each containment type, with a more detailed assessment for each containment type provided below.

Table 1. Recommendation 5.2 and 6 – Other Containment Designs and Hydrogen Control Requirements and Practices

	Core Cooling Functions	Venting/Heat Removal for Containment Pressure Control		Other Containment Failure Modes/Core Debris Cooling	Release Reduction (Filtering)	Hydrogen Control	
		Pre-Core Damage	Severe Accident			Containment	Other
Mark I	EA-12-049 EA-13-109	EA-13-109 EA-12-049 EOPs, FSGs	EA-13-109 SAMGs	EA-13-109 (CPRR)	N/A (CPRR)	10 CFR 50.44 EA-13-109 SAMGs	EA-13-109 SAMGs
Mark II	EA-12-049 EA-13-109	EA-13-109 EA-12-049 EOPs, FSGs	EA-13-109 SAMGs	EA-13-109 (CPRR)	N/A (CPRR)	10 CFR 50.44 EA-13-109 SAMGs	EA-13-109 SAMGs
Mark III	EA-12-049	EA-12-049 EOPs, FSGs	SAMGs	SAMGs	N/A (current assessment)	10 CFR 50.44 GSI-189 EA-12-049 SAMGs, FSGs	GSI-189 EA-12-049 SAMGs, FSGs
Ice Condenser	n/a	EOPs	SAMGs	SAMGs	N/A (current assessment)	10 CFR 50.44 GSI-189 EA-12-049 SAMGs, FSGs	GSI-189 EA-12-049 SAMGs, FSGs
Large Dry	n/a	EOPs	SAMGs	SAMGs	N/A (current assessment)	10 CFR 50.44 SAMGs	N/A (current assessment)

EA-12-049: Mitigation Strategies Order
EA-13-109: BWR Mark I/II Severe accident capable vent order
EOPs: Emergency Operating Procedures
FSGs: FLEX (Mitigating Strategies) Support Guidelines
SAMGs: Severe accident management guidelines
GSI-189: Generic Safety Issue re: Hydrogen Issues

Shaded area indicates scope of Order EA-13-109 and draft regulatory basis document for CPRR rulemaking
10 CFR 50.44 defines generic and containment-specific features and analyses related to combustible gas control

BWR Mark I and II

Containment Performance

As part of implementing Order EA-13-109 requirements, licensees are planning to install a wetwell venting system that remains functional under severe accident conditions, and an approach involving severe accident water addition (SAWA). Licensees are expected to implement a severe accident water management (SAWM) strategy to control the water levels in the suppression pool, such that it is unlikely a licensee would need to vent from the containment drywell during severe accident conditions. The NRC staff and industry evaluations have shown that the SAWA/SAWM strategies not only support the planned approach for compliance with Order EA-13-109, but could also prevent containment failure from mechanisms other than over-pressurization. As part of developing the CPRR regulatory basis, the staff analyzed numerous alternatives in relation to the NRC's quantitative health objectives (QHOs) described in the Safety Goal Policy Statement. As shown in Figure 1, taken from the CPRR draft regulatory basis document, significant margins are calculated between existing plant risks from an extended loss of electrical power and the NRC's safety goals; therefore, changes to Mark I and II containments beyond those required by Order EA-13-109 would not constitute substantial safety improvements.

