SAFETY EVALUATION BY THE OFFICE OF NEW REACTORS

RELATED TO AMENDMENT NO. 31

TO THE COMBINED LICENSES NOS. NPF-91 AND NPF-92

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GEORGIA POWER COMPANY

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MUNICIPAL ELECTRIC AUTHORITY OF GEORGIA

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VOGTLE ELECTRIC GENERATING PLANT UNITS 3 AND 4

DOCKET NOS. 52-025 AND 52-026

1.0 INTRODUCTION

By letter dated November 21, 2013 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML13326A973 (Reference 1)), Southern Nuclear Operating Company (SNC or the licensee) submitted a license amendment request ((LAR) 13-039) requesting U.S. Nuclear Regulatory Commission (NRC or Commission) approval for amendments to the Vogtle Electric Generating Plant (VEGP) Units 3 and 4 combined licenses (COLs) NPF-91 and NPF-92, respectively.

The LAR proposes to depart from Westinghouse Electric Company's (Westinghouse) AP1000 Design Control Document (DCD), Revision 19 (ADAMS Accession Number ML11171A457 (Reference 2)) Tier 2 information as incorporated into the VEGP Units 3 and 4 Updated Final Safety Analysis Report (UFSAR), Revision 3 (ADAMS Accession No. ML14178B362 (Reference 3)) to allow use of a new methodology to determine the effective thermal conductivity resulting from oxidation of the inorganic zinc (IOZ) used in the containment vessel coating system.

The AP1000 design includes an IOZ coating on the inside and outside of the containment vessel. The functions of the IOZ coating are to promote wettability, conduct heat, adhere to the steel, and inhibit corrosion. These functions are all safety-related and are described in Tier 2, Section 6.1.2, of the AP1000 DCD, Revision 19, and listed in Tier 2, Table 6.1-2. Since the design for a loss-of-coolant accident (LOCA) credits transfer of heat through the containment vessel to water from the passive containment cooling system (PCS) flowing over the outside surface, failure of any of the coating functions may affect the ability to remove heat from containment and maintain the containment pressure within the design basis.

Westinghouse used the WGOTHIC computer code to evaluate the post-LOCA containment pressure in WCAP-15846 (Reference 4). One of the many inputs to the model is the thermal conductivity of the IOZ coating on the containment vessel. To account for oxidation of the coating over the life of the plant, the thermal conductivity value used in the WGOTHIC evaluation was one-fourth of the assumed initial value of 1.21 BTU/h-ft-°F (2.09 W/m-K). This thermal conductivity decrease was considered to be conservative based on engineering judgment rather than on a mechanistic understanding of how thermal conductivity might change over time. This was accepted by the NRC staff as a conservative approach, as stated in Section 21.6.5.7.4.6 of the Final Safety Evaluation Report (FSER) for Revision 19 of the AP1000 DCD (NUREG-1793, Supplement 2, (Reference 5)).

As an alternative to applying the amount of thermal conductivity reduction stated above, the licensee submitted LAR-13-039 to apply a smaller thermal conductivity reduction from aging. The methodology originally proposed in LAR-13-039 was based on a mechanistic approach to thermal conductivity as a function of coating oxidation. The licensee described a technical basis for this change in a proprietary LAR enclosure, "Effective Thermal Conductivity Model of Inorganic Zinc Coating for Application to AP1000," WCAP-15846, Addendum 1, Revision 0, October 2013 (hereafter referred to as Addendum 1). LAR-13-039 proposes no change to the peak containment pressure because the approach proposed in the amendment results in the same end-of-life thermal conductivity value used in the AP1000 DCD (0.302 BTU/h-ft-°F, 0.522 W/m-K).

The licensee subsequently modified the LAR in a response dated March 5, 2014, (Reference 7) to a staff request for additional information (RAI) 01. Rather than referencing the Addendum 1 methodology for the value of thermal conductivity, the licensee proposed revising VEGP Units 3 and 4 UFSAR Subsection 6.2.1.1.3, "Design Evaluation," which describes the references for the inputs to the containment peak pressure evaluation. The revised VEGP Units 3 and 4 UFSAR states that the thermal conductivity for the inorganic zinc coating listed in VEGP Units 3 and 4 UFSAR Table 6.2.1.1-8 (0.302 BTU/h-ft-°F, 0.522 W/m-K) "is the minimum design requirement value after reduction by a factor of two to account for degradation due to aging." Therefore, the amendment would result in a minimum required initial thermal conductivity value of 0.604 BTU/h-ft-°F (1.04 W/m-K).

The licensee provided additional information in a letter dated June 30, 2014, (Reference 8) in response to the NRC staff's RAI 02. The additional information provided in the licensee's letters dated March 5 and June 30, 2014 did not expand the scope of the application as originally noticed and did not change the NRC staff's original proposed no significant hazards consideration determination as published in the *Federal Register* on March 18, 2014 (79 FR 15150).

2.0 REGULATORY EVALUATION

The following regulations, regulatory guidance and design criteria are applicable in whole or in part for review of the suitability of the effective thermal conductivity resulting from oxidation of the IOZ used in the containment vessel coating system that is associated with the Tier 2 departures requested in the LAR:

- Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, Appendix D, Section VIII.B.5.b(8) requires a license amendment for a Tier 2 departure if the proposed change "[r]esult[s] in a departure from a method of evaluation described in the plant-specific DCD used in establishing the design bases or in the safety analyses."

- 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 16 (“Containment design”) requires that reactor containment and associated systems be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

- 10 CFR Part 50, Appendix A, GDC 50 (“Containment design basis”) requires the containment structure be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident.

- NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (SRP) Section 6.2.1.1.A, addresses GDC 16 and 50. To satisfy the requirements of GDC 16 and GDC 50, SRP Section 6.2.1.1.A states that, in general, the peak calculated containment pressure should be approximately the same as at the design certification stage of review. Therefore, the NRC staff reviewed the LAR with respect to how the revised approach to IOZ coating thermal conductivity as a function of aging affects the calculated containment peak pressure. If a thermal conductivity value of 0.302 BTU/h-ft-°F (0.522 W/m-K) continues to be justified for the aged coating, then the new approach to IOZ coating thermal conductivity would not affect the calculated peak containment pressure. The LAR stated that there would be no change in the value of thermal conductivity assumed in the design basis or in the calculated design basis containment peak pressure associated with the new methodology for evaluating the thermal conductivity of the IOZ coating system.

3.0 TECHNICAL EVALUATION

3.1 Licensee Evaluation

In LAR-13-039, the licensee proposed UFSAR changes related to the basis for the effect of aging on IOZ coating thermal conductivity, and a methodology used to justify the changes. The methodology was in the form of Addendum 1 to WCAP-15846. Addendum 1 describes a review of candidate models for calculating the thermal conductivity of new and aged inorganic zinc coatings. The purpose of modeling was to calculate the effect of aging on thermal conductivity as an alternative to the assumption that aging would reduce the thermal conductivity to one-fourth of the initial value. Addendum 1 includes an initial measured thermal conductivity of the coating product being applied to the VEGP Units 3 and 4 containment vessels (**[ ]** BTU/h-ft-ºF, **[ ]** W/m-K)[1]. Addendum 1 concludes that an empirical model developed by Krischer (Reference 9) is suitable. That model requires a measured thermal conductivity value and the individual thermal conductivities and volume fractions of the coating constituents. The licensee applied the model to aging by assuming that all of the zinc in the coating was oxidized to zinc oxide. The calculated thermal conductivity decrease was relatively small, from **[ ]** to **[ ]** BTU/h-ft-ºF (**[ ]** to **[ ]** W/m-K). The LAR proposed using this modeling approach for calculating the end-of-life thermal conductivity of the IOZ coating on the Vogtle Units 3 and 4 containment vessels.

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[1] Brackets designate proprietary information.

Addendum 1 included an additional evaluation of the effect of aging by considering that oxidation of the zinc particles in the coating would decrease the coating porosity, thereby increasing the thermal conductivity of the coating due to the much higher thermal conductivity of zinc oxide compared to the air in the pores. The calculated thermal conductivity increased from **[ ]** to **[ ]** BTU/h-ft-ºF (**[ ]** to **[ ]** W/m-K), but the licensee did not propose applying this less conservative approach to VEGP Units 3 and 4. If aging reduces porosity and increases the thermal conductivity of IOZ coatings, then the increase provides margin in the licensee's evaluation of the effect of aging on thermal conductivity.

By letter dated March 5, 2014, the licensee responded to staff RAI 01 dated January 24, 2014 (ADAMS Accession No. ML14023A631). The licensee provided clarification regarding whether the coating and thermal conductivity identified in Addendum 1 (Carboline Carbozinc 11 HSN, **[ ]** BTU/h-ft-ºF, **[ ]** W/m-K) is the same coating applied to the VEGP Units 3 and 4 containment vessels. The licensee's response stated that it was the same coating. The licensee noted that the initial measured thermal conductivity value reported in Addendum 1 was provided by Westinghouse and the licensee had not yet checked it for conformance with quality requirements and industry standards. The licensee also provided measured thermal conductivity values of IOZ coatings, discussion of the applicability of the Krischer model, results of calculations showing the effect of thermal conductivity on peak containment pressure, uncertainty in the calculations and measurements, description of test procedures, characterization of coating porosity, and test results for new and aged coating material. Aged sample thermal conductivity values submitted by the licensee were provided by the coating manufacturer, based on testing of a sample which was nominally of the same coating material used for the VEGP Units 3 and 4 containment vessels and which had been exposed to an industrial atmosphere for 10 years.

By letter dated June 30, 2014, the licensee provided its response to staff RAI 02 dated May 15, 2014 (ADAMS Accession No. ML14127A224). The licensee provided confirmation of the initial measured coating thermal conductivity identified in Addendum 1 (**[ ]** BTU/h-ft-ºF, **[ ]** W/m-K). This was based on the measurement following the applicable American Society for Testing Materials (ASTM) International standards and meeting the quality requirements of 10 CFR Part 50, Appendix B. The licensee also provided clarification on measurement methods and variability, corrections to previously reported test results, and revisions to the proposed UFSAR changes. The additional information clarified how different methods were used to derive the thermal conductivity of the thin coating applied to the much thicker steel substrate. The licensee's response also refined the coating thickness measurements, resulting in changes to calculated thermal conductivity values provided in the first response.

In the response to RAI 02, the licensee changed the proposed UFSAR revision to clarify that it is related to thermal conductivity. The licensee also removed the reference to Addendum 1 as a methodology for determining the end-of-life coating thermal conductivity. The current end-of-life for VEGP Units 3 and 4 is defined in the COLs as approximately 40 years. As modified by the RAI response, the LAR requests approval to assume a reduction in the initial thermal conductivity of the IOZ coating by one-half to account for aging, without relying on the Addendum 1 methodology or any other predictive model. The request does not change the Initial Test Program requirement (UFSAR Section 14.2.9.1.4) to determine the initial thermal conductivity of the applied coating using sample coupons from the containment shell.

