April 30, 2013

Mr. Mark Leyse
P.O. Box 1314
New York, NY 10025

Dear Mr. Leyse:

Your petition dated February 28, 2012, supplemented on April 4, 2012, and addressed to the Executive Director for Operations was referred to the Office of New Reactors pursuant to the Nuclear Regulatory Commission's (NRC's) regulations in Section 2.206 of Title 10 of the *Code of Federal Regulations* (10 CFR). In your petition, you requested the NRC order the licensee of Vogtle Electric Generating Plant Units 3 and 4 (VEGP) to take the following actions:

1. Conduct safety analyses of severe accident scenarios in which the AP1000 hydrogen igniter system would be actuated too late (either due to flawed emergency response guidelines or plant operator error), after a local hydrogen concentration of eight percent or greater was reached in the containment, which could cause a fast hydrogen deflagration, and after a local detonable concentration of hydrogen developed in the containment, which could cause a hydrogen detonation,

2. Demonstrate that actuating hydrogen igniters in a severe accident after the core-exit temperature exceeds a predetermined temperature (1200 °F) is a productive and safe emergency response guideline for all severe accident scenarios, and

3. Conduct safety analyses of severe accident scenarios in which the AP1000 passive autocatalytic hydrogen recombiner system would malfunction by having unintended ignitions after a local hydrogen concentration of eight percent or greater was reached in the containment, which could cause a fast hydrogen deflagration, and after a local detonable concentration of hydrogen developed in the containment, which could cause a hydrogen detonation.

As the bases for these requests, you stated that Westinghouse does not consider that the AP1000 containment's hydrogen igniter system would be capable of providing enough energy to directly initiate a detonation or that the containment's passive autocatalytic hydrogen recombiner system would be capable of providing enough energy to directly initiate a detonation. You also stated that recent reports have questioned the safety of using igniters to mitigate hydrogen at certain times in severe accidents and/or without having conducted thorough safety analyses with computer codes. Finally, you stated that Westinghouse does not consider that experimental data indicates that core-exit temperature measurements would not be an adequate indicator for when to either correctly or safely actuate hydrogen igniters in a severe accident.

You met with our petition review board (PRB) via teleconference on March 28, 2012 and again on October 24, 2012, to discuss your petition. The results of that discussion have been

considered in the PRB's determination of whether or not your petition meets the criteria for consideration under 10 CFR 2.206. For the reasons provided below, the staff has concluded that your submittal does not meet the criteria for consideration under 10 CFR 2.206.

The staff has concluded that Request 2 above is based on the same underlying concern raised in petition for rulemaking PRM-50-105, "In-core Thermocouples at Different Elevations and Radial Positions in Reactor Core," (77 FR 30435), dated May 23, 2012. That concern is the adequacy and reliability of core-exit thermocouples used to determine when to actuate hydrogen igniters. Because this is a generic issue not limited to VEGP or the AP1000 design, this request is being addressed in the staff's review of PRM-50-105.

The staff has also concluded that Requests 1 and 3 above do not meet the criteria for review. Although the petition asks the NRC to take enforcement action against a particular licensee, the issues raised in these requests relate to the AP1000 design, which has already been the subject of NRC staff review and evaluation as part of the AP1000 design certification. Under 10 CFR Part 52, Appendix D, Section VI.B, the safety issues raised in Requests 1 and 3 are considered resolved. Because the licensee for VEGP references the relevant portions of the AP1000 design without departure or exemption, there are limited circumstances in which the NRC may take plant-specific enforcement action. Under 10 CFR 52.63(a)(4) and 10 CFR Part 52, Appendix D, Section VIII.B.3, the NRC may not impose new requirements by plant-specific order on a plant that references the AP1000 design unless a modification is necessary to secure compliance with NRC regulations or to ensure adequate protection. The petition did not demonstrate that such circumstances exist. The enclosure to this letter provides additional discussion of how Requests 1 and 3 were addressed in the AP1000 design certification review.

Please contact Ms. Denise McGovern at (301) 415-0681 or denise.mcgovern@nrc.gov if you have additional questions.

Sincerely,

/RA/

Frank Akstulewicz, Deputy Director
Division of New Reactor Licensing
Office of New Reactors

Docket Nos. 52-025 and 52-026

cc: VEGP (w/copy of incoming 2.206
Request) Additional Distribution
via Listserv

Enclosure: Summary of NRC Staff
Consideration of 2.206 Petition
from M. Leyse, G20120142

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cc: VEGP (w/copy of incoming 2.206 Request) Additional Distribution via Listserv

Enclosure: Summary of NRC Staff Consideration of 2.206 Petition from M. Leyse, G20120142

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Evaluation of Mark Edward Leyse's February 28, 2012 Petition for Enforcement Action

Introduction

In August 2007, the NRC published Title 10, *Code of Federal Regulations*, Part 52, Appendix D, "Design Certification Rule for the AP1000 Design." The rule was amended in December 2011. Southern Nuclear Operating Company referenced the amended design in its application for a combined license (COL) to build and operate Vogtle Electric Generating Plant Units 3 and 4 at its site in Waynesboro, Georgia. The COL was issued February 10, 2012.