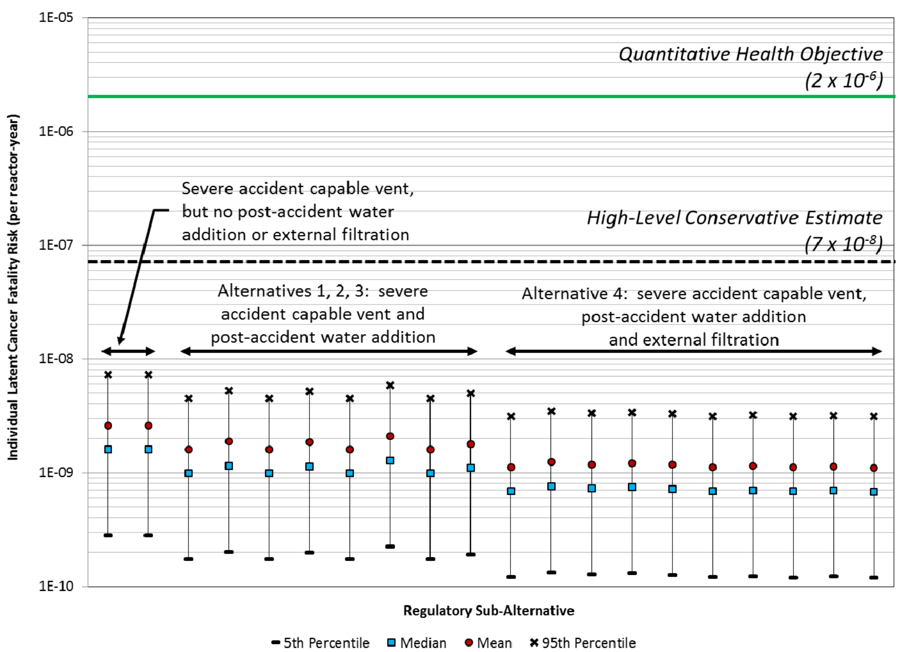

Figure 1

The Commission's SRM related to SECY-15-0085 directed the staff to discontinue further CPRR-related rulemaking activities. The actions taken under Order EA-13-109 and decisions made on SECY-15-0085 have resolved the shaded areas in Table 1 for Mark I and Mark II containments.

<u>Hydrogen Control</u>

The issue of hydrogen control in Mark I and II primary containments was considered in the technical analyses supporting the severe accident functions of Order EA-13-109 and the consideration of additional containment performance issues as part of the CPRR regulatory basis document. Mark I and II containments are inerted during normal operations to address the requirements of 10 CFR 50.44. The Fukushima accident also highlighted the possible migration of hydrogen to buildings outside the primary containment and the need to evaluate possible features or procedures to prevent explosions in the reactor building or other structures.

The NRC staff performed detailed evaluations of possible severe accident conditions, including the generation of hydrogen and other combustible gases within Mark I and II containments, as part of the work supporting Order EA-13-109 and the CPRR draft regulatory basis document. Similar studies performed by the industry are documented in the Electric Power Research Institute report, “Technical Basis for Severe Accident Mitigating Strategies, Volume 1,” issued April 2015. In the CPRR draft regulatory basis document, the staff described the benefits of improved venting operations for the control of hydrogen in the primary containment and other buildings as follows:

> The behavior of hydrogen in the containment is shown in Figure 4-19 [Figure 2 below], “Mark I Hydrogen Generation and Transport for Case 9 (SAWA).” The blue line represents the total hydrogen generation which should be almost identical with the amount remaining inside the containment and the amount that is vented (represented by the green line). The amount of hydrogen that remains inside the containment (both the drywell and the wetwell air space as shown by the red line) quickly decreases as a result of venting. With the wetwell vent open during the transient, the total amount of hydrogen is kept very low in the long term (below 30 kg). Therefore, containment venting is very efficient in purging the hydrogen from the containment. The presence of water seems to avoid containment failure and any uncontrolled release of hydrogen to the reactor building which remains intact for the duration of the accident.