3.2 NRC Staff Evaluation

The licensee’s proposed amendment would require a minimum initial coating thermal conductivity of twice the design-basis minimum value to prevent the containment accident pressure from exceeding the design limit. For VEGP Units 3 and 4, this would require an initial coating thermal conductivity of 0.604 BTU/h-ft-ºF (1.04 W/m-K) to maintain the end-of-life (aged) thermal conductivity of 0.302 BTU/h-ft-ºF (0.522 W/m-K). The staff evaluated this request by considering the characteristics and aging of IOZ coatings, the licensee’s measured values for thermal conductivity of IOZ coatings, and models for calculating thermal conductivity. The staff also gained insights from using some of the models to calculate the thermal conductivity of new and aged IOZ coating. The evaluation is discussed below following a description of the significance of the IOZ coating thermal conductivity and the Vogtle Units 3 and 4 design and licensing bases.

3.2.1 Thermal conductivity significance and background

The containment peak pressure during a postulated LOCA depends, in part, on the transfer of heat from the inside surface of the containment vessel to the water flowing over the outside of the containment vessel. Therefore, the thermal conductivity of the IOZ coating affects the containment peak pressure. The IOZ coating on both inside and outside of the containment vessel is considered safety-related and is applied, maintained, and inspected in accordance with the plant’s 10 CFR Part 50, Appendix B program for special processes. Chapter 6 of the VEGP Units 3 and 4 UFSAR identifies the industry standards that form the basis for the coatings program.

In RAI 01, with 10 questions, Questions 1-5, 1-6, and 1-7 requested the calculated peak containment pressure for three combinations of coating initial thermal conductivity and thermal conductivity aging reduction. In its March 5, 2014, response, the licensee stated that the WGOTHIC version used in the design certification predicts a LOCA peak containment pressure of **[ ]** psig when using the initial thermal conductivity value provided by Westinghouse (**[ ]** BTU/h-ft-ºF, **[ ]** W/m-K) and the aging reduction assumed in WCAP-15846 (i.e., a factor of 4 reduction), which results in an aged IOZ thermal conductivity of **[ ]** BTU/h-ft-ºF (**[ ]** W/m-K). This aging effect in IOZ thermal conductivity results in a containment vessel pressure that is greater than the design basis limit (59.0 psig) and the calculated peak containment pressure in the certified design (58.3 psig). This indicates that the peak containment pressure is not highly sensitive to the coating thermal conductivity, since a factor-of-two change in thermal conductivity corresponds to **[ ]** psig in containment pressure (Table 1.) However, this change is significant because of the small margin between the calculated peak containment pressure (58.3 psig) and the design basis limit (59.0 psig).

TABLE 1: Effect of Aging (assumed thermal conductivity reduction factor) on the Calculated Peak Containment Pressure

Thermal Conductivity Unaged BTU/h-ft-ºF	Aging Reduction Factor	Thermal Conductivity Aged BTU/h-ft-ºF	Calculated Peak Containment Pressure psig
1.21	4	0.302	58.3
[ ]	4	**[ ]**	**[ ]**
[ ]	Addendum 1	**[ ]**	**[ ]**
Design maximum allowable pressure		59.0 psig	

In RAI 02, Question 2-1 asked the licensee to identify the IOZ coatings determined to comply with its 10 CFR Part 50, Appendix B program and applicable ASTM standards. The licensee stated that the Carbozinc 11 HSN coating was the only coating determined to be in compliance at that time, and the thermal conductivity reported by Westinghouse had been measured in accordance with ASTM E1530 (Reference 10), which is endorsed by the staff through Regulatory Guide (RG) 1.54, Revisions 1 and 2 (Reference 11). RG 1.54 endorses ASTM Standard D5144 (Reference 12), which lists E1530 as a method for measuring coating thermal conductivity. These standards apply to the licensee through its conformance to RG 1.54, as committed to in the FSAR. As explained below, the staff concludes that the licensee's response validates the measured value of **[ ]** BTU/h-ft-°F (**[ ]** W/m-K) discussed in the preceding paragraph.

3.2.2 AP1000 Design Basis and Vogtle Licensing Basis

The containment heat transfer calculations for the AP1000 design were performed as reported in WCAP-15846, which included calculations using IOZ coating thermal conductivity values reduced to account for aging over the life of the plant. The staff accepted this approach as conservative as stated in the FSER for AP1000 DCD, Revision 19. The approved design basis minimum value of the thermal conductivity is 0.302 BTU/h-ft-°F (0.522 W/m-K). This requirement applies to Vogtle Units 3 and 4 because the licensee references the AP1000 design certification. The staff notes that the corresponding, assumed initial thermal conductivity value of 1.21 BTU/h-ft-°F (2.09 W/m-K) for the AP1000 is also listed as typical for an IOZ coating in ASTM D5144.

3.2.3 Description of Inorganic Zinc Coatings

IOZ is a mixture of several components. In terms of weight, IOZ coating is almost entirely metallic zinc particles and a silicate binder material. In terms of volume, zinc particles and the silicate binder are the two most abundant material constituents, but this type of coating also contains a significant volume fraction of air in the form of porosity. Specific coating formulations are proprietary. For the Carboline Carbozinc 11 HSN coating described in the LAR, the porosity is about **[ ]** of the volume, and it also contains about **[ ]** percent by volume of additional binder and pigment materials.

3.2.4 Evaluation of the Measured Inorganic Zinc Coating Thermal Conductivity

Addendum 1 identifies a value for the initial thermal conductivity of the Carboline Carbozinc 11 HSN product, measured according to ASTM E1530. At the time of the LAR submittal, the licensee had not verified that the testing had been performed in accordance with the 10 CFR Part 50, Appendix B, and the applicable ASTM standards. The licensee provided the following additional information about the thermal conductivity measurements in RAI responses and in a July 24, 2014, public meeting (Reference 13):

- Verification that the value reported by Westinghouse in Addendum 1 (**[ ]** BTU/h-ft-°F, **[ ]** W/m-K) conformed to the requirements of Appendix B and ASTM E1530.

