UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

March 15, 2016

The Honorable Stephen G. Burns
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: CLOSURE OF FUKUSHIMA TIER 3 RECOMMENDATIONS RELATED TO CONTAINMENT VENTS, HYDROGEN CONTROL, AND ENHANCED INSTRUMENTATION

Dear Chairman Burns:

During the 632nd meeting of the Advisory Committee on Reactor Safeguards (ACRS), March 3-5, 2016, we reviewed the NRC staff's publicly available draft white paper, "Closure of Fukushima Tier 3 Recommendations Related to Containment Vents, Hydrogen Control, and Enhanced Instrumentation." Our Fukushima Subcommittee reviewed material related to this matter on October 6, 2015, and February 18, 2016. During these reviews, we had the benefit of discussions with the staff and representatives of the Nuclear Energy Institute. We also had the benefit of the referenced documents.

CONCLUSION AND RECOMMENDATIONS

1. No further regulatory action is warranted for closure of the Fukushima Tier 3 recommendations related to containment vents, hydrogen control, and enhanced instrumentation.

2. The staff should perform a more complete examination of the mechanisms and pathways for unmitigated releases of hydrogen from each major containment design into surrounding structures and the consequences of hydrogen combustion.

3. The staff should continue to participate on standards committees, revise applicable regulatory guidance, and actively engage in ongoing activities that are examining needs for enhanced severe accident instrumentation.

BACKGROUND

In SECY-15-0137, the staff presented their plans to resolve and close the remaining open Tier 2 and Tier 3 recommendations developed in response to the March 11, 2011, accident at the Fukushima Dai-ichi nuclear power plant. Those plans divided the recommendations into three resolution groups. To support closure of the recommendations in Group 2, the staff prepared a draft white paper which supplemented the information in SECY-15-0137 and benefited from further public interactions. The white paper addressed the following Fukushima Tier 3 recommendations:

- Consideration of reliable vents for other than Mark I and II containments
- Evaluation of hydrogen control and mitigation
- Reactor and containment instrumentation enhancements

The staff's initial assessments concluded that these recommendations could be closed without the need for further regulatory action. However, additional interaction with external stakeholders and the ACRS was needed before final justifications could be made. The white paper was discussed during our February 18, 2016 Subcommittee meeting. A forthcoming Commission Paper, based on subsequent enhancements to the white paper, will describe the final closure plans for these Group 2 recommendations. We did not receive an updated version of the white paper or the draft Commission Paper in time to support our deliberations for this letter report. Our conclusion and recommendations account for information in the draft white paper, supplemented by the staff's briefing material for our March 3, 2016 meeting.

DISCUSSION

The staff often refers in the white paper, to the Staff Requirements Memorandum on SECY-15-0065, in which the Commission disapproved formal regulatory requirements for the implementation of Severe Accident Management Guidelines (SAMGs). Since elements of the Group 2 recommendations are related to severe accident mitigation, the staff then infers that regulatory requirements for these recommendations similarly cannot be justified. We do not agree with that line of reasoning. Our letter report of April 22, 2015, contains our views on the benefits of SAMGs and it provides the rationale for our conclusion that formal regulatory requirements for their implementation are not needed. All licensees have submitted formal commitments to implement SAMGs, train personnel on their use, and maintain the SAMGs current throughout the life of each facility. The staff is also making changes to inspection procedures to provide assurance that these commitments are maintained. We reviewed the Group 2 recommendations and examined their merits with recognition that plant-specific SAMGs will be implemented and maintained at every operating reactor.

In their discussion of the other containment types, the staff refers to the analyses that were performed to support decisions regarding the proposed Containment Protection and Release Reduction rulemaking for boiling water reactors (BWRs) with Mark I and Mark II containments. In our letter report of April 22, 2015, we noted that those evaluations considered only a limited set of accident scenarios involving a so-called "long-term" station blackout with an extended loss of all AC power. We noted further that those limited analyses are not sufficient to justify broad conclusions about the quantitative benefits from SAMGs for a complete spectrum of events across the entire U.S. operating reactor fleet. Unique features of the BWR Mark I and Mark II designs and their integrated strategies for venting, water addition, and water management prolong operation of core cooling systems, provide post-accident core debris cooling and containment heat removal, and provide controlled removal of hydrogen. Those design features and integrated accident management strategies do not apply in the same way to other plants. Furthermore, the selected long-term station blackout scenarios provide time to implement accident mitigation strategies, due to the initial operation of turbine-driven core cooling systems. Less time is available to implement proposed strategies during other scenarios, such as a "short-term" station blackout when turbine-driven systems are not available. Our review of the Group 2 recommendations accounts for these considerations.