On February 28, 2012, Mr. Mark Leyse petitioned the Commission to modify the license pursuant to 10 CFR Part 2, Subpart B, "Procedure for Imposing Requirements by Order, or for Modification, Suspension, or Revocation of a License, or for Imposing Civil Penalties," §2.206, "Requests for action under this subpart."

Petition request and assertions

The petition asks the NRC to order the licensee of Vogtle Units 3 and 4 to conduct certain safety analyses. First, it requests analysis of severe accident scenarios in which the AP1000 hydrogen igniter system would be actuated too late (after cladding has started to react with coolant, generating large quantities of hydrogen that is released to the containment). Second, it asks for analysis of the consequences of ignition of hydrogen by a passive autocatalytic recombiner (PAR) when locally detonable concentrations of hydrogen may exist elsewhere in containment. (See petition at pages 3 and 4.)

The petition implies that Westinghouse erred by failing to consider that the hydrogen igniters or a PAR could directly induce a detonation. (See petition at pages 8-9 and 9-10.)

Disposition

As part of the application for certification of the AP1000 design, Westinghouse submitted a report on the AP1000 probabilistic risk assessment (PRA). Chapter 41 of the PRA documented severe accident scenarios that involved hydrogen burning (deflagration) and exploding (detonation). The analyses bounded the cases identified by the petitioner. The staff reviewed the applicant's analyses; all issues related to hydrogen deflagration and detonation were resolved before certifying the AP1000 design. The staff's evaluation is documented in NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design". Since the Vogtle COL application referenced the relevant portions of the AP1000 certified design without departure or exemption, the requests identified above are rejected because the issues have already been reviewed by the staff.

Discussion

If an accident in a light-water reactor progresses to core damage, the core is likely to reach temperatures where the metal cladding reacts rapidly and exothermically with water, oxidizing the metal and generating large quantities of hydrogen. This combustible gas must be controlled.

In the AP1000, the hydrogen control system includes instruments to monitor hydrogen concentration, PARs to remove hydrogen released during design-basis accidents, and a hydrogen igniter system to limit the concentration of hydrogen in the containment during severe accidents. The hydrogen igniter system has the following features:

- The hydrogen igniter system comprises 64 glow plug igniters that, when energized, quickly become hot enough to start a flame if the concentration of hydrogen is high enough to allow ignition.

  Igniters are placed (a) where diffusion flames can burn hydrogen before it is distributed in the containment atmosphere and (b) where higher-than-average concentrations of hydrogen may accumulate. Where detonable concentrations of hydrogen may develop in a severe accident, igniters are spaced closely enough that flame fronts do not have the opportunity to accelerate to detonation (even if the igniters are not energized until after a detonable concentration is achieved).

- For redundancy, each igniter receives power from one of two divisions of the non-safety-related onsite ac power system. If offsite ac power is available, it supplies the system; otherwise, onsite nonessential diesel generators do. The igniters can also be powered by non-Class 1E batteries via inverters (devices that convert dc to ac). The batteries have the capacity to power the igniters for four hours.

- Control room operators manually actuate the igniters when core exit temperature exceeds 1200 °F. This is one of the first steps in emergency response guideline AFR.C-1. It is early in the sequence of actions to ensure that operators activate the igniters before rapid cladding oxidation begins.

In addition, the two non-safety-related PARs are designed to control the hydrogen that is formed by radiolysis and normally dissolved in the reactor coolant. This hydrogen would be released in a loss of coolant accident (LOCA), but hydrogen concentrations will not reach the lower flammability limit at any location in containment during a LOCA.

In normal operation, the AP1000 containment is not inerted; its atmosphere is air. During severe accidents, the AP1000 containment atmosphere is likely to contain a significant concentration of steam, which raises the lower flammability limit of hydrogen. If the volume fraction of the containment atmosphere that is steam reaches 55 percent, hydrogen cannot burn at all. (This phenomenon is called “steam inerting.”)

In a severe accident, large quantities of hydrogen are generated by metal-water reaction between the fuel cladding and the reactor coolant. As long as the reactor coolant system is intact, the gas would pass through the surge line to the pressurizer, then through relief and depressurization valves into spargers in the in-containment refueling water storage tank (IRWST), then through vent valves into the containment atmosphere. If the final stage of depressurization is reached (or if there is a break in the reactor coolant pressure boundary) hydrogen will pass directly into the containment, most likely by way of the loop compartments.