- Measured thermal conductivity values for unaged and aged Carbozinc 11 HSN samples provided to Westinghouse by the coating vendor (Carboline). Westinghouse performed visual examinations before sending them to an independent test laboratory for thermal conductivity testing. The laboratory used a combination of ASTM D5470 (Reference 14) for the coated steel coupons, and ASTM E1225 (Reference 15) for uncoated steel coupons, to derive the thermal conductivity of the coating.

- Corrected thermal conductivity values for the unaged and aged Carbozinc 11 HSN samples tested at the independent laboratory. Westinghouse made the corrections, in response to an RAI, based on re-examination of the coating thickness measurements used in the original testing.

- Clarification in RAI responses and the July 24, 2014, public meeting on the test methods selected, the detailed procedures, and the measurement uncertainty.

As noted above, the licensee confirmed that the initial measured thermal conductivity value reported by Westinghouse for the coating used on the VEGP Units 3 and 4 containments is **[ ]** BTU/h-ft-°F (**[ ]** W/m-K). This was based on the licensee's confirmation that the measurement was performed in accordance with ASTM E1530, a test method the staff previously accepted through RG 1.54. The licensee also stated that use of stacked specimens in accordance with another ASTM test method (D5470) revealed that the thermal conductivity derived from a stack of samples was higher than that derived from a single sample. The staff has not reviewed D5470 but used the licensee's test results as an illustration of the effect of aging. The staff also notes that the D5470 measurements produced measured values similar to the initial thermal conductivity value assumed in WCAP-15846.

In response to RAI Questions 2-2 and 2-5, the licensee provided more detail on how the ASTM E1530 and D5470 measurements were made using coated steel specimens, and how ASTM E1225 was used for the uncoated steel substrate material. The responses explained sample sizes and stacking, and showed the parameters that were measured and tabulated for the effective thermal conductivity measurement. The response to Question 2-5 also clarified how the Harmonic Series model was applied to the test data in order to calculate conductivity of the IOZ layer on the steel. The staff asked additional clarification questions about the methodology in the July 24, 2014, public meeting. The licensee clarified how it set up the ASTM test methods, how it applied the equations in the test methods, and the terminology in its March 5, 2014, response that originally appeared to be inconsistent with the test procedures. The staff performed confirmatory calculations from the data to understand and reproduce some of the licensee's effective thermal conductivity values. These calculations are discussed below in Section 3.2.7.

According to ASTM test methods E1530 and D5470, sample thickness must be known in order to calculate thermal conductivity. The licensee stated that sample thickness was measured with a micrometer. In RAI Question 2-6, the staff asked how the licensee accounted for the variable thickness of the coating that would result from the specified substrate surface profile of 0.001 to 0.003 inch. In its response, the licensee stated that the micrometer thickness measurements were subsequently compared to measurements from photomicrographs that allowed thickness measurements from standard imaging tools. The response provided examples of the images and results. The licensee identified a significant difference between the thickness measurement methods and provided revised thermal conductivity calculations based on the photomicrograph method. The staff concludes that the thickness measurement methods based on photomicrographs were appropriate because they account for the substrate surface profile. The average coating thicknesses measured from the photomicrographs were lower than those based on micrometer measurements of coated and uncoated substrates. The recalculated effective thermal conductivity values were less than those calculated from the micrometer thickness results and reported in the response to Question 1-10. However, the recalculated effective thermal conductivity measured values were higher than the minimum measured value of **[ ]** BTU/h-ft-°F (**[ ]** W/m-K) using ASTM E1530, and the measured value for the aged coating reported by Westinghouse was higher than that for the new coating. The measured values are listed below in Table 2.

TABLE 2: Licensee's Thermal Conductivity Measurements Compared to Design Basis

	Effective Thermal Conductivity, BTU/h-ft-°F (W/m-K)	
	Method ASTM E1530	Method ASTM D5470
New Sample	**[ ]**	**[ ]**
Aged Sample	Not measured	**[ ]**
Design Basis Required Thermal Conductivity, BTU/h-ft-°F (W/m-K)		
0.302 (0.522)		

The response to Question 1-10 included extensive discussion of both the licensee's thermal conductivity measurements of the new coatings, and the measurements of an aged coating sample. The licensee stated that the aged sample was an identical formulation to the new coating and had been aged outdoors and uncovered for 10 years. In response to RAI Question 2-8, the licensee stated that the aged coating was exposed to an industrial type of atmosphere near St. Louis, Missouri. The higher thermal conductivity for the aged sample is not direct evidence that aging increases the thermal conductivity and decreases the porosity. That would require a comparison with an identical new sample, or measurements on a larger population of aged and new coating samples. Nonetheless, the fact that the coating sample aged for 10 years, directly exposed to the atmosphere, has a higher thermal conductivity than the new sample with the same nominal composition indicates that the coating is at least maintaining a high thermal conductivity rather than degrading. The staff concludes that this information supports a finding of small changes in thermal conductivity due to aging of IOZ coatings.

The licensee addressed measurement uncertainty in several RAI responses. The licensee stated that the uncertainty reported by the testing laboratory for the thermal conductivity measurements was seven percent for ASTM E1530 and ten percent for ASTM D5470 and E1225). These are uncertainties in measurements specific to the thermal conductivity test, such as heat flow and thermocouple precision, and do not include variations in sample geometry. The responses describe how the uncertainty in uncoated substrate thermal conductivity and coating thickness uncertainty were biased in order to minimize the derived coating thermal conductivity measurements reported. For the uncoated substrate measurement apparatus (ASTM E1225), the licensee stated that the measured values for the reference sample were within 0.5 to 1.8 percent of the industry accepted value. Based on these responses, the licensee applied measurement uncertainties to minimize the measured effective thermal conductivity values reported in the response to Question 2-6.

