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June 3, 2011

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-11169

Subject: **MHI's Responses to US-APWR DCD RAI No. 751-5709 Revision 0 (SRP 06.02.05)**

Reference: 1) "Request for Additional Information No. 751-5709 Revision 0, SRP Section: 06.02.05 – Combustible Gas Control in Containment, Application Section: 6.2.5," dated May 2, 2011.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document as listed in Enclosures.

Enclosed is the response to one RAI contained within Reference 1.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of the submittals. His contact information is below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

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NRO

Enclosures:

1. Responses to Request for Additional Information No. 751-5709 Revision 0

CC: J. A. Ciocco
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Enclosure 1

UAP-HF-11169
Docket Number 52-021

Responses to Request for Additional Information
No. 751-5709 Revision 0

June 2011

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

6/3/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 751-5709 REVISION 0**

SRP SECTION: **06.02.05 – Combustible Gas Control in Containment**

APPLICATION SECTION: **6.2.5**

DATE OF RAI ISSUE: **5/2/2011**

QUESTION NO. : 06.02.05-43

Clarify how the US-APWR RWSP design complies with 10 CFR 50.44(c)(1) and (c)(2). In RAI Number 696-5433 Question Number 6.2.5-41, the staff requested that you clarify how the US-APWR containment complies with 10 CFR 50.44(c)(2) in light of a recognized indication of greater than 10% by volume concentration in the RWSP under certain accident sequences.

In your response, you have proposed a manual operator action to fill the RWSP with firewater in these scenarios, in order to eliminate the potential for a hydrogen combustion that may pose a challenge to containment integrity.

Your justification for this mitigation strategy is based on the low frequency of the accident sequences and the time required to reach conditions that result in conditions beyond the 10 CFR 50.44 limits specified for a mixed containment atmosphere.

The deterministic requirements of 10 CFR 50.44(c)(2) should be met without consideration for the period of time required for hydrogen to concentrate to levels that exceed the regulation, and without consideration of the analyzed frequency of scenarios that result in conditions that exceed the requirements of the rule.

In addition, the staff believes that it is a less optimal solution to propose operator actions to ensure that the containment is in a configuration that ensures that it conforms to 10 CFR 50.44(c)(1) and (c)(2)requirements. Manual operator actions to fill the tank would cause an increased operator burden. Such actions would necessitate additional instrumentation that would need to be designed to survive a severe accident in order to verify that operator actions to completely fill the RWSP were successful. RAI 5593 question 6.2.5-42 requests additional details on the instrumentation and controls required to support this operator action.

Regulatory Guide 1.7 regulatory position 3 states that atmospheric mixing systems may be active or passive. As it relates to the RWSP compartment, the staff considers that the proposed mixing system for the US-APWR is an active system. The regulatory guide provides design requirements for active systems.

Therefore, in accordance with RG 1.7, please provide a discussion on how the structures, systems and components used to fill the RWSP act to be reliable, redundant, single-failure proof, able to be tested and inspected, and remain operable with a loss of onsite or offsite power. Revise section 6.2.5 of the DCD as necessary to record these design commitments for these components.

In regard to the Hydrogen monitor, since it is established that there is potential to have hydrogen concentration in the RWSP that is different from the rest of containment, please provide additional details of the US-APWR hydrogen monitoring system that allows monitoring of this compartment. In accordance with 50.44(c)(4)ii. Please also discuss compliance with Regulatory Guide 1.97, regulatory position 5. Revise section 6.2.5 of the DCD as necessary to record these design commitments for these components.

ANSWER:

1. <u>**Compliance with 10CFR50.44**</u>

Regulatory Guide (RG) 1.7, Rev. 3 describes methods that are acceptable to the NRC staff for implementing 10CFR50.44 for reactors subject to the provisions of 10CFR50.44(c). Regulatory Guides provide guidance that the NRC has determined will provide a sufficiently high level of confidence that the systems, structures, and components (SSCs) chosen by an applicant to meet regulatory requirements will be capable of performing their intended design-basis functions. In this case, the SSCs' design-basis function is to mitigate combustible gas generated during a severe accident.

10CFR50.44(c)(1) and (c)(2) require that a mixed atmosphere be provided to prevent local elevated hydrogen levels and control hydrogen levels by limiting the overall (uniformly distributed) hydrogen concentration. The US-APWR design features to achieve these requirements are the containment spray system and the hydrogen igniters, as discussed in DCD Subsection 6.2.5 Rev. 3.

