TECHNICAL REPORT SUPPORTING CLOSURE OF GENERIC ISSUE 189: SUSCEPTIBILITY OF ICE CONDENSER AND MARK III CONTAINMENTS TO EARLY FAILURE FROM HYDROGEN COMBUSTION DURING A SEVERE ACCIDENT

1.0 INTRODUCTION

The Office of Nuclear Reactor Regulation (NRR) has completed its actions supporting closure of Generic Issue (GI) 189, "Susceptibility of Ice Condenser and Mark III Containments to Early Failure from Hydrogen Combustion during a Severe Accident." Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.44, "Combustible Gas Control for Nuclear Power Reactors," requires hydrogen igniters at Pressurized Water Reactors (PWRs) with ice condenser containment designs and Boiling Water Reactors (BWRs) with Mark III containments. However, these hydrogen igniters received power from the safety related Alternating Current (AC) electrical power distribution system and, thus, would not be available during station blackout events. Hydrogen igniters or other equivalent combustible gas control systems are necessary to prevent early containment failure in these containment designs because the containments have relatively small free volumes and low design pressures.

The resolution of GI-189 focused on the provision of alternate power supplies for the hydrogen igniters that could be employed during rare extended station blackout scenarios. The staff has verified deployment of capabilities to provide alternate power to hydrogen igniters at all affected reactor sites, consistent with regulatory commitments. In addition, the staff ensured appropriate consideration of the nexus of this issue to the events following the March 2011 earthquake and tsunami in Japan in the implementation of lessons-learned activities.

2.0 BACKGROUND

Technical Background

The zirconium alloy fuel cladding used in U.S. light water reactors can produce substantial quantities of hydrogen gas during events that expose hot fuel to steam. At fuel cladding temperatures of about 1000°C (1832°F), the zirconium metal in the fuel clad begins reacting with steam at a significant rate, producing zirconium oxide, hydrogen gas, and heat. The rate of heat production from this reaction can cause a rapid rise in cladding temperature, which further increases the reaction rate. The mass of zirconium present in a typical commercial light water reactor core is sufficient to produce hundreds of kilograms of hydrogen.

Certain sequences of events could result in the exposure of hot fuel cladding in the reactor vessel to a steam environment, which can result in the rapid production of hydrogen. Loss-Of-Coolant Accidents (LOCAs) involve a rapid loss of coolant, and steam oxidation of the fuel cladding may begin before the emergency core cooling systems re-flood the core. In addition, a few low-frequency transient event sequences that result in a sustained loss of adequate decay heat removal, including extended station blackout sequences, would expose the fuel cladding to a high-temperature steam environment. The resulting hydrogen is not combustible within the reactor coolant system because of both the large amount of steam present within the system and the lack of free oxygen.

However, the hydrogen can migrate to the containment atmosphere through leaks associated with the event sequence, relief valve actuation, and deliberate venting of the reactor vessel.

These low frequency event sequences may result in accumulation of combustible or explosive mixtures of gases within containment. Design features and operational requirements applicable to U.S. light water reactors provide assurance that combustible gas accumulation would not be a significant challenge to containment integrity within the first 24 hours after the onset of core damage. The staff found that large dry and sub-atmospheric containments used for PWRs have sufficient strength and free volume to withstand potential combustion events within that period. Mark I and Mark II containments used for BWRs are maintained with an inert nitrogen gas atmosphere during reactor operation, thereby preventing formation of a combustible gas mixture. Operational hydrogen igniters distributed throughout PWR ice condenser and BWR Mark III containments maintain the accumulation of hydrogen gas below explosive levels by initiating hydrogen combustion as soon as flammable concentrations develop in small volumes adjacent to the igniters.

The igniters that have been installed in PWR ice condenser and BWR Mark III containments rely on power from the safety-related AC power distribution system. Thus, for some very low frequency events, such as extended station blackout and event sequences with similar loses of AC power like large fires or beyond-design basis seismic events, the hydrogen igniters would have no available power from the safety-related AC power distribution system to control combustible gas accumulation.

The PWR facilities with ice condenser containments are the dual unit facilities at Catawba, D.C. Cook, McGuire, Sequoyah, and Watts Bar, with Watts Bar Unit 2 under operating licensing review. Figure 1 represents the PWR ice condenser containment design, which consists of upper and lower compartments separated by a barrier that directs flow from the lower compartment through the ice beds to the upper compartment. For all the above sites except D.C Cook, the ice condenser containments consist of a free-standing steel containment vessel with a reinforced concrete shield building enclosing an annular space around the containment, as depicted in Figure 1. The D.C. Cook containment is a different design, consisting of reinforced concrete containment with a steel liner.

The BWR facilities with Mark III containments are the single unit facilities at the Clinton, Grand Gulf, Perry, and River Bend sites. Figure 2 represents the BWR Mark III containments, which consist of an inner drywell surrounding the reactor vessel and an outer wetwell with a barrier that directs flow from the drywell through the suppression pool to the wetwell. The Clinton and Grand Gulf containments are constructed of reinforced concrete with a steel liner, as depicted in Figure 2. The Perry and River Bend containment designs consist of a free-standing steel containment with an outer reinforced concrete shield building. Unlike the lower compartment of the ice condenser containment, the Mark III containment wall is not part of the drywell outer wall.