In summary, the staff concludes that the licensee's measurements indicate aging did not decrease the Carbozinc 11 HSN thermal conductivity significantly and may have increased it.

3.2.5 Aging of Inorganic Zinc Coatings

The staff was not able to find data in the technical literature addressing thermal conductivity values for IOZ coatings and the effect of aging. WCAP-15846, Addendum 1 submitted with the

LAR postulates that aging of the coating increases the thermal conductivity because the zinc oxide corrosion product is more voluminous than the corresponding zinc metal, expanding into and reducing the porosity. In order to better understand how the thermal conductivity of IOZ coatings might change with aging, the staff considered how aging of metallic zinc and IOZ coatings occur, and at what rate, for environments representative of the internal and external surfaces of the containment vessel.

Inorganic zinc coatings protect steel from corrosion through a two-stage process of initial galvanic cathodic protection followed by barrier protection as corrosion products seal the porosity (Reference 16). For atmospheric exposure of zinc and IOZ coatings, the specific corrosion products depend on the conditions, with zinc oxide, hydroxide, and carbonate being the most common (References 17 and 18). Exposure tests at the Kennedy Space Center (KSC) found that carbon steel test samples coated with Carboline Carbozinc 11 were completely protected after 34 years (Reference 19). This is an older version of the coating being applied to the VEGP Units 3 and 4 containment vessels. In other tests at the KSC site, Carbozinc 11 samples exposed for 18 months performed at the highest level not only in terms of appearance, but also in terms of abrasion, adhesion, and thermal resistance tests (Reference 20).

With respect to IOZ coating used specifically as a Service Level I coating (inside containment) at nuclear power plants, the Electric Power Research Institute (EPRI) published a survey in 2006 of experience with aging and degradation of Service Level I coatings at nuclear plants (Reference 21). The survey found that the amount of degraded IOZ coating was about six percent of the total IOZ coating, and the only failures of IOZ coatings under atmospheric exposure in pressurized water reactor (PWR) containments resulted from errors during application, not during service. Service-related degradation occurred in immersion service in boiling water reactor (BWR) suppression pools or in chemical exposure outside the pH range of 4-10.

Based on this experience with IOZ coating atmospheric corrosion, and the conditions of exposure for the inside and outside surfaces of the AP1000 containment vessel, the staff concluded that it is reasonable to expect little or no change in thermal conductivity from aging. The fact that IOZ coating has remained intact and fully protective in long-term exposure tests suggests the zinc may not be fully oxidized and supports the theory that the oxidation product seals the porosity. The condition of the AP1000 containment vessel coating, with respect to base-metal rusting and other signs of degradation, will be monitored through required periodic inspections of the inside and outside surfaces. This supports the licensee’s position that the thermal conductivity change with aging can be evaluated conservatively based on conversion of the zinc particles to a corrosion product. Ignoring the corresponding reduction of porosity appears to be conservative. Although the staff did not find data in the open literature on thermal conductivity of aged IOZ coatings, the licensee obtained a proprietary sample from the vendor and provided the measurements discussed above in Section 3.2.4.

3.2.6 Thermal Conductivity Models

The staff considered the role of modeling as a tool for calculating the thermal conductivity of IOZ coatings and the effect of aging. WCAP-15846, Addendum 1, includes a review of six models for calculating the effective thermal conductivity of multicomponent, heterogeneous materials and complex porous media. Inorganic zinc coatings are heterogeneous with respect to thermal conductivity because the zinc particles, pores and other components have individual thermal conductivity values that vary greatly. The technical literature contains references, some of which are used in WCAP-15846, Addendum 1, that provide additional details about relevant thermal conductivity modeling. Table 3 below lists the models described in several references on thermal conductivity relevant to multicomponent, heterogeneous materials. The Parallel model yields the highest value of thermal conductivity because it assumes there is a conduction path through the most conductive component. The Harmonic Series model yields the lowest value because it assumes the components are layered through the thickness and the heat transfer is therefore limited by the least conductive component. Other theoretical models yield intermediate values. One model, named for Krischer, is an empirical model that has broad applicability if appropriate test data are available.

TABLE 3: Models for Effective Thermal Conductivity

Model Name	Description	Ref.
Parallel	Layers of the components are aligned parallel to the direction of heat flow. Effective thermal conductivity dominated by the most conductive component.	22
Harmonic Series	Layers of the components are aligned perpendicular to the direction of heat flow. Effective thermal conductivity dominated by the least conductive component.	22
Effective Medium Theory (EMT)	Assumes a completely random distribution of all of the components.	9
Maxwell-Euken 1 (ME1)	A two-component mixture of spheres in a continuous matrix, where the matrix is the solid phase and the spheres are dispersed pores ("internal porosity").	9
Maxwell-Euken 2 (ME2)	A two-component mixture of spheres in a continuous matrix, where the spheres are the dispersed, solid phase, and the porosity forms the matrix ("external porosity").	9
Krischer	An empirical model that uses a "distribution factor" to describe the distribution of the phases. This factor is derived from measured values and then used in the model to predict thermal conductivity of other, similar materials.	9

Other authors have described ways to combine and modify these models to understand the thermal conductivity of various materials, such as insulation and foods. Although the thermal conductivity of heterogeneous materials varies with position, models can be applied to a particular material if it is well characterized. Examples of these papers, such as Carson et al. (Reference 23) and Wang et al. (Reference 9), indicate that calculating the effective thermal conductivity of a multicomponent mixture, whether using a theoretical or empirical model, requires knowledge of the material type, the amount and distribution of constituents, and other factors. The staff concluded from these references that there is no model readily available for IOZ coatings but that existing models may provide insights for evaluating IOZ coatings and the effect of aging.

