**MITSUBISHI HEAVY INDUSTRIES, LTD.**
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**TOKYO, JAPAN**

March 29, 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-11084

**Subject: MHI's Responses to US-APWR DCD RAI No. 707-5556 Revision 2 (SRP 19)**

**Reference:** 1) "Request for Additional Information No. 707-5556 Revision 2, SRP Section: 19 – Probabilistic Risk Assessment and Severe Accident Evaluation, Application Section: 19.2," dated March 1, 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.

Enclosures:

1. Responses to Request for Additional Information No. 707-5556 Revision 2

CC: J. A. Ciocco
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Enclosure 1

UAP-HF-11084
Docket Number 52-021

Responses to Request for Additional Information
No. 707-5556 Revision 2

March 2011

## RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**3/29/2011**

**US-APWR Design Certification**

**Mitsubishi Heavy Industries**

**Docket No.52-021**

**RAI NO.:** NO. 707-5556 REVISION 2

**SRP SECTION:** 19 – Probabilistic Risk Assessment and Severe Accident Evaluation

**APPLICATION SECTION:** 19

**DATE OF RAI ISSUE:** 3/1/2011

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**QUESTION NO.: 19-499**

The US-APWR PRA report includes an equipment survivability assessment that considers electrical and mechanical instruments and equipment required for severe accident management. The applicant classified the time frames for equipment survivability, selected the necessary equipment and instruments, analyzed severe accident environments, and finally assessed equipment survivability. The time frames for equipment survivability are classified in accordance with the characteristic stages of the severe accident progression. The time frames are as follows:

- T0: before the core has uncovered, the reactor core is intact and the environmental conditions in the containment are within the envelope of the DBA conditions.

- T1: from core uncovered to core damage, the reactor core is overheated and hydrogen generation starts due to cladding-water interaction. However, the environmental conditions in the containment are almost the same as in T0.

- T2: from core damage to reactor vessel failure, fission products are released from fuel to RCS and hydrogen is rapidly generated. The decay heat and oxidation heat promote the core degradation. Consequently core material relocates to the lower plenum if water is not properly injected into the reactor vessel. However, the environmental conditions in the containment are not harsh, i.e. the containment pressure at vessel failure is likely to be below the design pressure regardless of the containment cooling system condition. On the other hand, hydrogen release to the containment atmosphere is very likely in this time frame.

- T3: after reactor vessel failure, rapid hydrogen generation is expected to proceed immediately after the reactor vessel failure because un-oxidized metal in molten core reacts with water in the reactor cavity. After this transient oxidation event, hydrogen may be continuously generated due to MCCI, although further rapid hydrogen generation is unlikely. Hydrogen generation from MCCI occurs if reactor cavity is not flooded. The reactor cavity is flooded, and hence the possibility of MCCI is considered low. The environmental conditions in the containment for this time frame are maintained stable as long as containment heat removal is successful, regardless of hydrogen combustion by igniters. If containment heat removal is not achieved, harsh conditions for equipment are anticipated, mostly governed by pressurization and corresponding temperature rise. Influence by hydrogen combustion is considered insignificant.

The equipment survivability assessment only considered devices, systems or properties needed in time frames T2 or T3 that would be located either in the RCS or inside containment. The equipment and instruments necessary to function in each time frame are tabulated in Tables 15-23 and 15-24 of the US-APWR PRA. Thirteen countermeasures against severe accidents are also identified in the tables and described in the PRA.

This information is judged by the staff as important enough to be included in the DCD. Accordingly, please include in the DCD a description of the countermeasures and the time frames when they would be used. Also, please include the material in Tables 15-23 and 15-24, and discuss the relevant information regarding necessary devices, systems, and physical properties, and where each would be located.

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**ANSWER:**

The Containment and Ventilation Branch 1 (AP1000/EPR Project) (SPCV) staff has issued several RAIs concerning the equipment survivability study in relation to the functionality of hydrogen igniters (including RAI 551-4356 and RAI 635-4954). In the answer for these RAIs, MHI has proposed revising the description of equipment survivability study in DCD Subsection 19.2.3.3.7, and this change proposal is incorporated in the DCD Revision 3. DCD Section 19.2.3.3.7 will be therefore further revised to be consistent with the answers for these RAIs as follows. Please note that the underlined portion is the modification to the RAI responses provided earlier and is not a modification to the DCD Revision 2.