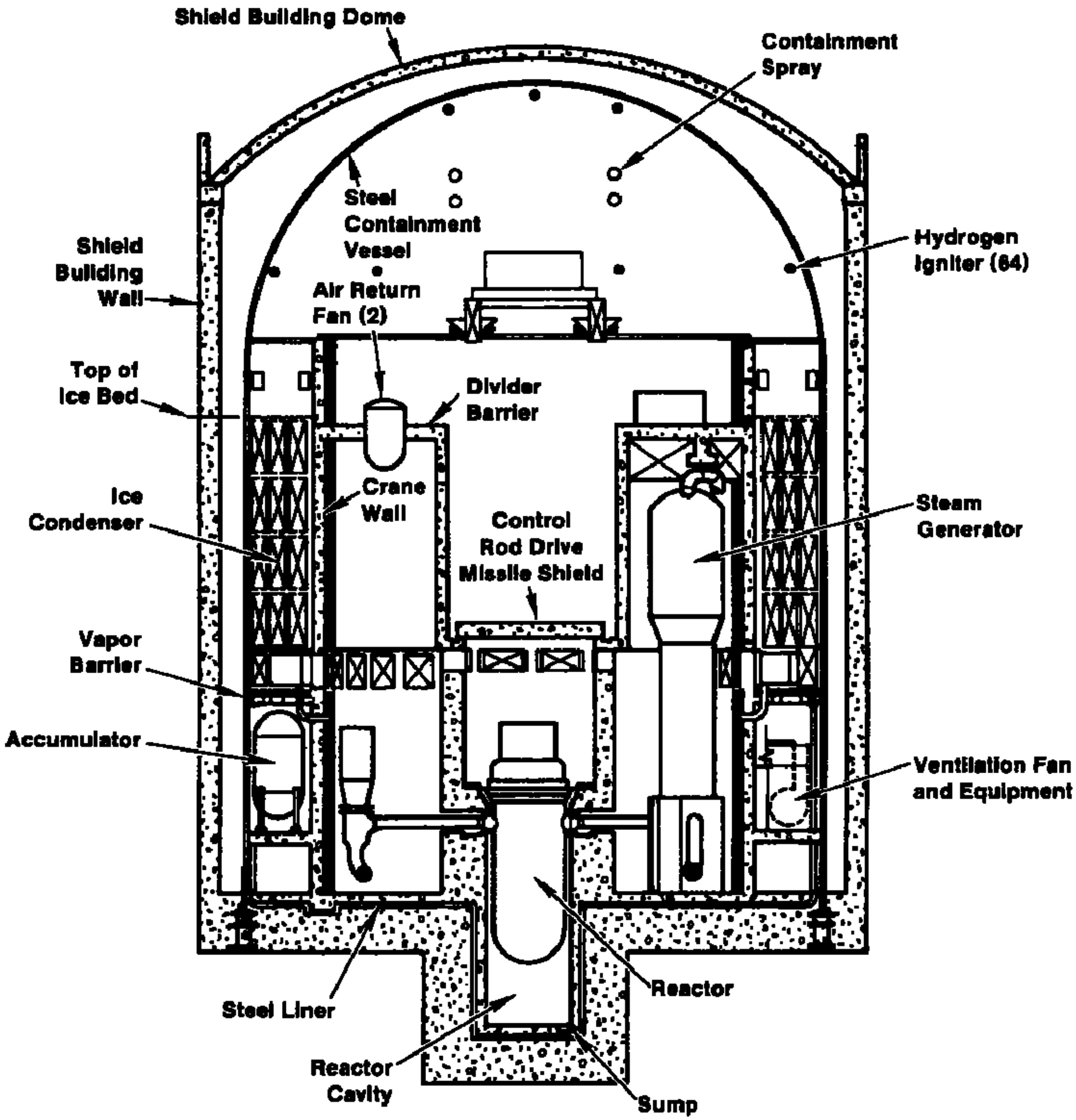

Figure 1: Free-Standing Steel Ice Condenser Containment with Steel Reinforced Concrete Shield Building