3.2.7 Staff Calculations of Inorganic Zinc Coating Thermal Conductivity

To supplement the licensee's measurement and modeling, the staff calculated thermal conductivity of the IOZ coating using adaptations of several of the models since there is no model directly applicable to IOZ coatings. Table 4 lists the calculations, which were performed with Engineering Equation Solver Version 9.653 computational software (F-Chart Software, 2014). In Row 1, the staff reproduced the Krischer empirical model calculation from

Addendum 1 to validate the software for this modeling. Using the measured value of **[ ]** BTU/h-ft-°F (**[ ]** W/m-K) for the new coating, the staff derived the same distribution factor (**[ ]**) and aged coating thermal conductivity (**[ ]** BTU/h-ft-°F, **[ ]** W/m-K) as the licensee. The calculations used the constituent volume fractions tabulated by the licensee in WCAP-15846, Addendum 1.

Along with volume fractions for each coating constituent, WCAP-15846, Addendum 1 tabulates thermal conductivity values for the coating constituents. The staff used these values in its calculations after verifying them independently from several references. The most significant constituents are zinc, zinc oxide (or other aging products), air, and silicate binder, since they comprise about 90 percent of the volume. The thermal conductivities for zinc, zinc oxide, and air are readily found in printed and electronic handbooks. The staff was not able to find a published thermal conductivity value for the silicate binder used in the coating, but verified the licensee's reference of 0.64 BTU/h-ft-°F (1.1 W/m-K). This value corresponds to fused silica filler material. The staff found a published thermal conductivity value for the liquid form of a silicate binder ("silibond") with a liquid thermal conductivity of 0.087 BTU/h-ft-°F (0.15 W/m-K) (Reference 24). In general, solids are more thermally conductive than liquids due to intermolecular spacing (Reference 25); for example, ice is approximately four times more conductive than water and zinc is about 14 times more conductive than mercury. The staff did not have a basis for determining how well fused silica filler or the silibond represent the IOZ coating material, or the difference between liquid and solid thermal conductivity for these materials. Despite this uncertainty, the staff considered the value of 0.64 BTU/h-ft-°F (1.1 W/m-K) reasonable for the silicate binder based on the type of material, the comparison with a similar material in liquid form, and the purpose of the calculations (which was to gain insights on IOZ coatings and the effect of aging using approximations). For the other three constituents (mica, titanium dioxide, aluminum silicate), the staff checked the references the licensee used and verified the thermal conductivity values. These three constituents have an insignificant effect on the coating thermal conductivity due to their small volume fractions. The table in the Appendix to this Safety Evaluation shows the values of thermal conductivity used in the calculations (licensee and staff), and the sources the staff used for these values.

Rows 2-4 of Table 4 show calculated values from the standard Effective Medium Theory (EMT), which assumes a random mixture, and two hybrid models described by Wang et al. (Reference 9). The EMT model does not appear to represent the IOZ coating material well because the effective thermal conductivity values are so much higher than the measured values (Section 3.2.4), even for the aged coating, and the change due to aging is much larger than the measured change. Row 3 of Table 4 is from a version of the Maxwell-Euken 2 (ME2) model proposed by Wang et al. for mixtures with more than two components. The calculation is performed with a binary calculation method, beginning with two components and then adding one additional component at a time for a total of six components. Every step requires a new set of adjusted volume fractions to conform to the assumption of a binary mixture. This model yields the lowest value for an aged coating (zinc oxide replacing zinc). It is not clear how useful this is as a reference point since the calculation method does not represent the coating structure well.

Row 4 of Table 4 is a combination of the EMT and ME2 models proposed by Wang et al. Again, this model assumes two different structures, one a random mixture and one an external porosity material (conductive dispersed phase surrounded by porosity). This requires assumptions about structure factors and volume fractions to account for a binary structure (EMT + ME2). The thermal conductivity for the aged coating calculated using this method is much higher than measured even for the new coating.

Since the staff was unable to find these models applicable to IOZ coatings, the staff considered an alternative combination. The final three rows in Table 4 are based on the staff's combination of the EMT and ME2 models, where the overall coating is treated as a single ME2 structure. In this case the zinc particles are treated as the dispersed phase surrounded by a matrix of the other coating constituents, a structure called "external porosity" (Reference 23). The staff calculated the thermal conductivity of the matrix using the EMT (random mixture) model, and then combined the matrix with the zinc particles as a binary system using the ME2 model. This is different than EMT+ME2 because the coating is treated as a single ME2 structure rather than a mixture of EMT and ME2 regions. The staff considered this a reasonable physical representation of the coating because the constituents other than zinc appeared to form a well-mixed matrix, and had a range of thermal conductivity values that would determine the matrix conductivity in proportion to the volume fractions.