Any new regulatory requirement imposed as a result of the Group 2 recommendations must be justified, as required by Section 50.109 of Title 10 of the *Code of Federal Regulations*, "Backfitting." The staff's evaluations and conclusions explicitly account for this backfit requirement. A conclusion that no further formal regulatory action is warranted does not mean that voluntary actions have not been taken or that plant improvements will not be pursued.

Our review of each of the Group 2 recommendations follows.

Consideration of Reliable Vents for Other than Mark I and Mark II Containments

In this section, we examine the need for reliable hardened venting systems to prolong or restore core cooling, core debris cooling, or containment heat removal during severe accident scenarios. Control and mitigation of hydrogen for each containment design is addressed in the next section of this report.

Four operating BWRs use the Mark III containment design. Suppression pool venting is less effective at reducing risk for the Mark III design, compared to venting for the Mark I and Mark II designs. This is due to the presence of additional release pathways that can bypass the suppression pool. The primary focus of Mark III mitigating strategies to comply with Order EA-12-049 is provision of alternative means to prolong or restore suppression pool cooling. To provide insights about containment performance, the staff's white paper summarizes supplemental analyses for a long-term station blackout scenario without restoration of suppression pool cooling. If igniters are not available, hydrogen combustion is predicted to cause containment failure approximately 12 hours after loss of core cooling. With igniters available, containment failure occurs due to overpressurization at about 29 hours after loss of core cooling. Thus, if hydrogen deflagrations are prevented, adequate time is available to retrieve and align alternative suppression pool cooling equipment from onsite and offsite sources, as directed by the plant-specific strategies.

Ten pressurized water reactors (PWRs) use an ice condenser containment design. Venting is not an effective option that can be used to prolong or restore core cooling functions for these plants. The relatively small size of these containments presents accident mitigation issues that are generally similar to those for BWR Mark III plants. The primary focus of containment mitigating strategies to comply with Order EA-12-049 for ice condenser plants is provision of alternative means to restore the containment cooling and spray functions. To provide insights about containment performance, the staff's white paper summarizes supplemental analyses for a long-term station blackout scenario without restoration of containment heat removal or sprays. If igniters are not available, hydrogen combustion is predicted to cause containment failure approximately 16 hours after loss of core cooling. With igniters available, containment failure due to overpressurization is delayed for much longer than 72 hours after loss of core cooling. Thus, if hydrogen deflagrations are prevented, adequate time is available to retrieve and align alternative mitigation equipment from onsite and offsite sources, as directed by the plant-specific strategies.

Venting is not an effective option that can be used to prolong or restore core cooling functions for PWRs with large dry or subatmospheric containments. Furthermore, inadvertent or improperly controlled opening of containment vents may increase the risk associated with some accident scenarios at PWRs that rely on additional pressure inside the containment to maintain adequate net positive suction head for systems that provide core cooling and containment heat removal. The primary focus of containment mitigating strategies to comply with Order EA-12-049 for these plants is provision of alternative means to restore the containment cooling and spray functions. The staff's white paper summarizes analyses from NUREG-1935 for long-term and short-term station blackout scenarios without restoration of containment heat removal. Those analyses show that the latent cancer fatality risks from these scenarios are extremely small. The extremely low risk estimates from these unmitigated scenarios provide confidence that additional features beyond those required by Order EA-12-049 would not meet the integrated safety benefit criteria that must be satisfied to justify formal regulatory requirements.

Based on these considerations, we conclude that regulatory requirements to install reliable hardened vents to prolong or restore core cooling, core debris cooling, or containment heat removal during severe accident scenarios at plants other than BWR Mark I and Mark II designs are not warranted.

Evaluation of Hydrogen Control and Mitigation

For BWRs with Mark I and Mark II containments, the suppression pool vent path must be available to support extended operation of the turbine-driven core cooling systems. Operators are instructed to open the vent before suppression pool temperature exceeds the turbine system operating limits or before pressure exceeds the primary containment pressure limit (typically about 60 psig). They are also instructed to open the vent before hydrogen concentration in the drywell or the suppression pool gas space reaches 6%. The hardened vent path is either configured to preclude a detonable mixture, or it is designed to withstand the dynamic loading from a hydrogen detonation. Thus, according to their compliance with Order EA-13-109, hydrogen control and mitigation for these plants is achieved by controlled venting. Because anticipatory venting strategies are designed to prolong core cooling before core damage occurs, there is assurance that the vent path should be available at an early stage of the accident scenario.