10CFR50.44(c)(2) requires that all non-inerted containments must limit hydrogen concentrations (uniformly distributed) to less than 10 percent (by volume). The US-APWR hydrogen igniters follow the guidance of RG 1.7 Rev. 3 Section C1. The hydrogen igniters limit the uniformly distributed hydrogen concentrations below 10 percent under all conditions. Therefore, the US-APWR design meets the deterministic requirements of 10CFR50.44(c)(2).

10CFR50.44(c)(1) requires that all containments must have a capability for ensuring a mixed atmosphere during design-basis and significant beyond design-basis accidents. Per RG 1.7 Rev. 3 Section C3, this capability may be provided by active systems such as containment spray. These active systems should be "reliable, redundant, single-failure-proof, able to be tested and inspected, and remain operable with a loss of onsite or offsite power."

The US-APWR containment spray system is a safety-related system which meets these requirements of RG 1.7, Rev. 3. The US-APWR containment is designed with large cubicle volumes and ventilation paths to promote atmospheric mixing. Hydrogen diffusivity, convective heat transfer and the containment spray provide adequate atmospheric mixing to meet the requirements of 10CFR50.44(c)(1).

The occurrence of local elevated hydrogen concentrations in the RWSP during certain severe accident conditions is only relevant to the mixed atmosphere requirements of 10CFR50.44(c)(1).

However, this only occurs if the containment spray system is inoperable. That is, this condition is outside the design-basis of the SSC (containment spray) which has been determined by the staff in RG 1.7 to provide a sufficiently high level of confidence to meet 10CFR50.44(c)(1). Therefore, MHI has proposed an alternate strategy to mitigate this unlikely accident scenario, as described below, which is outside the plant design-basis.

2. Countermeasures to mitigate failure of combustible gas mixing and control systems

The response to DCD RAI 19-449 identified certain severe accident conditions for which hydrogen concentration in the RWSP might increase above 10% by volume if "the RWSP water is not utilized." The RWSP water is utilized by both the emergency core cooling system (ECCS) and containment spray system (CSS). This severe accident condition only occurs if the CSS, the active atmospheric mixing system which meets RG 1.7 Rev. 3, has failed (in addition to the ECCS). That is, this condition is outside the design-basis of the SSCs considered to be acceptable by the staff (per RG 1.7 Rev. 3) to meet 10CFR50.44.

MHI has proposed utilizing the firewater system as a countermeasure to mitigate such a severe accident condition (beyond the plant design basis) to comply with 10CFR50.44(c)(1) and (c)(2), considering the importance of controlling hydrogen in the containment. This countermeasure involves flooding the RWSP to eliminate the limited air space volume and therefore prevent any possibility of hydrogen accumulation in the RWSP.

Indications of the RWSP water level and the hydrogen concentration in the RWSP, as asked in the RAI 749-5593 questions 6.2.5-42-3 and 4, respectively, are not necessary to initiate or verify this RWSP flooding operation. The amount of water necessary to flood the RWSP gas space is evaluated as approximately 1800m^3 and the cumulative amount of injected firewater is measurable on the injection line outside of containment. Initiation of RWSP flooding operation should not be based on the RWSP hydrogen concentration but other triggers (e.g., identification of core damage or loss of ECCS/CS) prior to potential hydrogen accumulation.

Discussion regarding the frequency in the answer to RAI 19-449 was for the impact to the LRF and was not intended to apply to the requirements of 10CFR50.44(c)(2), which are met under all conditions as discussed above. It is impossible to deterministically eliminate the probability for failure of an active atmospheric mixing system which meets RG 1.7 Rev. 3. Therefore, the US-APWR design utilizes RWSP flooding as a countermeasure in the unlikely severe accident conditions considering the importance of controlling hydrogen in the containment as discussed in DCD RAI 19-449. Additional details of this severe accident mitigation capability are provided below.

2.1 Assumptions for CS / SI Failure

Some severe accident scenarios involving unavailability of the ECCS, CSS or hydrogen igniters may occur under certain severe accident sequences beyond the plant design basis. One of the example scenarios is a complete station blackout with no emergency gas turbine generators and no alternate AC power generators.