TABLE 4: Results of Staff's Effective Thermal Conductivity Calculations

Model	**Calculated Thermal Conductivity (new)**	**Calculated Thermal Conductivity (aged)***	**Comments**
Krischer	**[ ]** W/m-K **[ ]** BTU/h-ft-°F	**[ ]** W/m-K **[ ]** BTU/h-ft-°F	Based on coating composition and measured thermal conductivity provided by the licensee.
Effective Medium Theory	23.8 W/m-K 13.8 BTU/h-ft-°F	4.0 W/m-K 2.31 BTU/h-ft-°F	Random mixture of all constituents.
Maxwell-Euken 2 6-component	Not calculated	0.21 W/m-K 0.12 BTU/h-ft-°F	External porosity model. Wang method for more than 2 components.
EMT/ME2 binary	Not calculated	3.42 W/m-K 2.0 BTU/h-ft-°F	This model assumes a binary structure that is not representative of this coating
EMT/ME2 staff	0.68 W/m-K 0.39 BTU/h-ft-°F	0.65 W/m-K 0.37 BTU/h-ft-°F	Zinc oxide corrosion product, no change in porosity with aging
EMT/ME2 staff	0.68 W/m-K 0.39 BTU/h-ft-°F	0.70 W/m-K 0.41 BTU/h-ft-°F	Zinc oxide corrosion product, volume expansion 1.3 (porosity decreases with aging)
EMT/ME2 staff	0.68 W/m-K 0.39 BTU/h-ft-°F	0.63 W/m-K 0.36 BTU/h-ft-°F	Lower conductivity corrosion product (e.g., zinc carbonate). Corrosion product volume expansion 1.8 (porosity decreases with aging)

*Note: "Aged" coatings assume all zinc is converted to zinc oxide (or carbonate, in the last case).

As Rows 5-7 of Table 4 show, the calculated new and oxidized coating thermal conductivity values are lower than the measured value and the Krischer model calculation for complete oxidation of zinc to zinc oxide, but the values are of the same order, including the amount of reduction due to aging. These calculations are not meant to imply an accurate predictive capability; rather, they are meant to approximate the effective thermal conductivity and effects of postulated changes due to aging.

The staff's calculations with this model included variations in the density ratio (specific volume) of the aging product to metallic zinc (1.0 – 2.0) and the thermal conductivity of the aging product (from 0.6 to 67 BTU/h-ft-°F, or 1 to 116 W/m-K). Varying the specific volume of the corrosion products represents expansion of the metallic zinc during oxidation. Allowing the corrosion products to expand into the porosity resulted in an increase in the thermal conductivity of the matrix and the coating overall. Zinc carbonate was considered as a corrosion product based on the description of zinc atmospheric corrosion in Section 3.5. The last two rows in Table 4 show two specific examples:

- Complete oxidation of zinc to zinc oxide (conductivity 8.7 BTU/h-ft-°F, specific volume 1.3 times that of zinc); the resulting thermal conductivity increased from 0.39 to 0.41 BTU/h-ft-°F (0.68 to 0.70 W/m-K).

- Complete conversion of zinc to zinc carbonate (estimated conductivity 1.7 BTU/h-ft-°F, specific volume 1.8 times that of zinc); the resulting thermal conductivity decreased from 0.39 to 0.36 BTU/h-ft-°F (0.68 to 0.63 W/m-K). (The thermal conductivity assumed for zinc carbonate was based on References 25 and 26, which give a range of about 1.1 to 2.3 BTU/h-ft-°F for calcium carbonate and magnesium carbonate at ambient temperature.)

The staff's insight from the calculations was that the simple physical model the staff used for thermal conductivity calculations - a dispersed phase within a composite external matrix-yielded results similar to the licensee's measured values for the new coating and the amount of change due to aging. The staff considered these calculations useful for evaluating changes in the corrosion product and the volume expansion. The numbers suggest there is margin between the aged coating thermal conductivity and the required minimum value. Even with a postulated corrosion product having an estimated thermal conductivity lower than zinc oxide (intended to represent zinc carbonate), the calculated thermal conductivity of the aged coating remained close to the value for the new coating.

3.2.8 Measured Inorganic Zinc Coating Thermal Conductivity for the Initial Test Program

In response to Question 1-10, the licensee noted that pre-operational test requirements in VEGP Units 3 and 4 UFSAR Section 14.2.9.1.4(g) include thermal conductivity tests on IOZ-coated coupons from the containment vessel. This is part of the Initial Test Program for the Passive Containment Cooling System. In Question 2-4, the staff asked about the timing, method, and acceptance criteria of the tests, and how they account for aging. In its response, the licensee stated that the thermal conductivity testing required under the initial test program will be performed according to ASTM E1530 prior to fuel load. The response also stated that the acceptance criteria will be the same as the design requirement (0.302 BTU/h-ft-°F) multiplied by two to account for aging as modified by this amendment to assume a factor of two for aging. Based on the conclusion that the factor of two is reasonable to account for the effect of aging, the staff finds 0.604 BTU/ h-ft-°F (1.04 W/m-K) acceptable for the minimum required thermal conductivity of the initial test program coupons.

3.2.9 Summary of Staff Findings

- Experience with IOZ coatings in similar applications indicates that aging of IOZ on both the inside and outside of the VEGP Units 3 and 4 containment vessels is likely to generate a corrosion product that will provide long-term corrosion protection to the substrate. The condition of the IOZ will be monitored through the coatings program. (Section 3.2.5)
- The staff calculated the effective thermal conductivity using a model representative of new and aged IOZ coating (dispersed zinc particles in a well-mixed matrix). The calculated values are reasonably close to the licensee's measured values and indicate that aging will cause an increase or a small decrease in thermal conductivity that will not challenge the value used in the safety analysis. (Section 3.2.7)
- The staff did not find a direct comparison of new and aged coating samples originally coated at the same time. However, the licensee's measurements indicate aging can increase the thermal conductivity of the IOZ coating. The thermal conductivity of a sample exposed directly to an industrial atmosphere for 10 years was higher than that of a new sample of the nominally identical coating. (Section 3.2.4)
- Since modeling and measurements indicate that the thermal conductivity will decrease slightly or increase, and the degradation from aging is negligible, a factor-of-two margin in the thermal conductivity provides reasonable assurance that the licensing basis will be met for coating thermal conductivity (0.302 BTU/h-ft-°F) (0.522 W/m-K).
- The factor of approximately two in measured values over the design basis minimum required value provides margin for variations in the coating composition and structure, corrosion product composition, and measurement uncertainties.