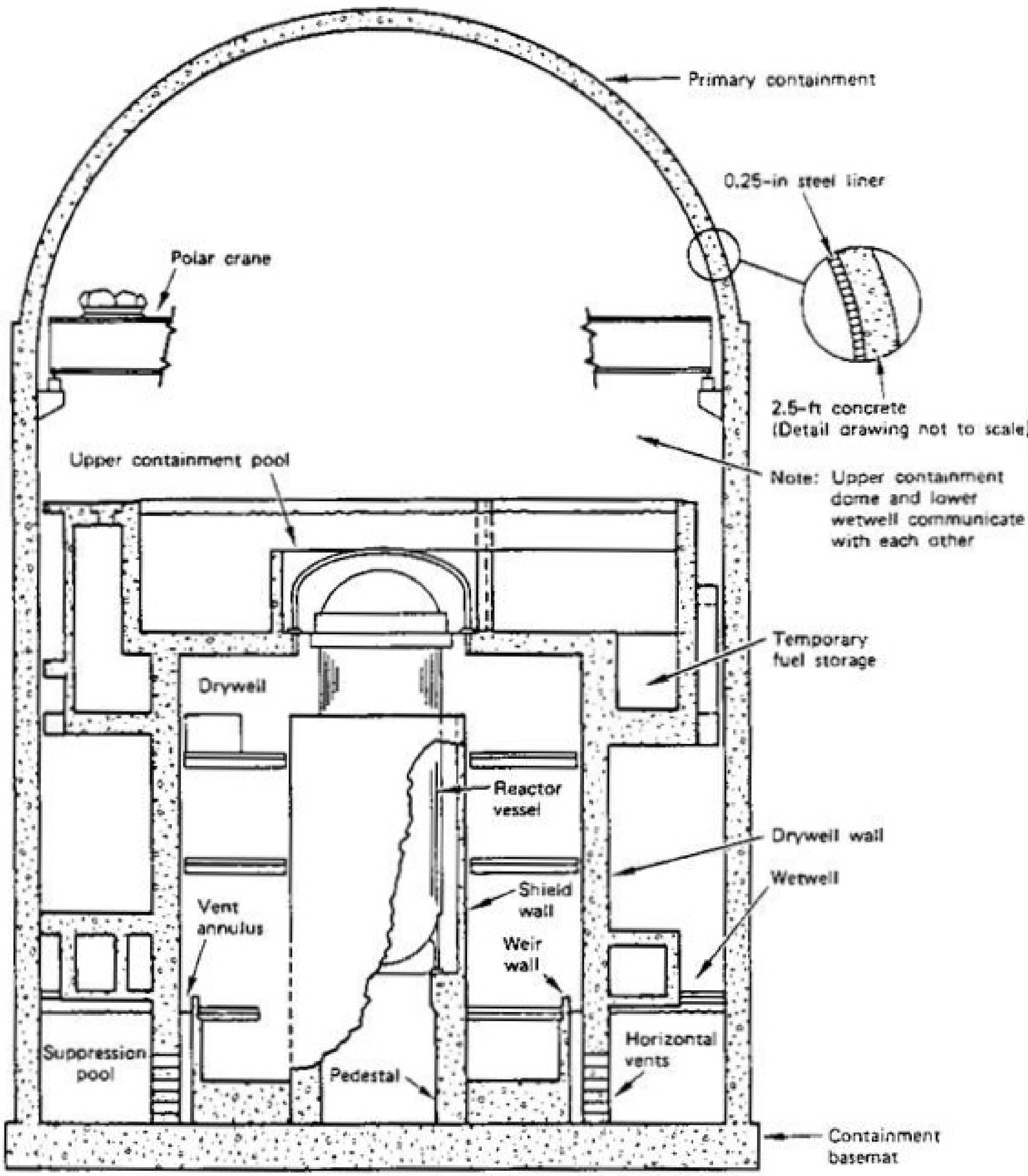

Figure 2: Steel-Reinforced Concrete Mark III Containment with Steel Liner

Both the PWR ice condenser and BWR Mark III containment designs have design pressures of about 15 psig and internal free volumes of about 1.5 million cubic feet. The design pressures of these containments are about one-third to one quarter of the design pressure for other operating reactor containment designs. The free volume of the ice condenser and Mark III containments is much larger than the free volume in BWR Mark I and Mark II containments, which have free volumes well under 0.5 million cubic feet. However, the dry PWR containments (i.e., PWR containments other than the ice condenser design) are significantly larger with free volumes of over 3 million cubic feet for the largest containments. Thus, the large dry PWR containments have the greatest capacity to contain energy.

A study of direct containment heating during severe accidents determined that early failure of ice condenser containment designs was dominated by sequences involving hydrogen combustion (Ref. 1). These sequences consisted mainly of extended station blackout and similar accident sequences because existing combustible gas control systems relied on the same AC power sources as equipment necessary to prevent core damage. These power sources would be unavailable during extended station blackout scenarios. This issue applies to BWRs with Mark III containments as well because the free volume and strength of these containments are comparable to that of ice condenser containments and the BWRs with Mark III containments also rely on AC power for the igniters.

The staff concluded GI 189 was not applicable to proposed new reactors with certified designs and those undergoing design certification reviews. New reactor designs with low-volume pressure suppression containments (i.e., the Advanced Boiling Water Reactor and the GE-Hitachi Economic Simplified Boiling Water Reactor) have free containment volumes of about 0.5 million cubic feet and have been designed to operate with inert containment atmospheres. These designs are thus protected against accumulation of combustible gas mixtures early in a severe accident. The remaining proposed designs for new reactors consist of PWRs with large dry containments (i.e., Westinghouse Advanced Passive 1000, Areva U.S. Evolutionary Power Reactor, and Mitsubishi Advanced Pressurized Water Reactor), which have free volume and design pressure comparable to operating PWRs with large dry containments. Thus, the staff expects these containment designs to have a similarly low conditional probability of containment failure following early hydrogen combustion events without active combustible gas control. Nevertheless, pursuant to the requirements of 10 CFR 50.44(c)(2), these PWR designs include passive auto-catalytic recombiners and/or AC powered hydrogen igniters to maintain hydrogen concentration less than 10 percent following an accident that releases an amount of hydrogen equivalent to that released by a 100 percent fuel cladding-coolant reaction.

Regulatory Background

Generic Issue 189 resulted from efforts to use risk information to enhance the Nuclear Regulatory Commission's (NRC) regulations in 10 CFR Part 50. In SECY 2000-198 (Ref. 2), "Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.44 (Combustible Gas Control)," the NRC staff described a framework developed to develop risk informed alternatives to technical requirements included in 10 CFR Part 50 and proposed changes to 10 CFR 50.44 based on application of the framework to that regulation.