2.2 Hydrogen Accumulation

Hydrogen generated due to zirconium reaction is released to the containment atmosphere through the break of reactor coolant pressure boundary (RCPB), and at this time the hydrogen concentration in the RWSP is almost zero. The containment atmosphere including hydrogen flows into the RWSP through the paths connecting the RWSP and the containment compartments, i.e. vent pipes, recirculation water transfer pipes, etc. The containment atmosphere flowing into the RWSP is very rich in steam, most of which is condensed in the RWSP because the temperature in the RWSP is maintained very low relative to other containment compartments due to the large amount of cold water in the RWSP. Through this steam condensation mechanism, the relative hydrogen concentration in the RWSP becomes higher than in other compartments although the absolute hydrogen concentration is almost the same or even lower than in other compartments. In situations where the RWSP water is utilized by the ECCS or CSS, the RWSP water temperature increases and limits the amount of condensation.

The hydrogen concentration presented in Figure 19-449-6 of RAI #627-4926 Question 19-499, which was calculated for a SBO with RCP seal LOCA scenario, is manipulated to observe the dry hydrogen concentration as shown in Figure 6.2.5-43-1 below. The dry hydrogen concentration is a hypothetical value assuming that steam does not exist in the air. Time zero is the initiation of RCP seal LOCA (assumed simultaneously occurring with SBO) and core melt occurs at approximately 5 hours. At that time, hydrogen is released to the containment compartment. It can be observed from this figure that the hydrogen concentration in the RWSP gradually increases when the containment atmosphere containing hydrogen and steam flows into the RWSP, although the dry hydrogen concentration in the RWSP is always lower than that in other compartments.

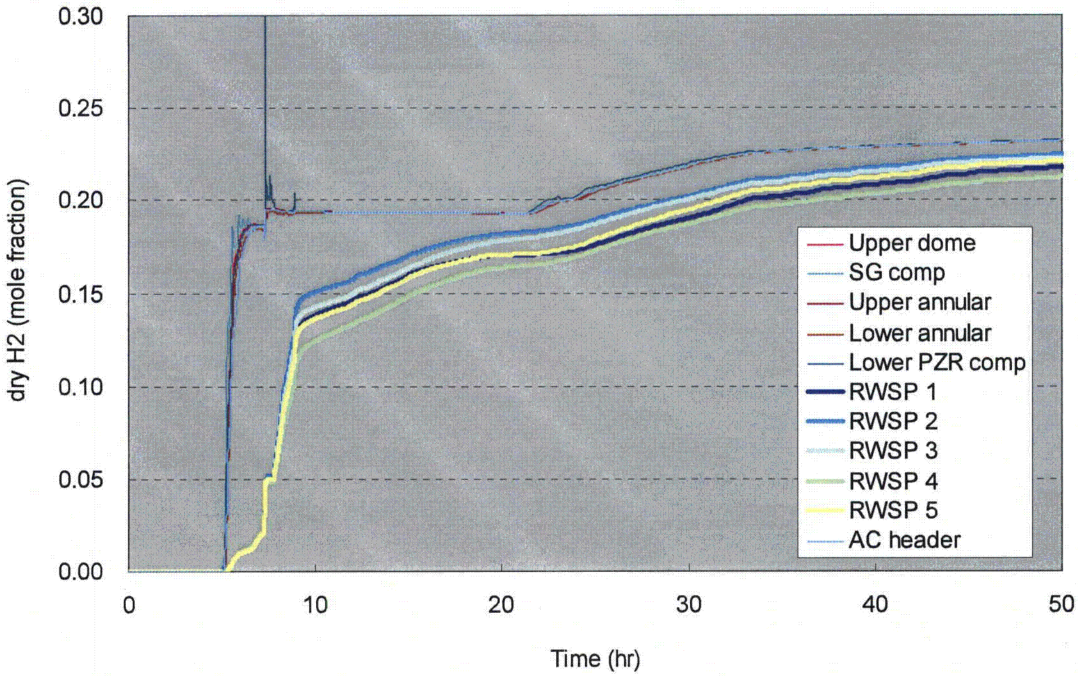

Figure 6.2.5-43-1 Dry Hydrogen Concentration for SBO Scenario

It can be considered from this evaluation result that the overall level of atmospheric mixing in the containment (including the RWSP) is still high even when the CSS is not available. This high level of mixing is the cause of the high RWSP hydrogen concentration because it allows a constant and continuous replenishment of the flow into the RWSP (due to condensation of the steam-rich atmosphere by the sub-cooled RWSP water).

2.3 Instrumentation

Indications of the RWSP water level and qualification of additional instrumentation for severe accident environmental conditions (as asked in the RAI 749-5593 questions 6.2.5-42-3 and 4) and RWSP hydrogen monitoring (as asked above) are not necessary to accomplish RWSP flooding.