3.2.10 Conclusion Regarding Change in Thermal Conductivity Resulting from Oxidation of the Containment Vessel IOZ Coating System

The NRC finds that the licensee provided a reasonable technical basis to continue using a value of 0.302 BTU/h-ft-ºF (0.522 W/m-K) to bound the effective thermal conductivity resulting from oxidation of the IOZ coating system used on the Vogtle Units 3 and 4 containment vessel. With respect to the measured value listed in Addendum 1 for a coating sample, the value of 0.302 BTU/h-ft-ºF represents slightly more than a factor-of-two reduction in the thermal conductivity of the VEGP Units 3 and 4 IOZ coating system over the life of the plant and also provides additional conservatism to account for uncertainties in the calculated value of the oxidized thermal conductivity value. This conclusion is partly based on the Initial Test Program requirement to measure the initial thermal conductivity of coupons from the containment shell per VEGP Units 3 and 4 UFSAR Section 14.2.9.1.4(g). The initial thermal conductivity must be at least 0.604 BTU/h-ft-ºF (1.04 W/m-K). Therefore, the staff finds there is reasonable assurance that GDC 16 and GDC 50 will be met with respect to the IOZ coating thermal conductivity, and the staff finds the proposed amendment acceptable.

4.0 STATE CONSULTATION

In accordance with the Commission's regulations in 10 CFR 50.91(b)(2), the Georgia State official was notified of the proposed issuance of the amendment. The State official had no comments.

5.0 ENVIRONMENTAL CONSIDERATION

The amendment changes a requirement with respect to installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20, “Standards for protection against radiation.” The NRC staff has determined that the amendment involves no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission has previously issued a proposed finding that the amendment involves no significant hazards consideration, and there has been no public comment on such finding (*Federal Register,* 79 FR 15150*,* dated March 18, 2014). Accordingly, the amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with issuing the amendment.

6.0 CONCLUSION

The staff has concluded, based on the considerations discussed above, that there is reasonable assurance that (1) the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or the health and safety of the public.

7.0 REFERENCES

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3. Vogtle Electric Generating Plant (VEGP) Updated Final Safety Analysis Report (UFSAR), Revision 3, dated June 20, 2014 (ADAMS Accession No. ML14178B362).

4. WCAP-15846, “WGOTHIC Application to AP600 and AP1000, Revision 1,” dated March 2004. (Proprietary)
5. Final Safety Evaluation Report (FSER) for Revision 19 of the AP1000 DCD (NUREG-1793, Supplement 2), dated September 2011 (ADAMS Accession No. ML12271A045).

6. Deleted

7. Letter from Brian H. Whitley, SNC, to U.S. Nuclear Regulatory Commission, “Response to NRC's Request for Additional Information Letter No. 01 Related to License Amendment Request (LAR 13-039) for Coating Thermal Conductivity,” dated March 5, 2014 (ADAMS Accession No. ML14064A573).

8. Letter from Brian H. Whitley, SNC, to U.S. Nuclear Regulatory Commission, “Response to NRC's Request for Additional Information Letter No. 02 Related to License Amendment Request (LAR 13-039) for Coating Thermal Conductivity,” dated June 30, 2014 (ADAMS Accession No. ML14184B161).

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APPENDIX: Thermal Conductivity of Principal Constituents in New and Aged IOZ Coating

Coating Constituent	**TC, Btu/hr-ft-ºF** (W/m-K)	**Comments and Verification**
Zinc	67.0 (116)	Value used in licensee and staff calculations. Thermal conductivity of pure metals at ambient temperature is readily available in printed and online handbooks. Staff verified this value using the CRC Handbook and internet references, such as Engineer's Toolbox.
Zinc Oxide	8.7 (15.05)	Value used in licensee and staff calculations. Staff found a range of values, depending on form and orientation (8-20 BTU/h-ft-°F). Staff judged the licensee's value conservative. CRC Handbook gives a range of 13-17 BTU/h-ft-°F. Yaw's Critical Property Data (Knovel internet reference), Table 88, gives a value of 13.5 BTU/h-ft-°F (Reference 15).
Zinc Carbonate	1.7 (3.0)	The staff included zinc carbonate as an alternative corrosion product to zinc oxide based on corrosion literature (see Section 3.5). The actual corrosion product is likely to be a mixture. The licensee did not provide calculations using zinc carbonate. Staff assumed a thermal conductivity based on values in the range of 1.1-2.3 BTU/h-ft-°F for other carbonates in References 14 and 15.
Air	0.015 (0.026)	Value used in licensee and staff calculations. Thermal conductivity of air at ambient temperature is readily available in printed and online handbooks. Staff verified this value using the CRC Handbook.
Silbond	0.64 (1.1)	Value used in licensee and staff calculations. The staff checked the licensee's referenced value for solid silica filler material. Staff did not find a value for solidified Silbond binder. However, an online Material Safety Data Sheet under the name "ethyl silicate," "silibond," "ethyl orthosilicate," and other names, gave a value for the liquid of approximately 0.087 BTU/h-ft-°F. Staff considered the value of 0.64 reasonable, as discussed in the text.
Mica	0.28	Value used in licensee and staff calculations. Staff verified the licensee's reference and independently verified the value using the Engineering Toolbox online reference.
Titanium dioxide	4.9	Value used in licensee and staff calculations. Staff verified the licensee's reference.
Aluminum silicate	0.041	Value used in licensee and staff calculations. Staff verified the licensee's reference.