**19.2.3.3.7 Equipment Survivability**

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Analysis result

During accident conditions, key systems and components are maintained with the most appropriate set of mitigation measures.

The key systems and components are selected by considering:

- The time frame of the severe accident progression, i.e. when the system or components are expected to be functional
- The location that equipment and instrumentation are arranged, i.e. at the inside or the outside of containment
- The significance of evaluations, i.e. if the system is backed up by an alternative measure, etc.

The time frames for equipment survivability are classified in accordance with the characteristic stages of the severe accident progression. Classification of the time frames enables limits to be placed on the equipment to be assessed for the survivability evaluation.

- T0: before core uncovered

  T0 is defined as the time frame that the reactor core is intact and the environmental conditions in the containment are within the envelope of the DBA conditions.

- T1: from core uncovered to core damage

  In this time frame, the reactor core is overheated and hydrogen generation starts due to cladding-water interaction. However, the environmental conditions in the containment are almost the same as in T0. The amount of hydrogen generation is limited and hence the impact of hydrogen burn to equipment functionality is not significant.

- T2: from core damage to reactor vessel failure

  In this time frame, fission products are released from the fuel to the RCS and hydrogen is rapidly generated. These physical phenomena are both caused by core damage. The decay heat and oxidation heat promote core degradation. Consequently, core material then relocates to the lower plenum if water is not injected into the reactor vessel. However, the environmental conditions in the containment are not harsh yet, i.e. the containment pressure at vessel failure is likely to be below the design pressure regardless of the containment cooling system condition. Hydrogen release to the containment atmosphere is very likely in this time frame. Therefore, the influence of containment temperature rise due to hydrogen burn must be evaluated.

- T3: after reactor vessel failure

  In this time frame, rapid hydrogen generation is expected immediately after reactor vessel failure because un-oxidized metal in the molten core reacts with water in the reactor cavity. After this transient oxidation event, hydrogen may be continuously generated due to molten core concrete interaction (MCCI) although at a much slower rate. Hydrogen generation from MCCI occurs if the reactor cavity is not flooded. When the reactor cavity is sufficiently flooded, the possibility of MCCI is considered low. The amount of hydrogen generated in this time frame is considered significant so that the impact of hydrogen burn must be evaluated.

The equipment survivability assessment is performed considering the following two criteria:

(1) The SSCs or parameters needed in the T2 and T3 time frames
(2) Equipped location is either in the RCS or inside the containment

Equipment and instruments are screened out from the survivability assessment in accordance with the following three criteria:

(1) The function of equipment and instruments are not directly related to the prevention of containment failure or fission product release,
(2) Alternative countermeasures are available
(3) Equipment is static and robust

The equipment and instruments necessary to function in each time frame are tabulated in Tables 19.2-10 and 19.2-11.

The selected systems and components include containment penetrations, hydrogen igniters, depressurization valves used for severe accident mitigation, and a containment pressure sensor (wide range).

| Systems / Components | Timeframe required to be functional |
|---|---|
| (1) Containment penetration | After core damage (T2 and T3) |
| (2) Hydrogen igniter | After core damage (T2 and T3) |
| (3) Depressurization valve | After core damage till reactor vessel failure (T2) |
| (4) Containment pressure sensor (wide range) | After core damage (T2 and T3) |

An environmental condition associated with hydrogen burning via hydrogen ignition system operation has been evaluated using GOTHIC code. Detailed evaluation results are described in Section 15.7 of the PRA technical report "US-APWR Probabilistic Risk Assessment" (Reference 19.2-15). The environmental conditions which the above four systems/components must satisfy are the following.

(1) Containment penetration

Based on the following screening evaluation, the containment penetrations that are included in the equipment survivability study under the hydrogen burn condition can be limited to the electrical penetrations that provide power to the hydrogen igniters and the depressurization valves.