RWSP water level indication is considered unnecessary for this severe accident mitigation strategy because alternate reliable instrumentation is available. The amount of water necessary to flood RWSP gas space is evaluated as approximately 1800m^3 and the cumulative amount of firewater injection is measurable on the injection line outside of containment.

RWSP hydrogen concentration indication is unnecessary because initiation of RWSP flooding operation should not be based on the RWSP hydrogen concentration. Instead, other triggers should be utilized such as identification of core damage or containment atmosphere hydrogen concentration other than RWSP. This is because firewater injection operation is not just only to maintain the RWSP hydrogen concentration to be less than 10% but also because it is a fundamental safety operation for debris cooling during severe accidents (especially for dry-containment sequences, typically a SBO scenario).

It should be noted that the accident scenario shown in Figure 6.2.5-43-1 considers an extremely conservative assumption, which is the RCP seal LOCA from all four RCPs with a 300gpm leak immediately after SBO. In reality, it is more likely that the seal leak rate is less than this assumption so that longer time may be available for recovery action for various mitigation systems before core damage. Initiation of firewater injection may be determined when these recovery actions have all failed and core damage is highly anticipated or has already been identified.

2.4 <u>RG 1.7 for RWSP Flooding</u>

Manual operator actions are not prohibited by 10CFR50.44, RG 1.7 Rev. 3, or SRP Subsection 6.2.5. The US-APWR design does not credit manual operator actions to meet 10CFR50.44, as described above. Manual operator actions are a core component of defense-in-depth offered by severe accident mitigation plans. Prohibiting manual operator actions for mitigation of severe accidents defeats the purpose of planning for potential severe accidents beyond the plant design basis.

As discussed above, RWSP flooding is only necessary if the CSS has failed and is outside the CSS design basis for meeting 10CFR50.44(c)(1). Therefore, the structures, systems, and components to accomplish RWSP flooding are not necessary to meet the requirements of RG 1.7, Rev. 3.

Impact on DCD

DCD Section 6.2.5 and Section 19.2.3.3.2 will be revised as follows.

6.2.5 Combustible Gas Control in Containment

The containment hydrogen monitoring and control system consists of the following systems:

- Hydrogen monitoring system
- Hydrogen ignition system

The hydrogen monitoring system consists of one hydrogen monitor that is located outside of the containment and measures hydrogen concentration in containment air extracted from the containment through the radiation monitoring system containment air sampling line. The containment penetration portion of this line is shared with the post-accident containment atmospheric sampling line.

Hydrogen concentration is continuously indicated in the MCR after the containment isolation valves of the radiation monitoring system (RMS) containment air sampling line are manually opened. Figure 6.2.5-1 presents a schematic of the hydrogen monitoring system.

The hydrogen ignition system consists of twenty hydrogen igniters that are positioned in containment areas and subcompartments where hydrogen may be produced, transit, or collect as follows:

- One hydrogen igniter near the PRT
- One hydrogen igniter in the upper area of the pressurizer compartment
- One hydrogen igniter in the lower area of the pressurizer compartment
- Four hydrogen igniters, one in each SG/reactor coolant loop subcompartment
- Four hydrogen igniters in the 2nd floor of containment
- Four hydrogen igniters in the 3rd floor of containment
- Five hydrogen igniters in the containment dome (near the top of each SG and pressurizer subcompartments)

The hydrogen ignition system is automatically initiated by the ECCS actuation signal. This system may also be actuated manually. The hydrogen igniters reduce the concentration of hydrogen in the containment. The hydrogen igniters are designed to burn hydrogen continuously at a low concentration, thus, preventing significant hydrogen accumulation. Hydrogen igniters limit combustible gas concentration in the C/V following an accident, uniformly distributed, to less than 10% (by volume).

The containment spray system, in conjunction with convective heat transfer and hydrogen diffusivity, performs atmospheric mixing to ensure uniform distribution of hydrogen and contact with the installed hydrogen igniters. Figure 6.2.5-2 presents the typical air-hydrogen flow patterns within the C/V. The containment spray system is a design-basis safety-related system which is reliable, redundant, single-failure-proof, able to be tested and inspected, and remains operable with a loss of onsite or offsite power per RG 1.7, Rev. 3. The technical report "US-APWR Probabilistic Risk Assessment" Section 15.3.3 (Ref. 6.2-37) demonstrates that the atmospheric mixing provided by the containment spray system as well as the combustible gas control provided by the hydrogen igniters ensures that combustible gases will not accumulate within a compartment or cubicle to form a combustible or detonable mixture that could cause loss of containment integrity.