Hydrogen in the containment atmosphere will start to burn if its concentration is above the lower ignitability limit[1] (~8 percent in dry air) and sufficient activation energy is supplied to start the reaction. This energy can be supplied in several ways such as a spark, flame, or hot surface.

When actuated, the surface of each hydrogen igniter is designed to be hotter than 870 °C (1600 °F) even under severe accident conditions. As soon as the local concentration of hydrogen is above the lower ignitability limit, the igniter will cause combustion to begin.

The PARs become hot because of the energy released when hydrogen and oxygen react on the catalytic surface. At some point (slightly above the lower flammability limit of hydrogen), this energy is also sufficient to ignite a hydrogen-air mixture. The petitioner characterized this as a malfunction (see petition at page 9). The staff does not agree that the ignition of hydrogen at PARs is a malfunction; rather, it is a predictable consequence of PAR operation. The PARs are designed to control hydrogen released to containment during design-basis events, where core damage is prevented and flammable concentrations of hydrogen are not produced. For the AP1000, PARS are not credited in the analysis of severe accidents. As discussed below, ignition by PARs (or any other source) was evaluated by Westinghouse and considered in the staff's review of the AP1000.

Once it is ignited, any oxygen-deprived combustible gas will burn as it encounters air, forming a static flame front called a diffusion flame. (Gas stoves and propane torches are common examples.) In the AP1000, hydrogen igniters are located where hydrogen would be released into containment in a severe accident (e.g., IRWST vents and where the loop compartments are open to the rest of containment). Ignition of the hydrogen by the igniters will consume the hydrogen before it can mix with the general containment atmosphere, ensuring that the AP1000 meets 10 CFR 50.44(c), which requires that hydrogen concentrations in containment must be limited to less than 10 percent by volume and containment structural integrity must be maintained.

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[1] The ignitability limit is the concentration at which hydrogen starts to burn. Once hydrogen is burning, a lower concentration is needed to maintain the flame. This is called the lower flammability limit. In theory, there are also upper ignitability and flammability limits, but for practical purposes, those limits do not need to be considered.

If enough hydrogen mixes with air and it is then ignited, it will burn rapidly. Unlike a diffusion flame, this rapid burning produces an abrupt increase in containment pressure. Starting at the point of ignition, a flame front moves through the flammable mixture, leaving behind the products of combustion (water vapor) and unburned hydrogen—whatever remains when the concentration of hydrogen drops below the lower flammability limit. (In dry air, this limit varies from 4 percent for a flame front moving upward to 10 percent for a flame front moving downward.)

Combustion with a flame front that travels more slowly than the speed of sound is a deflagration. The pressure that deflagration can produce is bounded by adiabatic, isochoric, complete combustion (AICC). AICC is the result of filling the containment with all the hydrogen generated in a severe accident, completely mixing it with dry air, then burning it all at once. For the AP1000, Westinghouse reported that the resulting pressure is not high enough to cause the containment to fail (see Section 19.34.2.3 of the PRA). The staff confirmed this assertion in an independent analysis using MELCOR, discussed in Section 19.2.3.3.7 of the staff's Final Safety Evaluation Report (FSER).

Combustion with a flame front that travels supersonically is a detonation (explosion). The dynamic effects associated with detonation of hydrogen could cause the containment to fail. For hydrogen in dry air, the lower detonability limit is about 18 percent by volume. In addition, the activation energy to initiate a detonation directly is *two hundred million times greater* than that required to initiate a deflagration. Neither the igniters nor the PARs can deliver that much energy to the containment atmosphere (see Section 19.41.2 of the PRA). Thus, the staff accepted Westinghouse's assertion (in Section 19.34.2.3 of the PRA) that direct detonation will not result in containment failure because there are no ignition sources of sufficient energy to directly initiate a detonation.

Although, as explained above, direct detonation of hydrogen in the AP1000 is not considered credible, indirect detonation is possible. If a flame front travels through a compartment with both the right shape and high enough concentrations of hydrogen and oxygen, then the flame front will accelerate. If the flame front accelerates for a long enough period of time to reach the speed of sound, it becomes a detonation. This is a deflagration-to-detonation transition (DDT). Westinghouse stated in Section 19.34.2.3 of the PRA that DDT is the only mechanism likely to produce a detonation in the AP1000.