Figure 4-19: Mark I Hydrogen Generation and Transport for Case 9 (SAWA)

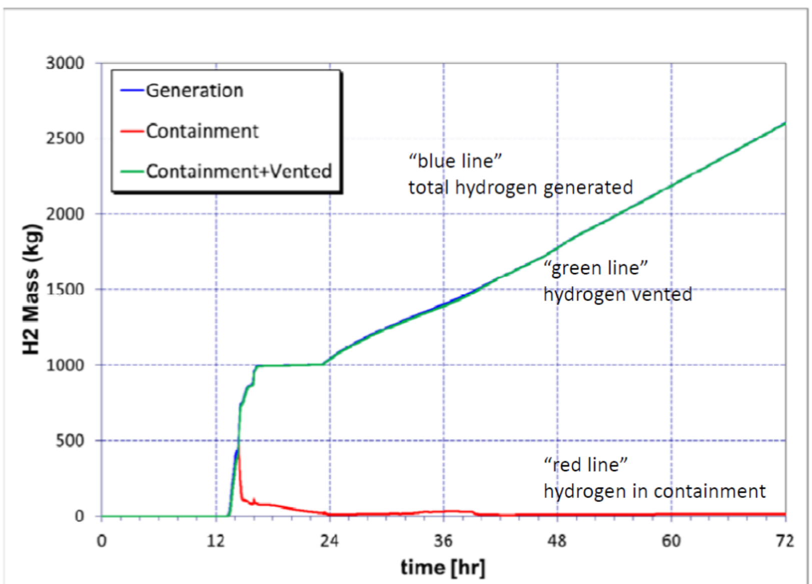

Figure 2

The technical analyses for Order EA-13-109 and the CPRR draft regulatory basis show that the threat of explosions from combustible gases is significantly reduced by effective venting strategies and the SAWA/SAWM approaches being taken as part of implementing the Order. Severe accident management guidelines (SAMGs), which are maintained by licensees and are being updated after the Fukushima accident, also include specific measures to monitor and vent Mark I and II containments to address hydrogen issues. The enhancements provide some further risk reductions by improving the control of hydrogen in Mark I and II containments, even though more specific regulatory actions would likely not be justified given the large margins between plant risks and the NRC's safety goals (as shown in Figure 1). The improvements to capabilities and guidelines for venting the containment ensures that the hydrogen is discharged to the environment and prevents the migration of hydrogen to the reactor building, as occurred at Fukushima Dai-ichi. Further evaluations to identify other possible improvements for hydrogen control in primary containments or other buildings are unlikely to justify the imposition of additional regulatory requirements. As such, the staff's initial assessment is that Recommendation 6 can be closed for Mark I and II containments.

BWR Mark III

Containment Performance

There are four operating BWRs with Mark III containments located at four sites in the United States. The Mark III containment is approximately five times the volume of the Mark I containment and 65 to 85 percent of the volume of a large dry pressurized water reactor (PWR) containment. The containment design pressure of a Mark III containment is 15 pounds per square inch gauge (psig) (25 percent of a Mark I and 30 percent of a large dry containment). Unlike Mark I and II containments, the Mark III containment is not inerted, but instead has igniters for hydrogen control. The NRC evaluated a Mark III containment (Grand Gulf) as part of the activities associated with NUREG-1150. Supporting evaluations of containment issues for Mark III containments are described in NUREG/CR-5529, "An Assessment of BWR Mark III Containment Challenges, Failure Modes, and Potential Improvements in Performance," published in January 1991. The modern BWR design incorporating the Mark III containment includes a diversity of ways to provide water to the core, and therefore, reactors with this type of containment have a relatively low estimated core damage frequency related to plant transients and malfunctions (on the order of 10^{-6}/year). The pre-Fukushima evaluations of core damage and containment performance for licensed Mark III plants did not identify generic improvements that warranted regulatory actions (see NUREG-0933).

Mark III containments are pressure suppression containments and have system interactions between the core cooling and containment functions, similar to plants with Mark I and II containments. These interactions are especially important during an extended loss of electrical power when cooling systems used for design-basis accidents are not available. Order EA-12-049 requires all operating plants to develop mitigating strategies for events involving extended losses of electrical power and loss of normal access to the plant's ultimate heat sink. The mitigating strategies include three phases: (1) an initial phase which must be survived with installed equipment such as steam-driven pumps; (2) a transition phase which uses portable, onsite equipment; and (3) a final phase which may credit offsite resources.