~~Hydrogen igniters limit combustible gas concentration in the C/V following an accident, uniformly distributed, to less than 10% (by volume). Figure 6.2.5-2 presents the typical air-hydrogen flow patterns within C/V. Convective heat transfer and hydrogen diffusivity, in conjunction with containment spray discharges, ensure uniform mixing of hydrogen and contact with the installed hydrogen igniters.~~

6.2.5.1 Design Bases

The containment hydrogen monitoring and control system is designed in accordance with 10 CFR 50.34(f)(2)(ix), "Additional TMI-related requirements;" 10 CFR 50.44, "Combustible Gas Control for Nuclear Power Reactors;" and GDC 41, "Containment Atmosphere Cleanup." ~~The systems~~ The containment hydrogen monitoring and control system and the containment spray system also address the recommendations of RG 1.7, "Control of Combustible Gas Concentrations in Containment;" and NUREGs 0737 and 0660, as presented in Section 1.9.

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6.2.5.3 Design Evaluation

Hydrogen monitoring and control is provided for the unlikely occurrence of an accident that is more severe than a postulated design-basis accident. Thus, the hydrogen monitor has detection and display ranges of 0 to 10% by volume in the containment air. This monitoring range satisfies the requirements of 10 CFR 50.34(f)(2)(ix)(A) and 50.44(c)(2) for combustible gas control. The accuracy of the hydrogen monitor is less than or equal to ±10% of full span. The measured value of hydrogen concentration is utilized for operator actions and this accuracy is sufficient to accomplish the actions. These operator actions are briefed in Subsection 19.2.5. The hydrogen igniters are automatically energized by the ECCS actuation signal. However, the design evaluation is neither required nor provided for such a beyond-design-basis event.

Beyond-design-basis evaluations documented in Chapter 19 include a combustible gas release within containment corresponding to the equivalent amount of combustible gas that would be generated from a 100% fuel-clad coolant reaction, uniformly distributed. As discussed in Section B of Revision 3 of RG 1.7 (Ref. 6.2-29), these Chapter 19 evaluations are intended to show that hydrogen concentrations, uniformly distributed, do not exceed 10 volume percent (10 vol.%) and that the structural integrity of the containment pressure boundary is maintained. Detailed evaluation for hydrogen generation and control is provided in the technical report "US-APWR Probabilistic Risk Assessment" Section 15.3 (Ref. 6.2-37).

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19.2.3.3.2 Hydrogen Generation and Control

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Analysis result

Accident progression analyses for hydrogen generation and control utilizing the hydrogen ignition system have been performed using GOTHIC code. In the developed GOTHIC model, hydrogen igniters are located at 20 locations in the containment and are modeled to initiate hydrogen burning when hydrogen concentration becomes greater than 8% by volume except under the condition inerted by steam.

Hydrogen concentration in each compartment is either lower than 10% or the compartment is inerted by steam. The pressure in containment is kept below 68 psia, and this pressure is much lower than the containment ultimate pressure 216 psia as described in DCD section 19.2.4. For several sequences, especially when RWSP water is not utilized ~~for decay heat removal~~ due to failure of the safety injection system and the containment spray system, the hydrogen concentration in the RWSP may increase to greater than 10% long after the initiation of an accident. Under such a situation, operator action to inject firewater into the containment is initiated. As the result, the RWSP is filled with water, thus preventing high hydrogen in the RWSP air volume. Therefore, the containment integrity is maintained against hydrogen combustion events, and the requirements of 10 CFR 50.44(c)(1), 10 CFR 50.34(f)(2)(ix), 10 CFR 50.44(c)(2), 10 CFR 50.34(f)(3)(v) (A)(1), and 10 CFR 50.44(c)(5) are therefore met.

The maximum pressure in the containment vessel under the adiabatic isochoric complete combustion condition is 127 psia. This pressure is lower than the containment ultimate pressure of 216 psia thus the requirement of 10 CFR 50.44(c)(5) is met.

Impact on DCD

There is no impact on the DCD

Impact on R-COLA

There is no impact on the R-COLA

Impact on S-COLA

There is no impact on the S-COLA

Impact on PRA

There is no impact on the PRA