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**Subject: NRC Request for Additional Information Letter Number 11 Related to Chapter 6 for GE Hitachi Nuclear Energy, Advanced Boiling Water Reactor Design Certification Rule Renewal Application – GEH Response to RAI 06.03-3**

In Reference 1, the NRC requested information from GE Hitachi Nuclear Energy (GEH) regarding the Advanced Boiling-Water Reactor (ABWR) design certification renewal application emergency core cooling system. Enclosure 1 provides the GEH response to Request for Additional Information (RAI) 06.03-3. No ABWR Design Control Document markups are included in this response to RAI 06.03-3.

If you have any questions, please contact me or Patricia Campbell (202-637-4239).

Sincerely,

Jerald G. Head  
Senior Vice President, Regulatory Affairs

Commitments: None.

References:

1. NRC to GEH, Request for Additional Information Letter Number 11 Related to Chapter 6 for GE-Hitachi Nuclear Energy Advanced Boiling-Water Reactor Design Certification Rule Renewal Application, March 28, 2017

Enclosure:

1. GEH Response to RAI 06.03-3

cc: A. Muniz, NRC  
DBR-0028519

## **Enclosure 1**

**M170106**

### **GEH Response to RAI 06.03-3**

#### **IMPORTANT NOTICE REGARDING CONTENTS OF THIS DOCUMENT Please Read Carefully**

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## **NRC REQUEST FOR ADDITIONAL INFORMATION**

### **QUESTION 06.03-3:**

*In parts B.1, B.2, and B.3 of RAI 06.03-2, the staff requested that GE Hitachi Nuclear Energy (GEH) provide a description of the use of certain materials in the Advanced Boiling Water Reactor (ABWR) containment, how the design establishes limits on the quantities of those materials, and how the materials were evaluated for chemical effects. The staff requested this information in accordance with 10 CFR 52.59(a) (2014) as part of determining if the ABWR design complies with requirements in 10 CFR 50.46(b)(5)(1997) for emergency core cooling systems (ECCS). Chemical effects may increase strainer and reactor core clogging and form deposits on the fuel.*

### ***Follow-Up Question on the response to RAI 06.03-2, Parts B.1 and B.3***

*The staff requested the specific information in B.1 and B.3 of RAI 06.03-2 because the quantity of a material affects the amount of corrosion product it can generate in a given time period. Limiting the amount of materials contributing to corrosion products in the pool limits the amount of corrosion that can occur and the uncertainty in the chemical effects evaluation.*

*Based on the latest revision to GEH's RAI response to RAI 06.03-2 dated February 23, 2017 (ADAMS Accession number ML17055C593), it is not clear to the staff how chemical effects from all of the materials are addressed. Therefore, the staff requests the following information:*

- 1. The response to B.1.b indicates that a large surface area of zinc (galvanized steel) could be exposed to the post-loss-of-coolant accident (LOCA) water and corrode, depending on the pH, temperature, and location of the galvanized steel. The response to B.1.b also states that this zinc will not make a significant contribution to corrosion products in the suppression pool. Provide the basis for disregarding galvanized steel corrosion and the potential for corresponding zinc chemical effects. Address how the location of the galvanized steel (i.e., communication with the suppression pool), the corrosion rate predicted for the pH and temperature conditions, the solubility of zinc under the expected pool conditions, the amount and type of zinc precipitate formed in the pool, etc. were considered.*
- 2. The response to B.1.d states that carbon steel is not a material of concern because it is not used in containment. DCD Section 6.1.1.1.2 indicates uncoated carbon and low-alloy steel is used in Engineered Safety Features components, and that corrosion is expected. If the iron in these components is released into the post-LOCA pool, describe how it was evaluated for chemical effects and the basis for concluding it would not be a concern.*
- 3. The response to B.1.e.i refers to the steel liner plate that isolates concrete from the post-LOCA fluid. If any of the coated carbon steel liner is within the zone of influence for the coating, describe how the potential chemical effects from the exposed carbon steel were evaluated.*

### ***Follow-up Question on the response to RAI 06.03-2, Part B.2***

*In B.2, the staff requested the ranges and timing of pH, pool temperature, and boron concentration following a LOCA. The response stated that:*