There are two major functions provided by containment penetrations; (1) provide the continuity of in-line, process flow paths between inside and outside containment across the containment boundary; and (2) maintain containment integrity at the location of the penetration. There are two basic types of containment penetrations; mechanical and electrical.

MHI has evaluated the environmental conditions in containment created by a local hydrogen burn. The results indicate that the pressure rise is not expected to be significant. The peak pressure has been determined to be below the containment design pressure of 68 psig. However, the local temperature rise is significant and in some locations the temperature rise could be as much as 1200°F. A high ambient temperature may not impact the containment integrity function at the penetration, but could impact the in-line process flow path function, especially for electrical penetrations.

Mechanical containment penetrations are robust by nature because they are made from heavy gauge metal, are firmly welded to the containment liner and can withstand excessive temperatures and pressures. Electrical containment penetrations are also robust in terms of containment integrity, but must be evaluated in terms of the severe accident (SA) survivability requirement for the in-line process flow path function, i.e., electrical current.

It is important to identify which electrical circuits that penetrate containment and that have functions that are fundamental to establish and maintain safe shutdown and containment structural integrity. Two circuits have been identified that serve components or systems with these functions; the circuits to the hydrogen igniters and the depressurization valves. As a result, these electrical penetrations which provide power to the hydrogen igniters and the depressurization valves are subject to the survivability study.

The highest temperature reached at the location of these electrical penetrations is evaluated to be less than 400°F, and the steady-state temperature is evaluated at about 200°F. The containment design temperature is 300°F. The highest pressure reached at the location of these electrical penetrations has been evaluated to be approximately 50 psig, which is lower than the containment design pressure of 68 psig. The amount of hydrogen burned in this analysis is conservatively assumed to be equivalent to that generated by oxidation of 100% of the active fuel length cladding. Hence, this analysis is conservative and brackets the various uncertainties involved in the hydrogen generation and burn calculation.

Based on the evaluation above, the environmental conditions that the electrical containment penetration must survive while maintaining containment integrity and supplying electricity to the circuits for the hydrogen igniters and depressurization valves are the containment design pressure of 68 psig and design temperature of 300°F for 24 hours, including consideration for an instantaneous temperature rise of 400°F due to a hydrogen burn.

(2) Hydrogen igniter

The hydrogen igniters can perform their function during and after exposure to the environmental conditions created by a hydrogen burn. Through the equipment survivability study, it has been evaluated that the peak temperature of containment atmosphere becomes as high as approximately 1200°F, and the temperature rise from 400°F and decline back to 400°F due to hydrogen burn takes approximately 10 minutes. The amount of hydrogen burned in this analysis is conservatively assumed to be equivalent to that generated by oxidation of 100% of the active fuel length cladding; hence this analysis bounds the uncertainties involved in the hydrogen generation and burn.

Therefore, in terms of the equipment survivability, it is required that the hydrogen ignition system keeps its function for at least 10 minutes at a containment atmosphere that is higher than 400°F with a peak temperature as high as 1200°F.

(3) Depressurization valve

Severe accident scenarios have been further evaluated in the equipment survivability study to determine when and under what conditions the functioning of the depressurization valve (DV) is considered necessary to establish and maintain safe shutdown and containment structural integrity. LOCA scenarios are eliminated because the initiating event depressurizes the RCS, and only transient scenarios resulting in high RCS pressure need be considered. Accordingly, it is concluded that the hydrogen burn condition does not directly affect the DV function, which is to depressurize the RCS after the core is significantly damaged. Potential hydrogen release paths from the RCS during transient events include a pathway via the pressurizer relief tank (PRT), the failure of the RCPB, or the opening of the DV. The hydrogen release from the PRT and the associated hydrogen burn has a negligible effect on the DV since the compartment where the PRT is located is apart from the location where the DV is located. Therefore, a hydrogen burn in the PRT compartment has very little influence on the functionality of the DV. Hydrogen release from a failure of the RCPB and the associated hydrogen burn may impact the functionality of the DV. However, the RCPB release simultaneously depressurizes the RCS, and hence the DV is not required for these accident scenarios. Hydrogen release via the opening of the DV and the associated hydrogen burn has the most significant impact on the functionality of the DV. Because a large amount of hydrogen is released via the opening of the DV, the atmosphere surrounding the DV becomes hydrogen-rich. This hydrogen is burned by the hydrogen igniters located near the DV. In such cases, the DV may encounter severe environmental conditions created by the hydrogen burn. However, after the DV is opened and hydrogen is released to the containment, the DV is not required to function. The DV is only operated under severe accident conditions in which the core has already been significantly damaged. Under such situations, the capability to close the DV is not required.