The staff concluded that risk information associated little to no safety benefit with some of the combustible gas control requirements of 10 CFR 50.44 and that the requirements existing in 2000 did not address some safety-significant concerns associated with certain accident scenarios.

The NRC published the original version of the 10 CFR 50.44 rule in 1978 to address hydrogen generation during a LOCA, recognizing that emergency core cooling system performance may permit cladding oxidation and hydrogen production following a LOCA. The rule required each Light-Water-Cooled Reactor (LWCR) to have a means for controlling hydrogen gas generated following a LOCA. The amount of hydrogen gas considered in this rule was limited to the amount produced by an oxidation reaction of 5 percent of the cladding metal with steam over a 2 minute period.

Following the 1979 Three Mile Island Accident, which produced an estimated 400 kg of hydrogen from reaction of the metal cladding with steam, the NRC evaluated the adequacy of the combustible gas control regulations. The evaluation of the regulations resulted in the NRC proposing two amendments to 10 CFR 50.44. The first amendment, which was issued in 1981, imposed requirements to inert BWR Mark I and Mark II containments, provide hydrogen recombiners for facilities reliant on purge or repressurization to control combustible gases, and install reactor vessel high point vents to release non-condensable gas from the vessel. The second amendment to 10 CFR 50.44, which was issued in 1985, imposed requirements for a hydrogen control system in ice condenser and Mark III containments capable of handling an oxidation reaction of 75 percent of the core metal without loss of containment structural integrity. The affected licensees studied methods of controlling combustible gas accumulation and selected AC powered igniters to limit hydrogen concentration. The NRC staff accepted this method of combustible gas control. In the statements of consideration that accompanied the 1985 amendment to 10 CFR 50.44 (50 FR 3498; January 25, 1985), the Commission stated:

> The staff has accepted AC-powered igniters without requiring a backup supply to the two examples cited above. The judgment was based upon the staff's perception that the incremental risk reduction associated with provision of the igniter system backup power supply did not warrant the additional cost at these particular facilities. Provision of a backup power supply is not required by this rule.

As part of the effort to risk-inform the combustible gas control regulations in 10 CFR 50.44, the staff examined studies of severe accidents. In SECY 2000-0198, the staff presented the following risk insights associated with core damage accidents that produce combustible gases from both fuel-cladding oxidation and core-concrete interaction:

- Combustible gases are not a significant challenge to containment integrity for approximately 24 hours after the onset of core damage for:
    - large dry and sub-atmospheric containments due to large volume.
    - Mark I and II containments due to an inert containment atmosphere.
    - Mark III and ice condenser containments due to combustible gas control provided by igniters (except for station blackout).

- For station blackout sequences at BWRs with Mark III and PWRs with ice condenser containments, defense-in-depth is a concern because conditional containment failure probabilities from combustible gases range from 0.1 to 1.0.
- Internal fire and seismic core damage sequences can have the characteristics of station blackout.
- Combustible gas concentrations may be a challenge to containment integrity after 24 hours because of:

    - Core-concrete interactions in large dry, sub-atmospheric, ice condenser and Mark III containments.
    - Oxygen generation from radiolysis leading to a de-inerted atmosphere in Mark I and II containments.

Based on these insights, the staff proposed the following changes to 10 CFR 50.44 requirements in SECY 200-0198:

- Specify a severe accident combustible gas source term
- Remove requirements to monitor hydrogen concentration and to control combustible gas resulting from the design LOCA because these capabilities had low safety-significance
- Modify the requirements for the hydrogen control system in Mark III and ice condenser containment designs to control combustible gas in safety-significant accidents

The staff proposed retention of requirements for reactor vessel high point vents, a mixed containment atmosphere, and an inert atmosphere within BWR Mark I and Mark II containments. The Commission approved the proposed implementation of risk-informed rulemaking in the associated staff requirements memorandum.

In SECY 2001-0162 (Ref. 3), "Staff Plans for Proceeding with the Risk-Informed Alternative to the Standards for Combustible Gas Control Systems in Light-Water-Cooled Power Reactors in 10 CFR 50.44," the staff informed the Commission that it had determined that requirements for hydrogen recombiners could be eliminated for all containment types and had established GI 189 to assess the costs and benefits of possible additional hydrogen control requirements for PWR ice condenser and BWR Mark III containment designs. The staff proposed two rulemaking options: 1) update 10 CFR 50.44, including deletion of the hydrogen recombiner requirement, and resolve GI 189 separately; or 2) perform a more comprehensive update of 10 CFR 50.44 and defer the rule change until the staff completes its resolution of GI 189. The staff recommended the first option proposing an immediate update of 10 CFR 50.44 and separate resolution of GI 189. In the associated staff requirements memorandum (Ref. 4), the Commission approved the staff's recommendation and stated that the staff should expeditiously resolve GI 189. The Commission also directed the staff to explain why the installation of passive autocatalytic recombiners (PARS) for hydrogen control, as implemented in France, was not justified on a cost/benefit basis.

The NRC issued the revision to 10 CFR 50.44 with an effective date of October 16, 2003. The NRC staff provided guidance for implementation of the revised regulation in Draft Regulatory Guide (DG) 1117 in August 2002, which was subsequently issued as Revision 3 to Regulatory

Guide (RG) 1.7 (Ref. 5), “Control of Combustible Gas Concentrations in Containment,” in March 2007. To clearly specify the compliance status of the combustible gas control systems in BWRs with Mark III and PWRs with ice condenser containment designs, the staff included the following statement in DG 1117 and RG 1.7:

> The combustible gas control systems in all BWRs with Mark III-type containments and all PWRs with ice condenser type containments must meet the requirements in Section 50.44. The staff considers that the combustible gas control systems installed and approved by the NRC as of October 16, 2003, are acceptable without modification.