- 1. The pH is maintained in the range 5.3 – 8.6*
- 2. No boron is present because the Standby Liquid Control System will not be used in a LOCA.*

*The staff requested the pH and temperature ranges and transients because of the effect these parameters have on corrosion and precipitation, possibly leading to chemical effects at the strainer or in the reactor core. The staff requested the boron concentration range and transient because of the effect on pH and corrosion. The staff requested the transient behavior because corrosion and precipitation can depend on the sequence of conditions favoring corrosion and precipitation. The response described why boron would not be present but did not address transient behavior of pH or temperature. Therefore the staff requests the following information:*

- 1. Describe how the pH during the post-LOCA period is maintained in the same range as during operation. (The response to Question B.2 suggests that the Suppression Pool Cleanup System (SPCU System) maintains the pH in the range 5.3-8.6. According to DCD Section 9.5.9, the SPCU function is terminated during a LOCA.)*
- 2. Describe the transient temperature and pH behavior during the post-LOCA period and how it was determined.*
- 3. How do these predictions of pH account for the potential generation of strong acids (e.g., nitric and hydrochloric) from radiolysis, and subsequent reduction of pH in the pool if it is unbuffered and the SPCU System is not in use.*
- 4. If a combined license (COL) applicant proposed using the SLC System during a LOCA, the application would need to evaluate the impact on chemical effects, ECCS strainer head loss, and downstream effects. Describe how this possibility will be addressed, for example by proposing a COL item requiring the applicant to perform this evaluation and submit the results for NRC review.*

## **GEH RESPONSE**

This response addresses the questions above. Note that there are references in this response that are GEH proprietary internal documents that are available for NRC audit at GEH facilities. The NRC questions are repeated and underlined.

### **A. Follow-Up Question on the response to RAI 06.03-2, Parts B.1 and B.3**

*The staff requested the specific information in B.1 and B.3 of RAI 06.03-2 because the quantity of a material affects the amount of corrosion product it can generate in a given time period. Limiting the amount of materials contributing to corrosion products in the pool limits the amount of corrosion that can occur and the uncertainty in the chemical effects evaluation.*

*Based on the latest revision to GEH's RAI response to RAI 06.03-2 dated February 23, 2017 (ADAMS Accession number ML17055C593), it is not clear to the staff how chemical effects from all of the materials are addressed. Therefore, the staff requests the following information:*

- 1. The response to B.1.b indicates that a large surface area of zinc (galvanized steel) could be exposed to the post-loss-of-coolant accident (LOCA) water and corrode, depending on the pH, temperature, and location of the galvanized steel. The response to B.1.b also states that this zinc will not make a significant contribution to corrosion products in the suppression pool. Provide the basis for disregarding galvanized steel corrosion and the potential for corresponding zinc chemical effects. Address how the location of the galvanized steel (i.e., communication with the suppression pool), the corrosion rate predicted for the pH and temperature conditions, the solubility of zinc under*

the expected pool conditions, the amount and type of zinc precipitate formed in the pool, etc. were considered.

**GEH Response:** Exposed metallic zinc in the ABWR containment is limited to galvanized steel in ladders, ductwork, unistruts, cable trays, conduit and grating. Galvanized component material properties are specified by applicable ASTM material requirements. While galvanized components are not considered coatings under the RG 1.54, Coatings Program, the amount of zinc used inside the containment structure is considered (under the Service Level I, II and III Protective Coatings Applied to Nuclear Power Plants), an inventoried item for review and is, therefore, included under the COL Applicants Protective Coatings Program defined under DCD Section 6.1.3.1.

Galvanized steel structures and components are installed in the ABWR containment outside normally wetted areas. DCD Table 3I-2, Thermodynamic Environment Conditions Inside Primary Containment Vessel Plant Normal Operating Conditions, lists environmental conditions to which galvanized steel structures and components are exposed. General corrosion of these items in drywell conditions (moist nitrogen surroundings) could result in debris collecting in the suppression pool. Under normal plant operating conditions, the maximum suppression pool water and wetwell airspace temperature is 35°C or less. The general corrosion of galvanized steel structures and components is evaluated under latent debris terms in the ECCS suction strainer sizing (see DCD Section 6C.5 and NEDE-33878P).