Suppression pool cooling is an important safety function within the mitigating strategies for the plants with Mark III containments. Venting is not a primary method for suppression pool cooling for three of the Mark III plants, while one does include venting from the suppression pool as part of its mitigating strategies. Instead, licensees for plants with Mark III containments have included in their mitigating strategies additional capabilities to power suppression pool cooling equipment (i.e., through the use of portable power supplies). The NRC staff has reviewed these approaches and issued interim staff evaluations documenting that the licensees for Mark III plants have developed an acceptable approach for addressing core cooling functions and containment pressure control, including the need to remove heat from the suppression pool.

These requirements address the functions deemed necessary to provide reasonable assurance of adequate protection of public health and safety in Order EA-13-109 issued to plants with Mark I and II containments. The estimated low frequency for extended losses of electrical power makes it unlikely that further evaluations of means to cool or vent suppression pools in Mark III containments beyond those required under Order EA-12-049 would identify a cost-justified substantial safety improvement.

The activities supporting implementation of Order EA-13-109 for Mark I and II containments highlighted the need to take a holistic approach to considering improvements to containment performance during potential severe accidents. An important insight from the CPRR activities is that potential safety benefits from improvements to address some failure mechanisms or reduce releases by adding engineered filters can be limited by other potential failure mechanisms and accident sequences. For example, the benefits from engineered filters are limited by factors such as the possible failure of equipment leading to releases that would not be scrubbed effectively by the filters. Similar relationships and limitations would likely apply to Mark III reactor designs and thereby limit the potential effectiveness of specific items related to improving containment performance during severe accidents. NUREG/CR-5529 described evaluations of potential severe accident improvements for Mark III containments and informed the NRC's decision that no regulatory actions were warranted, except additional consideration for improving the control of hydrogen (see next section). The closure of the CPIP for Mark III containments and subsequent assessments reflect that the low frequency of severe accidents and expected protective actions ensure significant margins between the risks to public health associated with plant operations and the NRC's safety goals. Insights from the Fukushima accident do not undermine the findings from these previous evaluations and actions taken following the event (e.g., implementation of mitigating strategies) provide additional margins between estimated plant risks and the QHOs.

In summary, the NRC staff concludes that additional detailed study of possible improvements to the performance of Mark III containments during the mitigation of events or during severe accident conditions would be unlikely to identify regulatory actions that would provide a substantial safety improvement. Therefore, the staff's initial assessment is that Recommendation 5.2 can be closed for Mark III containments with no additional requirements beyond those imposed by Order EA-12-049. In the absence of new information from external stakeholders, the staff expects that plans for additional evaluations of severe accident scenarios and associated risks relative to the QHOs will support and provide further justification for the initial conclusion.

Hydrogen Control

NUREG-1150 and other studies identified hydrogen issues as a potential concern for Mark III containments. The evaluations documented in NUREG/CR-6427, "Assessment of the DCH [direct containment heating] Issue for Plants with Ice Condenser Containments," issued April 2000, led to GSI-189, "Susceptibility of Ice Condenser and Mark III Containments to Early Failure from Hydrogen Combustion during a Severe Accident," updated February 4, 2009, and assessments of potential safety enhancements related to the reliability of igniter systems. To deal with large quantities of hydrogen, ice condenser and Mark III containments are equipped with alternating current (ac) powered igniters, which are intended to control hydrogen concentrations in the containment atmosphere by initiating limited "burns" of hydrogen. In essence, the igniters prevent the hydrogen (or any other combustible gas) from accumulating in large quantities and then suddenly burning (or detonating) all at once, which could pose a threat to containment integrity. For most accident sequences, the hydrogen igniters can address the potential threat from combustible gas buildup. The situation of interest for GSI-189 related primarily to accident sequences associated with station blackouts, where the igniter systems are not available because they are ac-powered. Thus, the concern does not affect the frequency of severe accidents, but does affect the likelihood of a significant release of radioactive material to the environment should such an accident occur.