The guidance documents also included the following footnote:

> Section 50.44 does not require the deliberate ignition systems used by BWRs with Mark III type containments and PWRs with ice condenser type containments to be available during station blackout events. The deliberate ignition systems should be available upon restoration of power. Additional guidance concerning the availability of deliberate ignition systems during station blackout sequences is being developed as part of the staff’s review of Generic Safety Issue 189, “Susceptibility of Ice Condenser and Mark III Containments to Early Failure from Hydrogen Combustion during a Severe Accident.”

Thus, the staff intends to make a revision to RG 1.7 to incorporate the resolution of GI-189 in updated regulatory guidance.

3.0 EVALUATION

Technical Assessment

The NRC Office of Nuclear Regulatory Research (RES) performed a preliminary assessment of GI 189 in 2002. The assessment included consideration of the addition of a back-up diesel generator to power igniters, a combination of igniters and air return fans to enhance mixing of the containment atmosphere, and the addition of PARS. These measures would not change the probability of an accident, but they would change the probability of early failure of ice condenser and Mark III containments during station blackout and similar event sequences. The assessment focused on the reduction in the conditional containment failure probability associated with combustible gas control being available during station blackout events. The RES staff converted this reduction in the conditional containment probability to a dollar value based on expected averted public exposure and offsite property damage associated with the enhanced availability of combustible gas control. The RES staff forwarded the assessment to the Advisory Committee on Reactor Safeguard (ACRS) (Ref. 6).

The RES staff determined that the comparison of costs and benefits was indeterminate because of large uncertainties related to the benefits of enhanced combustible gas control. However, the RES staff recommended further regulatory action because of the potential for large early releases of radioactive material in the absence of igniter function following core damage and the relatively low cost of providing an alternate power supply.

Moreover, the RES analysis did not explicitly consider the potential to avoid some late containment failures and mitigate some external initiated Station Blackout (SBO) events. Qualitative considerations, such as defense-in-depth, public confidence, and regulatory coherence, also contributed to the recommendation for further regulatory action.

The RES staff briefed the ACRS, and, in a letter to the Commission, the ACRS agreed that further regulatory action was warranted (Ref. 7). To resolve GI-189, the ACRS and the RES staff recommended the addition of a backup power supply for the combustible gas igniters for the plants with ice condenser or Mark III containments. The ACRS and the RES staff recommended that plant implementation of the backup power be controlled through severe accident management guidelines. The RES staff transferred GI-189 to the NRR staff for resolution with the above recommendation in December 2002 (Ref. 8).

Initial Stakeholder Interactions

The NRR staff developed plans for interaction with stakeholders regarding GI-189. On June 18, 2003, the NRC staff met with the Nuclear Energy Institute (NEI), utility groups, and other stakeholders (Ref. 9). The purpose of the meeting was (1) to provide information regarding GSI-189, (2) to provide the NRC's bases for considering the full range of alternatives to resolving GSI-189, including rulemaking, and (3) to obtain comments from applicable licensees, the general public, and other stakeholders regarding the need to add backup power for combustible gas igniters installed in plants with ice condenser and Mark III containments. Industry representatives commented on the need for specific criteria for an acceptable approach, the preference for alternatives that reduced the probability of severe core damage following station blackout events, and concerns that severe accident management guidelines would be inappropriate due to the need to repower the igniters prior to significant hydrogen generation.

In November 2003, the ACRS reviewed NRR staff recommendations for resolution of GI 189 and discussed the issue with the NRC staff, the BWR Owner's Group, Duke Energy, and the Union of Concerned Scientists. In its letter to the NRC Chairman (Ref. 10) dated November 17, 2003, the ACRS continued to support use of a backup power supply for the igniters on a safety enhancement basis. However, based on industry concerns with deployment of portable generators through the severe accident management guidelines, the ACRS recommended supplying backup power using a pre-staged generator with suitable connection equipment.

The staff sponsored additional public meetings with stakeholders to further discuss design criteria for the backup power supplies and gather additional information regarding costs and potential safety benefits associated with the proposed backup power supplies. During a public meeting (Ref. 11) on February 3, 2004, industry representatives suggested consideration of alternatives to resolve GI 189. The industry representatives indicated that a possible alternative for BWRs with Mark III containments would be use of the Division III diesel generator, which is the on-site power source for the high pressure core spray pump, as the backup power supply for the igniters. During subsequent communications, industry representatives indicated that a possible alternative for PWRs was deployment of existing large diesel generators, either fixed or portable, to repower the igniters. The NRC staff indicated that alternatives to small generators should be available during a large fraction of the station blackout event sequences that could lead to core damage.