Under design basis LOCAs inside primary containment, latent debris from galvanized steel structure and component corrosion deposits is transported to the suppression pool subject to ABWR suppression pool conditions (reactor water quality) with a pH of 5.3 to 8.6, as listed in DCD section 3I.3.2.3. DCD Table 3I-12, Thermodynamic Environment Conditions Inside Primary Containment Vessel Plant Accident Conditions, lists a maximum wetwell temperature of 122°C (251.6°F). The initial pool water temperature may rise to a maximum of 76.6°C (169.9°F) at 30 minutes. The continued release of decay heat after the initial blowdown may result in suppression pool temperatures as high as 88.7°C (191.7°F). These are the pH and temperature conditions that galvanized steel could be exposed under LOCA conditions. The Residual Heat Removal (RHR) System is available in the Suppression Pool Cooling mode to control the pool temperature. Heat is removed via the RHR heat exchanger(s) to the Reactor Building Cooling Water (RCW) System and finally to the Reactor Service Water (RSW) System.

BWROG Report, NWT 863, Review of Boiling Water Reactor Material Dissolution in Post- LOCA Containment Systems [ML14328A639] includes test data (Figure 6-7) that represents zinc release from galvanized carbon steel to air saturated demineralized water at temperatures to 200°C. A conservative average Zn release rate of 0.05 gm/m<sup>2</sup>-hr over a period of 100 hrs. was estimated for a pH range of 6 to 7. Using this corrosion rate, the weight of free zinc would be estimated for a 100-day period as follows:

Assume BWR containment= 1/10 vol of PWR containment with 1/10 of galvanized steel as listed in WCAP 16530-NP Table 3.1-1 with the maximum galvanized material to recirc water volume is 19.47 ft<sup>2</sup> / ft<sup>3</sup>

assuming sp vol = 126,427 ft<sup>3</sup> [Ref DCD Tier 1 T2.14.1 (10)]  
galvanized area = 126,427 ft<sup>3</sup> x 19.47 ft<sup>2</sup> / ft<sup>3</sup>  
galvanized area = 2,461,533 ft<sup>2</sup> = 228,676 m<sup>2</sup>

use 1/10 of the PWR galvanized steel area = 22,868 m<sup>2</sup> [Engineering Estimate]

It was assumed un-submerged material did not contribute to zinc releases after termination of the spray phase as described in WCAP-16530. The maximum Zone of Influence (ZOI) determined for a non-domestic ABWR was 4530.75 ft<sup>3</sup> (128.3 m<sup>3</sup>) during a MSL LOCA (reference GEH internal document 31113-0A51-2104 Section 6.1).

The galvanized area is adjusted to reflect that only a portion of the total galvanized inventory in the ABWR containment will be exposed to LOCA wetting conditions (ZOI):

A ratio of maximum ZOI volume (128.3 m<sup>3</sup>) to total ABWR net free volume (5960 m<sup>3</sup> is total free volume ABWR drywell and wetwell ref: DCD Table 6.2-2) to was used to adjust the total galvanized steel surface subjected to LOCA:

$$\text{Adjusted galvanized area} = 22,868 \text{ m}^2 (\text{galvanized area}) \times 128.3 \text{ m}^3 / 5960 \text{ m}^3$$

$$\text{Adjusted galvanized area} = \underline{493 \text{ m}^2} = \underline{5306 \text{ ft}^2}$$

LOCA mission time 100 days x 24 hr/day = 2400 hr [Ref DCD Section 1A.2.31]  
Minimum SP Volume = 3580 m<sup>3</sup> [Ref DCD Tier 1 T2.14.1 (10)]

Zinc release rate 0.05 gm/m<sup>2</sup>-hr [Ref. BWROG Report, NWT 863, Review of Boiling Water Reactor Material Dissolution in Post- LOCA Containment Systems [ML14328A639]

$$\text{Zinc release} = 0.05 \text{ gm/m}^2\text{-hr} \times 2400 \text{ hr} \times 493 \text{ m}^2$$
$$\text{Zinc release} = 59,160 \text{ gm} = \underline{130 \text{ lbs}}$$