For BWRs with Mark III containments and PWRs with ice condenser containments, the mitigating strategies for compliance with Order EA-12-049 involve provision of backup power supplies for the hydrogen igniters that are installed in those containments. The staff's white paper summarizes supplemental analyses of unmitigated long-term station blackout scenarios for these reactors. Short-term station blackout scenarios involve conditions that directly disable core cooling by turbine-driven equipment. Based on the long-term scenarios without mitigation, hydrogen combustion during a short-term blackout would cause containment failure approximately 12 hours after the initiating event for the Mark III design, and approximately 16 hours after the initiating event for the ice condenser design. We have not examined the mitigating strategies for these containment designs, including plant-specific guidance for equipment storage, mobilization, and connection of the backup power supplies. In particular, we do not know whether those strategies rely on the extended time margins that are available during the long-term station blackout scenarios, which are the focus for most of the current staff and industry evaluations. Nevertheless, provided that the plant-specific mitigation strategies do not contain substantial time delays for re-powering the hydrogen igniters, there is confidence that the risk from short-term scenarios can be managed adequately.

For PWRs with large dry containments, the staff's white paper addresses the issue of hydrogen control and mitigation with references to previous studies, such as those documented in NUREG/CR-5662. Those analyses concluded that deflagration is the most likely mode of hydrogen combustion in these containments. Large dry containments are sufficiently stout that they can withstand quasi-static pressurizations due to deflagrations. As long as the atmosphere is not steam-inerted, deflagrations are sufficiently probable that detonable concentrations of hydrogen do not develop. Although local detonations in some compartments are not precluded, the studies concluded that additional measures to control hydrogen could not be justified as a regulatory backfit. During our March 3, 2016 meeting, the staff also summarized the results from an analysis in NUREG/CR-7110 for an unmitigated long-term station blackout scenario for a PWR with a large dry containment. That analysis concluded that the containment would remain intact for approximately 45 hours. At that time, containment pressure had increased to more than twice design pressure. It is likely that at this pressure containment leakage would increase, thereby releasing containment gases and preventing a further significant increase in pressure. Nevertheless, Order

EA-12-049 requires that the mitigation strategies for these PWRs must maintain or restore containment capabilities. Therefore, the implementation guidance for those strategies must address methods for timely control and mitigation of hydrogen before substantial containment leakage occurs.

If plant-specific mitigation and control strategies developed in response to Order EA-12-049 and Order EA-13-109 are implemented appropriately for all containment types, with due consideration of variations in accident scenario progression, there is adequate assurance that the risk of containment damage from hydrogen detonations will not meet the threshold to justify further regulatory requirements. Based on these considerations, we conclude that additional regulatory requirements for control and mitigation of hydrogen inside the reactor containment are not warranted.

Releases of Hydrogen Outside Containment

The staff has not conducted systematic evaluations of scenarios and pathways that could result in a release of hydrogen outside each type of containment into surrounding structures. Possible release scenarios depend on the accident progression, plant-specific mitigating strategies, and the times when those strategies are implemented. Release pathways depend on the containment design, types of penetration seals, ventilation connections that may communicate with the containment atmosphere, and the plant configuration. The consequences from hydrogen combustion outside the containment depend on the release location and the affected structures, systems, and components. These assessments are complex and plant-specific. Based on the limited available information, it is not evident that additional enhancements to mitigate these releases would meet the integrated safety benefit criteria that must be satisfied to justify formal regulatory requirements. However, further research and evaluations are needed to provide confidence in that conclusion.

The staff should perform a more complete examination of the mechanisms and pathways for unmitigated releases of hydrogen from each major containment design into surrounding structures. The assessments should account for the progression of core damage during a variety of severe accident scenarios, the timing of mitigation strategies, and the likelihood and consequences of hydrogen combustion. The assessments should pay particular attention to releases that may result in combustion in locations that preclude personnel access for connection of severe accident mitigation equipment, cause direct damage to that equipment, cause structural damage to the spent fuel pool, or cause collateral damage in the pool that precludes heat removal from the stored fuel.