Regulatory Analysis

The staff initiated work on a regulatory analysis to aid decision-making. Based on the information collected in the public meetings and subsequent interactions, the staff completed the regulatory analysis (Ref. 12) in May 2005. The staff considered the following options in the regulatory analysis:

- No action (no rulemaking action; staff would rely on voluntary industry measures)
- Performance-based rulemaking
- Performance-based rulemaking after voluntary industry measures

For performance based rulemaking, the options considered both fast and slow station blackout events. The fast event corresponded to immediate loss of all pumps supporting the decay heat removal function. For fast station blackout events, the staff concluded that BWRs could transition to core damage before portable generators would be placed in service to power the igniters. Therefore, for BWRs, the staff considered both a pre-staged generator for fast and slow station blackout events and a lower-cost portable generator capable of operation to mitigate slow station blackout events. For PWRs, the staff considered only the lower cost portable generator because the larger initial water inventory in the reactor coolant system and steam generators extends the time necessary for transition to core damage in PWRs.

The staff considered the following approaches to reliably control hydrogen accumulation within containment:

- requiring reliable power to operate the hydrogen igniters
- requiring reliable power sufficient for air return fans as well as the hydrogen igniters in ice condenser containments
- using passive autocatalytic recombiners (PARs) for hydrogen control in lieu of the hydrogen igniters and/or air return fans
- requiring the provided reliable power to be qualified for seismic events
- using reliable power sufficient to operate both the hydrogen igniters and hydrogen analyzers

The technical assessment considered pre-staged generators for the fast SBO case for the BWRs and portable generators for the other cases with required backup power. The staff had evaluated the role of the air return fans in ice condenser containment combustible gas control and determined that igniters alone would be sufficient to prevent uncontrolled detonation. Also, the staff had determined that PARs were 5 to 6 times more expensive than portable power supplies, and the staff found the power supplies would provide nearly the same benefit. Therefore, the staff did not consider installation of PARs further in the regulatory analysis. The regulatory analysis similarly determined that qualification for seismic events would greatly increase costs, so this qualification was not further considered in the regulatory analysis. The NRC found that restoration of accurate hydrogen indication from the hydrogen analyzers would require too much time to be valuable and the presence of hydrogen can be adequately assessed based on other indications. Therefore, the staff determined operability of the hydrogen analyzers was not an essential condition for powering the igniters. Thus, the regulatory analysis focused on the benefit provided by alternate power supplies relative to the cost of implementation.

The staff determined benefits by calculating averted early releases of radioactive material resulting from provision of alternate AC power to the igniters prior to the onset of core damage. Containment failure from hydrogen detonation was considered the dominant failure mode for both containment types during station blackout sequences that progress to core damage. The staff considered early repowering of one train of hydrogen igniters effective in preventing early failure of PWR ice condenser and BWR Mark III containments as a result of hydrogen detonation because each train includes igniters distributed throughout containment. The conditional failure probabilities from hydrogen detonation without energized igniters for the PWR ice condenser containments were specifically determined for each site in Ref. 1. These probabilities range from 22 to 97 percent, based on the evaluated strength of the containment. The staff assumed the proposed backup power to the igniters would be 100 percent effective and reduce the conditional containment failure probability to zero. The staff also assumed the voluntary measures would be 90 percent effective. For Catawba and McGuire, which proposed voluntary capability to power one train of igniters from the Standby Shutdown Facility at those sites, the staff assumed a 90 percent reduction in the conditional containment failure probability. For D.C. Cook, Sequoyah, and Watts Bar, the staff assumed that the voluntary capability to connect large diesel generators to the plant power distribution system would reduce the station blackout core damage frequency by 90 percent rather than change the conditional containment failure probability. Numerically, these changes have the same effect on the frequency of an early radiological release.

The staff determined the averted dose benefit provided by energized igniters for BWRs with Mark III containments would be less than for PWRs because combustible gas mixtures would be less likely to result in an early radiological release. For BWR Mark III containments, combustible gas mixtures would most likely develop in the wetwell. The staff concluded that hydrogen detonation in the wetwell would seldom damage the integrity of the drywell. With an intact drywell structure, releases from BWR Mark III containments following hydrogen detonation would often be scrubbed by passage through the suppression pool. Overall, the staff estimated the conditional probability of an early, unscrubbed release from BWR Mark III containments with no igniters energized to be 19 percent. When a reliable backup power supply was available, the staff assumed the conditional probability of containment failure would be reduced by 90 percent to 1.9 percent for station blackout events. In the case of voluntary measures to provide power to the igniters from the high-pressure core spray system generator, the staff calculated the benefit of the voluntary measures by multiplying the benefit provided by a reliable backup power supply for the igniter by the probability the high pressure core spray generator would be available and power the igniters during station blackout events that progress to core damage. These probabilities were plant specific and ranged from 16 to 81 percent.

Operation of the hydrogen igniters would not prevent containment failure due to high pressure late in an accident. Therefore, the benefit provided by operational igniters early in the event would be reduced by the consequences of late containment failure. In the regulatory analysis, the staff assumed a conditional containment failure probability of 3 percent late in the event with hydrogen igniters energized for the ice condenser containments. For the BWR Mark III containments, any late failure would be scrubbed through the wetwell, and the staff considered the resultant late radiological consequences negligible for the purposes for the regulatory analysis.

The methodology used to determine the health and economic consequences of postulated radiological releases was based on the population density around the BWR Mark III and PWR ice condenser sites. The population density around PWR ice condenser containment sites was significantly higher than the population density of the BWR Mark III containment sites. As a result, the PWR ice condenser sites had larger consequences for a given release.