Because this issue was not incorporated into the original scope of security-related modifications implemented following the September 11, 2001, terrorist attacks, the staff held meetings with licensees to further explore the proper consideration of security insights in providing backup power to the igniter systems. The staff reviewed industry proposals and concluded that the proposed modifications would resolve GSI-189 and provide benefit for some security scenarios. On April 23, 2007, the NRC's Executive Director for Operations issued a memorandum informing the Commission of the staff's intent to accept the commitments associated with providing backup power to hydrogen igniters and perform verification inspections at the affected sites. On June 15, 2007, the NRC staff issued letters to affected licensees accepting these commitments. The regulatory commitments related to backup power to the igniter systems received additional attention during the development of guidance for Order EA-12-049. The guidance documents for compliance with Order EA-12-049 identify the backup power supplies to the igniter systems for ice condenser and Mark III containments to be part of the containment protection features within the scope of the Order. By improving the reliability of igniter systems during station blackout scenarios, the actions taken provide confidence that combustible gases will not cause a loss of primary containment integrity and reduce the chances that they will migrate to other structures, as occurred during the Fukushima accident.

Based on the assessments discussed above, the staff's initial evaluation concludes that the additional study of possible improvements to hydrogen control for Mark III containments or other buildings is unlikely to identify regulatory actions that would provide a substantial safety improvement.

PWR Ice Condenser

Containment Performance

There are nine operating PWRs with ice condenser containments located at five sites in the United States and an additional unit (Watts Bar Unit 2) is expected to enter commercial operation in the future. The volumes and design pressures for ice condenser containments are similar to the Mark III BWR containments. Ice condenser containments also have igniters for hydrogen control. The NRC evaluated an ice condenser containment (Sequoyah) as part of the activities associated with NUREG-1150. Supporting evaluations of containment issues for ice condenser containments are described in various studies, including NUREG/CR-6427. The pre-Fukushima evaluations of core damage and containment performance for licensed ice condenser plants did not identify generic improvements that warranted regulatory actions (see NUREG-0933).

Ice condenser containments are pressure suppression containments, but like other PWR designs, they do not have direct system interactions between core cooling functions and containment functions, as discussed above for BWRs[2]. As discussed above, Order EA-12-049 requires all operating plants to develop a three phase approach for mitigating events involving extended losses of electrical power and loss of normal access to the ultimate heat sink. Venting is not a primary method for protecting ice condenser containments as part of compliance with Order EA-12-049. Rather, these plants use the presence of the ice and containment sprays to maintain containment pressure and temperature within limits during an extended loss of electrical power. The NRC staff has reviewed these approaches and issued interim staff evaluations documenting that the licensees with ice condenser plants have developed an acceptable approach for addressing core cooling and containment functions. These requirements address the functions deemed necessary to ensure reasonable assurance of adequate protection of public health and safety. The estimated low frequency for extended losses of electrical power and expected plant response to loss of power scenarios, including the implementation of mitigating strategies, makes it unlikely that further evaluations of the means to protect ice condenser containments, beyond those developed for compliance with Order EA-12-049, would identify a cost-justified substantial safety improvement. Therefore, the staff's initial assessment is that Recommendation 5.2 can be closed for ice condenser containments.