Considering the discussion above, the function of the DV to open is not adversely affected by hydrogen burns from the hydrogen released by the PRT or the RCPB. The function of the DV to open is not adversely affected by the hydrogen burn from the hydrogen released by the DV since the function to open has already been fulfilled and the DV is open.

(4) Containment pressure sensor (wide range)

The highest temperature where the containment pressure sensor (wide range) exists is evaluated slightly below 800°F. The temperature rise from 400°F and decline back to 400°F due to hydrogen burn takes approximately 2 minutes. The highest pressure evaluated from this study is approximately 50 psig, which is lower than the containment design pressure of 68 psig. The amount of hydrogen burned in this analysis is conservatively assumed to be equivalent to that generated by oxidation of 100% of the active fuel length cladding; hence this analysis bounds the uncertainties involved in the hydrogen generation and burn.

Considering the above findings, the environmental conditions under which the containment pressure sensor (wide range) must maintain its function include at least 2 minutes under 400°F atmosphere, and an instantaneous temperature rise due to hydrogen burn with peak temperatures as high as 800°F.

These specific environmental conditions obtained from the equipment survivability study are addressed for the type test or analyses of these systems and components. It will be confirmed through the type test or analyses that the systems and components in the US-APWR design are able to support achieving and maintaining safe shutdown, are able to maintain containment structural integrity with high confidence, and are able to keep their functions under the postulated severe accident environmental conditions created by hydrogen burning. These qualification requirements will be appropriately carried forward in procurement documents.

Existing experiments and associated literature (References 19.2-11, 19.2-12, and 19.2-13) are appropriately used to evaluate the US-APWR equipment survivability.

## Table 19.2-10 Equipment and Instruments Used in Severe Accident Management (Sheet 1 of 2)

| Function | Countermeasure | Required at (*1) T0 | T1 | T2 | T3 | Required Device, System or Parameter | | Location | Judge (*2) | Note (*3) |
|---|---|---|---|---|---|---|---|---|---|---|
| Accident progression monitoring | Identification of core damage | X | X | - | - | parameter | Core exit temperature | in RCS | - | |
| | | | | | | | Containment radiation level | in-Cont | - | |
| | Monitoring of noble gas release path | X | X | X | X | parameter | Auxiliary building radiation level | ex-Cont | - | |
| | | | | | | | Main steam line radiation level | ex-Cont | - | |
| | | | | | | | Exhaust stack radiation level | ex-Cont | - | |
| | | | | | | | Environmental radiation level | ex-Cont | - | |
| Damaged core cooling | Water injection to primary system | X | X | X | - | system | Safety injection system | in-Cont | X | Screened out as it is normally open |
| | | | | | | | Alternate core injection | in-Cont | X | Screened out as insignificant for SA mitigation |
| | | | | | | | RV head vent | in-Cont | X | Screened out as insignificant for SA mitigation |
| | | X | X | - | - | parameter | Core exit temperature | in RCS | - | |
| | | | | | | | RWSP water level | in-Cont | - | |
| | | | | | | | RV water level | in RCS | - | |
| | Water injection to reactor cavity | X | X | X | X | system | CSS | ex-Cont | - | |
| | | | | | | | Firewater injection to reactor cavity | ex-Cont | - | |
| | | | | | | | Firewater injection to spray header | ex-Cont | - | |
| | | X | X | - | - | parameter | RWSP water level | in-Cont | - | |
| | | | | | | | Cavity water level | in-Cont | - | |
| | | | | | | | Cumulative firewater flow amount | ex-Cont | - | |
| Containment cooling | Containment depressurization | X | X | X | X | system | CSS | ex-Cont | - | |
| | | | | | | | Containment fan cooler unit | in-Cont | X | Screened out as it is static device |
| | | | | | | | CCW | ex-Cont | - | |
| | | X | X | X | X | parameter | Containment pressure | in-Cont | X | |
| | | | | | | | RWSP water level | in-Cont | X | Screened out as alternative device available |
| | Preparation for alternate containment cooling by containment fan cooler unit | X | X | X | X | system | CCW pressurization system | ex-Cont | - | |
| | | X | X | X | X | parameter | CCW surge tank pressure | ex-Cont | - | |
| | Firewater injection to spray header | X | X | X | X | system | Firewater spray system | ex-Cont | - | |
| | | X | X | X | X | parameter | Containment pressure | in-Cont | X | |
| | | | | | | | Cumulative firewater flow amount | ex-Cont | - | |