Zinc SP concentration (ppm) = gm zinc / 10<sup>6</sup> gm sp water 960 kg/m<sup>3</sup> (density at 207 C max temperature [Ref DCD Section 5.4.7.2.2])

$$\text{Zinc SP concentration (ppm)} = 59,160 \text{ gm Zinc} \times 1 \times 10^5 / (960 \text{ kg/m}^3 \times 3580 \text{ m}^3 \times 1000 \text{ gm / kg})$$

$$\text{Zinc SP concentration (ppm)} = \underline{17.2 \text{ ppm}}$$

Due to the amount of exposed zinc (as galvanized steel) in BWR drywells, zinc-based precipitates may be a concern, such as zinc hydroxide (Zn(OH)<sub>2</sub>) which can form in slightly alkaline environments. The solubility of zinc ((Zn(OH)<sub>2</sub>)) has been estimated in an aqueous solution at varying pH and temperature conditions. It can be shown that zinc hydroxide will not precipitate out of solution in significant amounts at ABWR suppression pool conditions of pH and temperature.

NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Plant- Specific Chemical Effect Evaluations, March 2008 (ML080380214), notes that results provided in WCAP-16530-NP, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191, consistent with previous work such as the Integrated Chemical Effects Test (ICET) program, show that the predominant chemical precipitates are aluminum oxyhydroxide, sodium

aluminum silicate and calcium phosphate (for plants using trisodium phosphate for pH control). Other minor silicate materials may also be generated (e.g., calcium aluminum silicate or zinc silicate), but the contribution of these materials is expected to be small relative to the predominant precipitates (i.e., less than 5 percent). On this basis, the chemical model considers only the release rates of aluminum, calcium and silicate. Other chemical species, such as zinc, may be ignored.

2. The response to B.1.d states that carbon steel is not a material of concern because it is not used in containment. DCD Section 6.1.1.2 indicates uncoated carbon and low-alloy steel is used in Engineered Safety Features components, and that corrosion is expected. If the iron in these components is released into the post-LOCA pool, describe how it was evaluated for chemical effects and the basis for concluding it would not be a concern.

**GEH Response:** While the internal surface of the containment is lined with welded steel plate to form a leak tight barrier, stainless steel plate or clad is used on wetted surfaces of the suppression chamber. Type 304L stainless steel or clad carbon steel plate is used for the containment liner in the wetted areas of the suppression pool as protection against any potential pitting and corrosion on all wetted surfaces and at the water-to-air interface area.

ECCS materials of construction are listed in DCD Table 6.1-1, Engineered Safety Features Component Materials. A contributor to the latent debris in the suppression pool is normal corrosion of carbon steel piping and components in the ECCS systems. This corrosion is applied as the sludge/corrosion product ABWR ECCS strainer load. The ABWR sludge generation rate is less than the typical operating BWR, therefore the assumed ABWR sludge load of 200 lbm (100 lbm per year with a two-year operating cycle) is considered reasonable. Furthermore, there is a COL Item in Section 6.2.7.3 of the ABWR DCD which requires the applicant to establish a method for maintaining a level of cleanliness that supports this assumption.

As discussed in response to A.1 for zinc, the release rates for iron from uncoated steel in the bench tests were on the same order as the zinc release rates, so iron can also be ignored in chemical effects precipitation modeling.

3. The response to B.1.e.i refers to the steel liner plate that isolates concrete from the post-LOCA fluid. If any of the coated carbon steel liner is within the zone of influence for the coating, describe how the potential chemical effects from the exposed carbon steel were evaluated.

**GEH Response:** It is assumed that all coatings, regardless of qualification, are assumed to fail within the LOCA jet Zone of Influence (ZOI). Where a LOCA jet directly impacts a coated surface, it is conservatively assumed the jet will strip off all the applied coating in the affected area without regard to coating qualification as discussed in NEDO-32686-A, Utility Resolution Guide for ECCS Suction Strainer Blockage. This will expose the carbon steel liner plate to the LOCA jet. Since this mechanism of debris generation is concentrated within the ZOI and of short duration, significant generation of corrosion or erosion products from the exposed steel liner are not expected.