As explained above, a DDT occurs only when a deflagration accelerates to the speed of sound. In a deflagration, the flame front travels some distance while it accelerates. As a flame front passes through a flammable mixture of hydrogen and air, nearly all of the hydrogen is consumed. If the flame front runs out of fuel before it can travel far enough to reach the speed of sound, there will be no DDT, and thus no detonation. In the AP1000, multiple igniters are placed in compartments where detonable concentrations of hydrogen could develop. There is too little distance between the igniters for flame fronts to accelerate to the speed of sound before colliding (and running out of fuel). Therefore, late actuation of the igniters is unlikely to lead to detonation, even after establishing locally detonable concentrations of hydrogen.

In the AP1000, the hydrogen control system prevents hydrogen from reaching a detonable concentration. It does this by burning it in two ways: (1) in diffusion flames at release points and (2) in deliberate deflagrations in the containment and its compartments. If the hydrogen igniter system is operable, the conditions necessary for DDT cannot develop unless a reactor operator makes a mistake (operator error), multiple igniters fail because of a shared flaw (common-cause failure), or the plant experiences an extended loss of alternating current (station blackout). These scenarios are unlikely but theoretically possible.

In Section 19.41 of the PRA, Westinghouse performed analyses for several cases where the hydrogen control system does not function. In these scenarios, detonable concentrations of hydrogen develop in compartments within the containment building. For each compartment, Westinghouse assumed that sufficient oxygen is present and that a random source within the compartment ignites the hydrogen. Because of the assumption in these scenarios that the igniters are inoperable, the acceleration time (and the distance the flame front travels) is limited only by the geometry of the compartment, not the spacing of igniters. If the compartment geometry allows DDT, detonation is assumed to occur.

The Westinghouse analyses assumed that detonation would result in containment failure. Assuming that detonation causes containment failure, the sum of all hydrogen-related contributions to risk of containment failure remains a very small percentage of the total. As documented in the NRC staff's evaluation found in FSER Section 19.1.3.2.2, Westinghouse conservatively estimated that containment failure from DDT had a containment failure frequency of 1.9E-10/yr, or less than 1 percent of the total containment failure frequency. In addition, staff considered a scenario where the igniters are unavailable and found that the operation of igniters is important to maintaining a low release frequency, but that system reliability can be reduced and not substantially impact risk.

This scenario bounds the case where all but one igniter fails in a given compartment and that igniter is not actuated until after a detonable concentration is achieved. It also bounds the case where hydrogen igniters are not actuated and ignition occurs at a PAR. (For detonation to be caused by a PAR, the flame front would have to propagate to the opening that connects the compartment to the rest of containment, and then accelerate to the speed of sound within the compartment.)

Conclusion

Actuated on time, the hydrogen ignition system would ignite diffusion flames where oxygen-starved hydrogen enters containment. Delayed actuation of the igniters could allow a larger volume of combustible hydrogen-air mixture to develop. In such a case, when the igniters are actuated (or if ignition occurs at a PAR) deflagration would occur. As explained above, the containment structure can withstand the limiting deflagration.

If the igniters fail, a detonable concentration of hydrogen could form and detonation (as a result of DDT) could occur and cause the containment to fail. Containment failure is the worst consequence that detonation can cause. Actual consequences are likely to be less severe. Assuming that detonation causes containment failure, the sum of all hydrogen-related contributions to risk of containment failure remains a very small percentage of the total (less than 1 percent of the total containment failure frequency).

In conclusion, Westinghouse evaluated scenarios that bound those suggested by the petitioner. After reviewing these severe accident scenarios, the staff concluded that the AP1000 containment design satisfies the Commission's containment performance goal and is acceptable. Therefore, the staff has addressed the issues raised in the petition and the issues were considered and resolved as part of the certification of the AP1000 design.

Documentation

The above analyses are described in the AP1000 Probabilistic Risk Assessment Report. Most of the details are provided in Chapter 34, "Severe Accident Phenomena Treatment,"[2] and Chapter 41, "Hydrogen Mixing and Combustion Analysis." The staff's evaluation is documented in NUREG-1793, Section 19.1, "Probabilistic Risk Assessment" and 19.2, "Severe Accident Performance":

19.1.2.2.2, "Large, Passively Cooled Steel Containment"

19.1.2.2.6, "Hydrogen Igniter System"

19.1.3.2.1, "Core Damage Sequences and Accident Classes Contributing to Containment Failure"

19.1.3.2.2, "Leading Contributors to Containment Failure from the Level 2 PRA"

19.1.3.2.3, "Important Insights from Level 2 PRA and Supporting Sensitivity Analyses"

19.1.8.28, "Hydrogen Igniter System"

19.2.3 "Deterministic Assessment of Severe Accident Mitigation"

19.2.6, "Conditional Containment Failure Probability Distribution"

[2] Specifically, Sections 34.2.3, "Hydrogen Combustion and Detonation" and 34.4.13, "Intermediate and Late Containment Failure Cases.