(*1) T0: Before core uncover, T1: After core uncover till core damage, T2: After core damage till RV failure, T3: After RV failure

(*2) Subject for study is judged considering the following criteria (1) the device, system or parameter is required at T2 and T3, and (2) location is either in RCS or in containment.

(*3) Judged as necessary to assess according to the above two criteria however screened out items are noted in this column with the reason screened out.

X: Included in the study, -: Excluded from the study

## Table 19.2-11 Equipment and Instruments Used in Severe Accident Management (Sheet 2 of 2)

| Function | Countermeasure | Required at (*1) | | | | Required Device, System or Parameter | | Location | Judge (*2) | Note (*3) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | T0 | T1 | T2 | T3 | | | | | |
| Prevention of Fission product release | Containment function | X | X | X | X | device | Containment body | in-Cont | X | Screened out due to its robustness |
| | | | | | | | Containment penetration | in-Cont | X | |
| | | X | X | X | X | parameter | Containment pressure | in-Cont | X | |
| | | | | | | | Containment temperature | in-Cont | X | Screened out due to less importance |
| | Containment isolation | X | X | X | X | device | Containment isolation valve | in and ex-Cont | - | |
| | | X | X | X | X | parameter | Containment isolation valve position | in and ex-Cont | - | |
| | Reduction of radiation at containment atmosphere | X | X | X | X | system | CSS | ex-Cont | - | |
| | | | | | | | Firewater spray system | ex-Cont | - | |
| | | X | X | X | X | parameter | Containment radiation level | in-Cont | X | Screened out as alternative device available |
| | Secondary system water supply | X | X | X | - | system | Emergency feedwater system | ex-Cont | - | |
| | | | | | | | Main feedwater system | ex-Cont | - | |
| | | X | X | - | - | parameter | SG water level | in-Cont | - | |
| | Primary system depressurization | X | X | X | - | device | Depressurization valve | in-Cont | X | (Severe accident dedicated valve) |
| | | | | | | | Safety depressurization valve | in-Cont | X | Screened out as insignificant for SA mitigation |
| | | | | | | | Main steam relief valve | ex-Cont | - | |
| | | | | | | | Main steam turbine bypass valve | ex-Cont | - | |
| | | X | X | - | - | parameter | RCS pressure | in RCS | - | |
| | Combustible gas control | X | X | X | X | device | Hydrogen igniter | in-Cont | X | |
| | | X | X | X | X | parameter | Hydrogen concentration | ex-Cont | - | |

(*1) T0: Before core uncover, T1: After core uncover till core damage, T2: After core damage till RV failure, T3: After RV failure

(*2) Subject for study is judged considering the following criteria (1) the device, system or parameter is required at T2 and T3, and (2) location is either in RCS or in containment.

(*3) Judged as necessary to assess according to the above two criteria however screened out items are noted in this column with the reason screened out.

X: Included in the study, -: Excluded from the study

**Impact on DCD**

The DCD will be revised as described above.

**Impact on R-COLA**

None

**Impact on S-COLA**

None

**Impact on PRA**

None