Testing (described in NEI 04-07 Vol 2 NRC SER ML050550156\_REVIEW OF NEI GUIDANCE APPENDICES Review of Appendix A, "Defining Coating Destruction Pressures and Coating Debris Sizes for DBA-Qualified and Acceptable Coatings in Pressurized Water Reactor (PWR) Containments) concluded that erosion was the primary mode of coating degradation from interaction with the waterjet in all test cases. The un-top-coated inorganic zinc coating failed at a distance up to 3 times greater than the epoxy. The industry concluded that a damage pressure of 333 psig for un-top-coated inorganic zinc and 1000 psig for epoxy systems should be used as the corresponding



coating destruction pressures. Testing showed that an elevated surface temperature impacted the amount of coating degradation and increased fluid jet temperature resulted in coating degradation at lower jet pressures.

The rationale that supports ignoring potential chemical effects precipitation modeling for iron (uncoated steel) was provided in response to A.2 above.

**B. Follow-up Question on the response to RAI 06.03-2, Part B.2**

In B.2, the staff requested the ranges and timing of pH, pool temperature, and boron concentration following a LOCA. The response stated that:

1. The pH is maintained in the range 5.3 – 8.6
2. No boron is present because the Standby Liquid Control System will not be used in a LOCA.

The staff requested the pH and temperature ranges and transients because of the effect these parameters have on corrosion and precipitation, possibly leading to chemical effects at the strainer or in the reactor core. The staff requested the boron concentration range and transient because of the effect on pH and corrosion. The staff requested the transient behavior because corrosion and precipitation can depend on the sequence of conditions favoring corrosion and precipitation. The response described why boron would not be present but did not address transient behavior of pH or temperature. Therefore the staff requests the following information:

1. Describe how the pH during the post-LOCA period is maintained in the same range as during operation. (The response to Question B.2 suggests that the Suppression Pool Cleanup System (SPCU System) maintains the pH in the range 5.3-8.6. According to DCD Section 9.5.9, the SPCU function is terminated during a LOCA.)

GEH Response: As described in DCD section 6.1.1.2, Demineralized water from the condensate storage tank or the suppression pool, with no additives, is employed in the core cooling water and containment sprays.

During operation, water in the 304L stainless steel-lined suppression pool is maintained at high purity (low corrosion attack) by the Suppression Pool Cleanup (SPCU) System. In the event of a LOCA, the SPCU function is automatically terminated to accomplish containment isolation. Therefore, this nonsafety-related system is not credited during LOCA / Post LOCA conditions.

Since the pH range (5.3 - 8.6) is maintained, corrosive attack on the pool liner (304L SS) will be insignificant over the life of the plant.

Because of the methods described above (coolant storage provisions, insulation materials requirements, and the like), as well as the fact that the containment has no significant stored quantities of acidic or basic materials, the post-LOCA aqueous phase pH in all areas of containment will have a flat time history. In other words, the liquid coolant will remain at its design basis pH throughout the event.

2. Describe the transient temperature and pH behavior during the post-LOCA period and how it was determined.

GEH Response: Under normal plant operating conditions, the maximum suppression pool water and wetwell airspace temperature is 35°C(95°F) or less. Under blowdown conditions following an isolation event or LOCA, the initial pool water temperature may rise to a maximum of 76.6°C (169.9 °F) at 30 minutes. The continued release of decay heat after the initial blowdown may result in suppression pool temperatures as high as 88.7°C (191.7°F). The Residual Heat Removal (RHR) System is available in the Suppression Pool Cooling mode to control the pool temperature. Heat is removed via the RHR heat exchanger(s) to the Reactor Building Cooling Water (RCW) System and finally to the Reactor Service Water (RSW) System. The containment response, including suppression pool temperature and level is described in DCD section 6.2.1.1.3.3, Accident Response Analysis, with suppression pool temperature transient behavior shown on the following DCD figures:

- Figure 6.2-7, Temperature Response of the Primary Containment for Feedwater Line Break
- Figure 6.2-15, Temperature Time History for Long-term MSLB

Information in DCD Section 6.1.1.2, (coolant storage provisions and insulation materials requirements) and the fact that the containment has no significant stored quantities of acidic or basic materials, explain why the post-LOCA aqueous phase pH in all areas of containment will have a flat time history. The liquid coolant will remain at its design basis pH throughout the event.

3. How do these predictions of pH account for the potential generation of strong acids (e.g., nitric and hydrochloric) from radiolysis, and subsequent reduction of pH in the pool if it is unbuffered and the SPCU System is not in use.