Studies documented in reports such as NUREG-1150 and NUREG/CR-6427 evaluated potential severe accident scenarios for ice condenser containments and contributed to the NRC's decision that no regulatory actions were warranted, except additional consideration for improving the control of hydrogen (see next section). The NUREG-1150 accident progression analysis models were used by the staff and its contractors in the evaluation of possible containment improvements for the PWR ice condenser and BWR Mark III designs. The result of the staff reviews of these designs (and all others except the Mark I containments) was that potential improvements would best be pursued as part of the individual plant examination process. The most significant finding discussed in NUREG/CR-6427 was that the early containment failure probability is dominated by non-DCH hydrogen combustion events (which only occur during station blackouts) rather than by DCH events. This is because the station blackout (SBO) probability is small, the high-pressure melt ejection probability is small, and because containment loads are non-threatening for any reasonable plant damage state associated with a non-SBO event. Insights from the Fukushima accident do not undermine the findings from these previous evaluations. The NRC staff is evaluating an ice condenser plant (Sequoyah) as part of a continuation of the SOARCA project as directed by the Commission in the SRM to SECY-12-0092, "State-of-the-Art Reactor Consequence Analyses - Recommendation for Limited Additional Analysis" (ADAMS Accession No. ML12341A349). Should the NRC staff continue the evaluation of this Tier 3 activity into 2016, preliminary results from the ongoing study could be used to provide further confirmation that no additional regulatory actions are warranted for ice condenser containments. In any case, significant findings from the SOARCA assessments will be shared with licensees and other stakeholders and any adverse findings would be evaluated for possible inclusion in the NRC's Generic Issues Program.

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[2] Note that some licensees for plants with various containment designs credit containment accident pressure to ensure sufficient net positive suction head for emergency core cooling pumps under some design-basis accident scenarios and do therefore have some less direct dependencies between containment and core-cooling functions than was described for the BWRs.

Hydrogen Control

The evaluation of hydrogen control for ice condenser containments follows the above discussion for Mark III containments. By improving the reliability of igniter systems during station blackout scenarios, the actions taken provide confidence that combustible gases will not cause a loss of primary containment integrity and will reduce the chances that they will migrate to other structures, as occurred during the Fukushima accident. Based on the assessments discussed above, the staff believes that additional study of possible improvements to hydrogen control for ice condenser containments or other buildings is unlikely to identify regulatory actions beyond those already taken that would provide a substantial safety improvement.

PWR Large Dry

Containment Performance

There are 56 operating PWRs with large dry containments located at 33 sites in the United States. Four PWRs with AP1000 designs are under construction and are discussed in a following section for reactors licensed under the provisions of 10 CFR Part 52, "Licenses, Certification, and Approvals for Nuclear Power Plants." For the sake of this discussion, large dry containments also include those maintained at sub-atmospheric conditions during normal operations. A large dry containment is designed to contain the blowdown mass and energy from a large break loss of coolant accident, assuming any single active failure in the containment heat removal systems. These systems may include containment sprays and/or fan coolers, depending on the particular design. Large dry containments can be of either concrete or steel construction. All United States concrete containments have steel liners to assure leak tightness. Large dry (and all other) containments have a large, thick basemat that provides seismic capability, supports the structures, and may serve to contain molten material during a severe accident. PWR designs with large dry containments do not have direct system interactions between core cooling functions and containment functions as discussed for BWRs.

As discussed above, Order EA-12-049 requires all operating plants to develop a three phase approach for mitigating events involving an extended loss of electrical power and loss of normal access to the ultimate heat sink. Venting is not a primary method for protecting large dry containments as part of compliance with this order. Instead, plants use containment sprays or restore containment cooling functions to maintain containment pressure and temperature within limits during an extended loss of electrical power. The NRC staff has reviewed licensees' approaches for compliance with this Order and issued interim staff evaluations documenting that the licensees for plants with large dry containments have developed acceptable approaches for addressing core cooling and containment functions. These requirements address the functions deemed necessary to ensure reasonable assurance of adequate protection of public health and safety. The estimated low frequency for extended losses of electrical power and the expected plant response to the loss of power scenarios, including the implementation of mitigating strategies, make it unlikely that further evaluations of the means to protect large dry containments beyond the overall integrated plans developed for Order EA-12-049 would identify a cost-justified substantial safety improvement. Therefore, the staff's initial assessment is that Recommendation 5.2 can be closed for large dry containments.

Large dry containments have been evaluated in terms of severe accident behavior in several major NRC studies, including NUREG-1150 and most recently in NUREG-1935 (SOARCA).