Considering the proposed industry voluntary measures, the regulatory analysis indicated that the no action alternative provided the greatest benefit. The backup power modification provided a substantial safety benefit at a justifiable cost for the PWRs with ice-condenser containment. However, if the proposed voluntary actions were implemented, the cost of further required enhancements would exceed the estimated benefit. For the BWRs, the direct and indirect cost of implementing any one of the considered options was not justified in view of the increased protection.

The regulatory analysis included a discussion of sensitivity of the results to several factors. Sensitivity assessments were performed for PWR station blackout core damage frequency, BWR conditional containment failure probability, PWR late containment failure probability, the effectiveness of the BWR high pressure core spray generators in powering the igniters, the BWR fraction of slow station blackout sequences, external events, and fission product release. Among the import insights from these assessments were the findings that changing the BWR containment failure mode to assume combined failure of both the drywell and wetwell indicated the conclusions of the analysis would not change, although the consequences increased by a factor of 5. Similarly, consideration of external event initiators (i.e., seismic events and fire) would increase the station blackout core damage frequency by a factor of 1.2 to 2.0, but this change would not affect the results of the analysis. Security insights were not fully evaluated in the regulatory analysis, and the staff noted defense-in-depth considerations in improving the balance among accident prevention and mitigation would provide an additional un-quantified benefit for both containment types.

Security Issue Interface and Voluntary Commitments

The staff elected to defer requests for commitments to proposed voluntary measures until ongoing security related reviews were complete (Refs. 13 and 14). However, the provision of backup power to hydrogen igniters was not incorporated in the scope of industry-wide security-related actions. Subsequently, the staff held closed meetings with affected licensees to discuss security insights related to the issue. The staff received industry proposals for modifications that incorporated security insights in late February and early March 2007 (Refs. 15 - 21). The staff reviewed the industry proposals and concluded that the proposed modifications would resolve GI-189 and provide benefit for some security scenarios.

The proposals for backup power would provide enhanced capabilities to power the igniters. Licensees operating BWRs with Mark III containments committed to voluntarily provide equipment, procedures, and training to support provision of commercial-grade backup electrical power from portable generators to one train of the igniters that is independent of much of the safety-grade ac and dc onsite power systems. These licensees also had developed procedures to connect the output of the Division 3 (HPCS) emergency diesel generator to electrical Division 1 or 2, which would allow operation of one train of igniters and possibly some pumps that could contribute to prevention or mitigation of core damage.

Licensees operating PWRs committed to voluntarily provide power from large diesel generators. For the PWRs at the Sequoyah and Watts Bar sites, the licensee committed to establish procedures, training and equipment to use existing portable 2 MW diesel generators to connect to the plant power distribution system and power the hydrogen igniters. For the PWRs at the DC Cook site, the licensee committed to establish procedures, training and equipment to use existing fixed supplemental diesel generators with a combined capacity of 4.5 MW to power either train of hydrogen igniters through the plant power distribution system. For the PWRs at the Catawba and McGuire sites, the licensee committed to provide an alternate power supply to one train of igniters from the existing standby shutdown facility diesel generator and implement appropriate procedures and training for this enhancement.

The staff evaluated the proposed voluntary changes and found the changes acceptable to resolve GI-189. The voluntary commitments to provide backup power from portable generators to the hydrogen igniters at operating BWRs with Mark III containments was consistent with the staff's original proposed resolution of GI-189. The capability to connect the output of the Division 3 (HPCS) emergency diesel generator to electrical Division 1 or 2 provides an additional small safety benefit.

The voluntary commitments to provide power from large capacity diesel generators at the DC Cook, Sequoyah, and Watts Bar sites provide a safety benefit both by improving the availability of on-site power sources for core cooling systems, which reduces the frequency of core damage due to station blackout, and by providing an alternate source of power to the hydrogen igniters in the event a cause other than a complete loss of internal AC power distribution results in core damage. However, the location of these large capacity diesel generators outside of plant structures and the reliance of these power sources on the central portion of the plant power distribution system to power the igniters limit the safety benefit.

The voluntary commitments to provide an alternate power supply direct to one train of hydrogen igniters from the standby shutdown facility diesel generator at the McGuire and Catawba sites provide a substantial safety benefit. The standby shutdown facility diesel generator is the alternate AC power source credited for station blackout coping capability. The alternate power supply to the igniters provides a safety benefit by supporting hydrogen igniter operation in the event the either unit's internal power distribution is degraded. However, the more extensive nature of the modifications resulted in a longer implementation period.

The NRC staff issued letters to affected licensees accepting the commitments. The NRC staff also notified licensees of the intent to perform verification inspections at the affected sites and clarified the scope of the inspection relative to the commitments.

Implementation and Verification Activities

Licensee implementation activities and NRC verification inspections have been completed at all affected sites. All affected sites committed to complete the necessary modifications, develop procedures, and implement a training program prior to the end of April 2008, with the exception of the Catawba and McGuire sites. The licensee for these two sites proposed more complex modifications for implementation during refueling outage periods, with final implementation at the last unit scheduled for January 2010.

The NRC staff developed NRC Temporary Instruction (TI) 2515/174 (Ref. 22), "Hydrogen Igniter Backup Power Verification," for implementation of the verification inspections. The TI specified performance of verification inspections for one unit at each site. The regional staffs completed these inspections by July 2009 (Refs. 23-31). Inspections were completed prior to the full implementation of modifications at the McGuire and Catawba sites because the staff specified inspection of physical modifications at only one of the two units at dual-unit sites in TI 2515/174. With the exception of a procedure error identified during the Sequoyah inspection, the inspectors identified no issues. The licensee for Sequoyah corrected the procedure error at Sequoyah, and the unresolved item was closed through an inspection report issued in May 2009 (Ref. 32).