GEH Response: The generation of chemical debris in the water chemistry that is representative of a BWR post-LOCA environment is expected to be less significant (as compared to PWRs) due to the typical BWR water chemistry and, more specifically, for the ABWR due to additional considerations in design features that minimize the potential for material interactions. Chemical debris generation through interaction with materials depends largely on the pH. Sources of acids and bases in a typical BWR include (1) cesium hydroxide produced by fission, (2) hydrochloric acid generated by the radiolysis of cable insulation, and (3) nitric acid generated by the radiolysis of water and air. These potential sources are not as significant in the ABWR due to design features as explained below.

Demineralized water, with no additives, is employed in ABWR core cooling water and containment sprays (see DCD Section 6.1.1.1.2) for a description of the water quality requirements). Leaching of chlorides from concrete and other substances is not significant. No detrimental effects occur on any of the ESF construction materials from allowable containment levels in the high-purity water. Thus, the materials are compatible with the post-LOCA environment.

Because of the methods described above (coolant storage provisions, insulation materials requirements, and the like), as well as the fact that the containment has no significant stored quantities of acidic or basic materials, the post-LOCA aqueous phase pH in all areas of the ABWR containment will have a flat time history. In other words, the liquid coolant will remain at its design basis pH throughout the event and strong acids will not be generated.

4. If a combined license (COL) applicant proposed using the SLC System during a LOCA, the application would need to evaluate the impact on chemical effects, ECCS strainer head loss, and downstream effects. Describe how this possibility will be addressed, for example by proposing a COL item requiring the applicant to perform this evaluation and submit the results for NRC review.

**GEH Response:** The ABWR Standby Liquid Control (SLC) System uses a dissolved solution of sodium pentaborate as the neutron-absorbing poison potentially added for reactivity control during accident mitigation. While the SLC system is capable of injecting borated water (pH control) for use as makeup water to the RPV in response to a LOCA, no credit is taken for buffering as a result of the sodium pentaborate injection into the RPV via the SLC system.

ABWR coolant storage provisions and insulation material requirements, as well as the fact that the containment has no significant stored quantities of acidic or basic materials, ensure that the post-LOCA aqueous phase pH in all areas of containment will have a flat time history (Ref: DCD section 6.1.1.2).

The pH of the suppression pool following a LOCA will be in the range of 5.3 to 8.6, but the exact values as a function of time will depend on the actions taken by the operating crew in accordance with emergency procedures.

As discussed in Review of Boiling Water Reactor Material Dissolution in Post-LOCA Containment Solutions-NWT 863, November, 2013 [ML14328A639], Zinc release rate tests in borated water solutions at 8.5 pH (25°C) resulted in solution concentrations one to two orders of magnitude lower than those for demineralized water. Therefore, zinc release from galvanized carbon steel when exposed to borated solutions during a BWR LOCA event is not expected to be significant and was not given further consideration.

The licensing basis pH range of 5.3 to 8.6 is specified in DCD Tier 2, Subsection 3I.3.2.3. Boron injection may be used to maintain the suppression pool pH within the specified range, but such use would be as directed by procedures. The COL applicant item for developing procedures is addressed in DCD Section 13.5.3. This includes development of plant operating procedures and emergency procedures, and specifically lists the SLC system and the conditions requiring use of the SLC system (see Sections 13.5.3.2 and 13.5.3.4).

In summary, the generation of chemical debris in the water chemistry that is representative of a BWR post-LOCA environment is expected to be less significant (as compared to PWRs) due to the typical BWR water chemistry and, more specifically, for the ABWR due to additional considerations in design features that minimize the potential for material interactions. ABWR coolant storage provisions and insulation material requirements, as well as the fact that the containment has no significant stored quantities of acidic or basic materials, ensure that the post-LOCA aqueous phase pH in all areas of containment will have a flat time history. Test results show zinc release is increased at lower pH. Also, solubility of zinc increases with increased water temperature resulting in zinc retained in solution at higher temperatures. At lower temperatures, zinc precipitate (and increased strainer headloss) is less of an issue since greater margin is available to ECCS pump NPSH. Test results show zinc release on exposure to borated solutions was minimal. Therefore, SLC operation and its impact on debris generation is minimal.

**IMPACT ON DCD:**

This response has no impact on ABWR DCD Revision 6.

Tier 1:

- None

Tier 2:

- None