Results from the SOARCA study for the PWR large dry containment pilot plant, Surry, are provided on the right side of Figure 3 in terms of individual latent cancer fatality risk. Similar to the evaluations presented in the CPRR regulatory basis document, the figure shows a significant (orders of magnitude) margin between the risks associated with an extended loss of ac power event and the QHOs defined by the NRC's Safety Goal Policy Statement. A preliminary assessment performed by the NRC staff determined that site-to-site variations related to reevaluated external hazards would not challenge the conclusion that a generic requirement is not warranted for severe accident measures beyond those already in place for large dry containments. Insights from the Fukushima accident do not undermine the findings from these previous evaluations. As directed by the Commission in the SRM to SECY-12-0092, an uncertainty analysis of the SOARCA Surry unmitigated short-term station blackout (STSBO) scenario is underway which will provide additional insights.

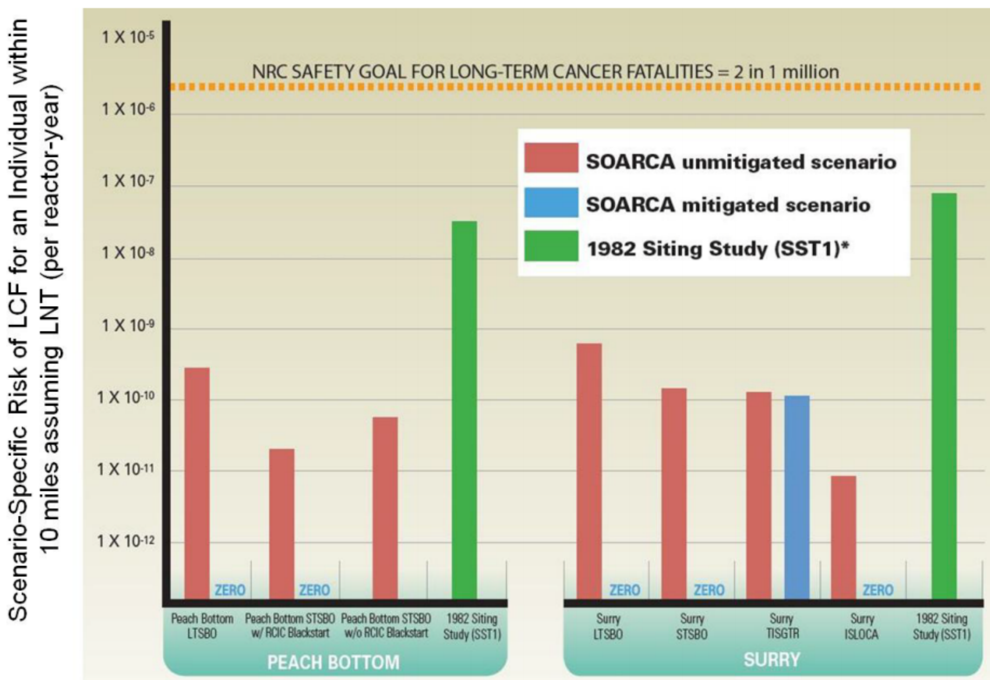

Figure 3 – Comparison of Individual Latent Cancer Fatality (LCF) Risk Results for SOARCA Scenarios to the NRC Safety Goal and to Extrapolations of the 1982 Siting Study SST1 (taken from NUREG-1935 Figure ES-3)[3]

Hydrogen Control

The capabilities for large dry containments to withstand possible hydrogen combustion events have been addressed in several NRC risk studies and documentation related to the development of 10 CFR 50.44 (SECY-03-0127), including the associated regulatory analysis. A detailed assessment is documented in NUREG/CR-5662, "Hydrogen Combustion, Control, and

[3] LTSB: long-term station blackout; LNT: linear no-threshold; RCIC: reactor core isolation cooling; ISLOCA: interfacing systems loss-of-coolant accident; SST: siting source term

Value-Impact Analysis for PWR Dry Containments," issued in June 1991. NUREG/CR-5662 discusses that additional requirements for hydrogen control, such as a requirement for hydrogen igniters, were not justified for reactors with large dry containment designs due to the large size and robust design of these containments. Based on the assessments discussed above, the staff concludes that additional study of possible improvements to hydrogen control for large dry containments or other buildings would be unlikely to identify regulatory actions meeting the threshold for a substantial safety improvement.