As part of the operating license review for Watts Bar Unit 2, the NRC staff requested a commitment to provide backup power to igniters at that unit. In October 2010, the staff received a commitment from the Tennessee Valley Authority (Ref. 33) to implement measures at Watts Bar Unit 2 equivalent to those measures verified to have been implemented at Watts Bar Unit 1. Consistent with TI 2515/174, the staff plans no verification inspection at Watts Bar Unit 2, but the implementation may be subject to general inspection if that unit becomes licensed for operation.

Relationship to Japan Lessons-Learned Activities

As a result of the March 2011 events in Japan, the staff reassessed its plans for final closure of GI-189. The staff concluded that the events in Japan had a clear nexus to GI-189 because the event involved an extended station blackout and, as a result, hydrogen generation was not adequately controlled to prevent detonation. However, the affected units in Japan were a different design than the units within the scope of GI-189, and effective measures to control combustible gas within containment had been implemented.

In SECY-11-0093 (Ref. 34), "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan," dated July 12, 2011, the staff provided the recommendations of the Near-Term Task Force (NTTF) to the Commission. In Recommendation 4.1, the NTTF called for strengthening station blackout mitigation capability through rulemaking to:

(1) establish a minimum coping time of 8 hours for a loss of all ac power.
(2) establish the equipment, procedures, and training necessary to implement an "extended loss of all ac" coping time of 72 hours for core and spent fuel pool cooling and for reactor coolant system and primary containment integrity as needed.
(3) preplan and prestage offsite resources to support uninterrupted core and spent fuel pool cooling, and reactor coolant system and containment integrity.

The NTTF specified that the 8 hour coping time strategy include the capability to preserve containment integrity for extended station blackout conditions by operation of one train of hydrogen igniters at BWR facilities with Mark III containments and at PWR facilities with ice condenser containments. In SECY-11-0137 (Ref. 35), "Prioritization of Recommended Actions to Be Taken in Response to Fukushima Lessons Learned," the staff recommended that the NRC, as a near-term action, undertake rulemaking activities to enhance the capability to maintain safety through a prolonged SBO. However, in Staff Requirement Memo 11-0137 (Ref. 36), the Commission stated it will evaluate the staff's basis for imposing new requirements when documented in notation vote papers for any new requirements promulgated by rulemaking.

Thus, the staff has defined a process to consider the lessons of the events in Japan and implement new requirements for combustible gas control during extended station blackouts, subject to Commission review and approval. Therefore, the staff concluded GI-189 can be closed without regard to completion of staff actions related to the events in Japan.

As directed by the Commission in SRM-SECY-12-0025 (Ref. 37), dated March 9, 2012, the staff has also undertaken regulatory actions that originated from NTTF Recommendation 4.2. On March 12, 2012, the staff issued Order EA-12-049 (Ref. 38), which requires that licensees develop, implement, and maintain guidance and strategies to maintain or restore core cooling, containment, and SFP cooling capabilities following a beyond design basis external event. In the Draft Japan Lessons-Learned Project Directorate Interim Staff Guidance (JLD-ISG) 2012-01 (Ref. 39), "Compliance with Order EA-12-049, Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," the staff position specified that licensees with installed hydrogen igniters develop and maintain strategies to provide alternative power from generating equipment independent of the safety-related on-site power sources to supply electricity to one train of hydrogen igniters. This position has been incorporated into Nuclear Energy Institute (NEI) 12-06, Revision 0 (Ref. 40), "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," dated August 2012. Upon full implementation of these Orders at nuclear power plants, the staff expects that affected licensees will have a robust capability to provide backup power to one train of hydrogen igniters.

4.0 CONCLUSION

The staff initially established GI-189 to investigate the potential for installation of backup power supplies for hydrogen igniters in a manner that would provide a substantial increase in overall safety that justified the cost of implementation at PWRs with ice condenser containments and BWRs with Mark III containments. The staff has established that the scope of GI-189 has been appropriately limited to the PWRs with ice condenser containments and BWRs with Mark III containments because other reactor designs have containments with significantly greater volume and strength.

The staff completed a regulatory analysis that found voluntary actions provided reasonable capability to provide backup power to one train of hydrogen igniters, and with full implementation of these voluntary actions, further regulatory requirements would not be justified by the increased benefits. Staff communication with affected licensees resulted in implementation of backup power capabilities with enhanced ability to mitigate security-related events at operating units within the scope of GI-189. In addition, the staff has received a commitment from the Tennessee Valley Authority to implement the identical capability at Watts Bar Unit 2 as the capability established at Watts Bar Unit 1, should Unit 2 receive an operating license. These voluntary actions have been implemented pursuant to regulatory commitments as part of GI-189, and the NRC staff completed inspections at the affected sites to verify implementation consistent with those commitments.

The staff expects full implementation of Order EA 12-049 to enhance this capability by establishing a means to power the hydrogen igniters that has been developed to withstand the effects of potential external events. Staff initiated rulemaking addressing station blackout offers a path to more fully assess containment integrity considerations during extended station blackouts.

Therefore, the staff concluded that lessons learned from the events in Japan will be appropriately incorporated into NRC requirements through established processes and the closure of GI-189 is appropriate.

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