Reactor and Containment Instrumentation Enhancements

As noted earlier in this report, our review of this recommendation explicitly accounts for the availability of SAMGs and an event response framework that integrates those guidelines with the Emergency Operating Procedures (EOPs). The EOPs instruct operators to confirm automatic responses or to take manual actions to prevent core damage and maintain containment functions, based on specific values of displayed parameters. Operators are instructed and trained to confirm the validity of those indications by a variety of methods, including channel-to-channel instrument checks, functional comparisons with other related parameters, and trend information. As long as plant conditions remain within the scope of the EOPs, all referenced instruments should continue to operate reliably according to their design and environmental qualifications.

We were briefed on integrated use of the EOPs and the SAMGs for an example severe accident scenario at a particular BWR, for which the plant-specific Severe Accident Guidelines[1] are at a relatively advanced stage of development. Although that briefing was focused on only one scenario, it provided valuable information about the overall structure of the SAMGs, their relationship to the EOPs, and use of the SAMGs by the emergency response organization and the control room operators. We have been assured that similar functional relationships apply for the SAMGs that are being developed for each PWR design. We plan to request a similar demonstration of the integrated EOPs and SAMGs for a severe accident scenario at a representative PWR plant.

The SAMGs are entered when plant conditions indicate that core cooling cannot be maintained and the reactor is on a trajectory toward core damage. The SAMGs then invoke technical guidance that is based on an engineering evaluation of the scenario, including an assessment of the available parameter indications, their functional consistency, and their trends throughout the plant transition to severe accident conditions that are beyond instrument design and environmental qualifications. The severe accident response strategies are then based on fundamental principles that do not rely on precise indications of parameter values, but rather on an integrated technical assessment of the evolving event scenario and the conditions which preceded the onset of core damage.

Provided that key parameter displays remain available and reliable during the accident progression up to the onset of core damage, we conclude that regulatory actions to require that selected reactor and containment instrumentation must be enhanced to withstand severe accident conditions are not warranted.

The staff has indicated that they plan to revise Regulatory Guide 1.97 to account for expanded criteria for severe accident monitoring instrumentation, as specified in a pending update to IEEE Standard 497. The staff has also indicated that they will continue their engagement with ongoing activities to examine needs for enhanced severe accident instrumentation that are being led by the Electric Power Research Institute, as well as international organizations. These activities may identify specific

[1] BWR licensees use the term "Severe Accident Guidelines" (SAGs). We retain the SAMG acronym in this discussion to emphasize the general nature of our conclusions.

combinations of plant designs, accident scenarios, and parameter sets for which further evaluation of potential safety benefits may be needed. We strongly encourage active staff participation in these collaborative efforts.

Dr. Joy Rempe did not participate in the Committee's deliberations regarding this matter.

Sincerely,

/RA/

Dennis C. Bley
Chairman

REFERENCES

1. U.S. Nuclear Regulatory Commission, White Paper, "Closure of Fukushima Tier 3 Recommendations Related to Containment Vents, Hydrogen Control, and Enhanced Instrumentation," February 2, 2016 (ML16020A245).

2. U.S. Nuclear Regulatory Commission, SECY-15-0137, "Proposed Plans for Resolving Open Fukushima Tier 2 and 3 Recommendations," October 29, 2015 (ML15254A008).

3. U.S. Nuclear Regulatory Commission, SRM-SECY-15-0065, "Staff Requirements – SECY-15-0065 – Proposed Rulemaking: Mitigation of Beyond-Design-Basis Events (RIN 3150-AJ49)," August 27, 2015 (ML15239A767).

4. Advisory Committee on Reactor Safeguards, "Draft SECY Paper, 'Proposed Rulemaking: Mitigation of Beyond-Design-Basis Events (RIN 3150-AJ49)'," April 22, 2015 (ML15111A271).

5. U.S. Nuclear Regulatory Commission, Order EA-12-049, "Issuance of Order to Modify Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," March 12, 2012 (ML12054A735).

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7. U.S. Nuclear Regulatory Commission, Order EA-13-109, "Issuance of Order to Modify Licenses with Regard to Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions," June 6, 2013 (ML13143A321).

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1. U.S. Nuclear Regulatory Commission, White Paper, "Closure of Fukushima Tier 3 Recommendations Related to Containment Vents, Hydrogen Control, and Enhanced Instrumentation," February 2, 2016 (ML16020A245).
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Letter to the Honorable Stephen G. Burns, Chairman, NRC, from Dennis C. Bley, Chairman, ACRS, dated March 15, 2016

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