Reactors Licensed Under 10 CFR Part 52

For nuclear power plants licensed under 10 CFR Part 52, including the AP1000 plants currently under construction, the NRC imposes additional requirements for containments beyond those for currently operating plants. This practice is consistent with the NRC's Severe Accident Policy Statement that new nuclear power plants should incorporate improvements during design and construction that were not practical or cost-effective to require as modifications to existing plants. New reactors licensed under 10 CFR Part 52 must address similar design basis accidents as operating plants, but must also have severe accident design features to increase the ability of containments to maintain their integrity during severe accident conditions. In addition, more conservative hydrogen generation rates and related controls are imposed in 10 CFR 50.44 for plants licensed after 2003. The NRC staff assessed potential enhancements beyond those already included for new plants licensed under 10 CFR Part 52 (e.g., hydrogen igniters for AP1000 design reactors and inerted containments and passive autocatalytic recombiners for Economic Simplified Boiling Water Reactors) and found that such measures would not likely be justified under the finality provisions established under 10 CFR Part 52 (similar to backfit requirements defined in 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities").

Stakeholder Interactions

The NRC staff held numerous public meetings with nuclear industry representatives related to the activities for Mark I and II containments. The staff also made presentations to subcommittees and the full committee of the Advisory Committee on Reactor Safeguards (ACRS). The NRC staff interacted with other interested stakeholders during discussions on petitions for enforcement actions, at public meetings, and in correspondence related to Mark I and II containments and various proposals for improvements, including the installation of engineered filters.

The staff has had fewer public interactions specifically related to Recommendations 5.2 and 6. However, during a meeting held on October 6, 2015, the NRC staff provided the Fukushima subcommittee of the ACRS with an overview of the staff's plans to resolving the open Tier 2 and 3 recommendations. A similar meeting is planned with the ACRS full committee on November 5, 2015. In addition, the staff provided an overview of its proposed resolution plans for all the open Tier 2 and 3 recommendations during a Category 2 public meeting held on October 20, 2015. The staff expects to conduct additional focused meetings on these recommendations with the ACRS and external stakeholders to support documenting its final analysis.

Conclusion and Recommendation

Based on the evaluations described above, the staff does not expect that additional regulatory action is needed to close Recommendations 5.2 and 6. However, the staff proposes to more fully document its basis for closing these recommendations, interact with the ACRS and external stakeholders, and provide more detailed documentation, incorporating insights from these interactions, to the Commission by March 2016.

Related to the staff's consideration of Recommendation 6, the Natural Resources Defense Council submitted a petition for rulemaking (PRM) on October 14, 2011, requesting the NRC revise 10 CFR 50.44 regarding the measurement and control of combustible gas generation and dispersal within a power reactor system (PRM-50-103). The petition addresses several issues beyond those identified in the NTTF report and will be addressed in a separate paper to the Commission.

Resources

The staff estimates that approximately 0.5 full-time equivalent staff (FTE) is needed to support public interactions, participate in ACRS meetings, and finalize the documentation of the staff's assessment. The resources are currently budgeted in fiscal year (FY) 2016 in the Operating Reactors Business Line, Licensing and Research Product Lines, Fukushima NTTF Product. If the staff identifies the need for additional resources in FY 2017 or beyond as it finalizes its evaluation, those resource needs will be addressed through the planning, budget, and performance management process.

Office	FY 2016	
	FTE	Dollars, $K
RES	0.2	-----
NRR	0.2	-----
OGC	0.1	-----
TOTAL	0.5	-----