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Proprietary Notice
This letter forwards proprietary information in accordance with 10CFR2.390. Upon the removal of Enclosure 1, the balance of this letter may be considered non-proprietary.

MFN 08-801

Docket No. 52-010

November 3, 2008

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

Subject: Response to Portion of NRC Request for Additional Information Letter No. 230 Related to ESBWR Design Certification Application ESBWR RAI Numbers 19.2-93 through 19.2-119

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission Request for Additional Information (RAI) dated August 15, 2008 (Reference 1).

The GEH responses to RAI Numbers 19.2-93 through 19.2-119 are in Enclosure 1. Enclosure 1 contains GEH proprietary information as defined by 10 CFR 2.390. GEH customarily maintains this information in confidence and withholds it from public disclosure.

Enclosure 2 is the non-proprietary version of the RAIs, which is suitable for public disclosure.

The affidavit contained in Enclosure 3 identifies that the information contained in Enclosure 1 has been handled and classified as proprietary to GEH. GEH hereby requests that the information of Enclosure 1 be withheld from public disclosure in accordance with the provisions of 10 CFR 2.390 and 9.17.

If you have any questions or require additional information, please contact me.

Sincerely,

Richard E. Kingston

Richard E. Kingston
Vice President, ESBWR Licensing

D068
NRO

Reference:

1. MFN 08-616, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request For Additional Information Letter No. 230 Related To NEDE-33392, "BIMAC TEST REPORT"*, dated August 4, 2008.

Enclosures:

1. Response to NRC Request for Additional Information Letter No. 230 Related to ESBWR Design Certification Application Probabilistic Risk Assessment RAI Numbers 19.2-93 through 19.2-119 - GEH Proprietary Information

2. Response to NRC Request for Additional Information Letter No. 230 Related to ESBWR Design Certification Application Probabilistic Risk Assessment RAI Numbers 19.2-93 through 19.2-119 - Non-Proprietary Version

3. Affidavit – MFN 08-801

cc:	AE Cubbage	USNRC (with enclosure)
	RE Brown	GEH/Wilmington (with enclosure)
	eDRF Section	0000-0092-1151 RAI 19.2-93
		0000-0092-1147 RAI 19.2-95
		0000-0092-1270 RAI Rev 1 19.2-94 and 19.2-96 thru 19.2-119

MFN 08-801

Enclosure 2

Response to NRC Request for

Additional Information Letter No. 230

Related to ESBWR Design Certification Application

ESBWR Probablilistic Risk Assessment

RAI Numbers 19.2-93 through 19.2-119

Non- Proprietary Information

NRC RAI 19.2-93

Question Summary Verification of final BiMAC tube design specifications

Full Text:

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*
2. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

Reference [1] states that the final design will be decided after the MAC experiments. Reference [2] argues in favor of a system incorporating tubes with [[···]] diameter and [[ ]] inclination. The experiments (single tube and multiple tubes) are also based on this design. Please confirm that the final design in the ESBWR plant will have [[ ]] tubes, [[ ]] in diameter each at an inclination of [[ ]] with the horizontal plane. If not, provide the final dimensions.

GEH Response

Yes, the tubes will be [[ ]] inches ([[ ]] cm) nominal diameter, at an inclination of [[···]] degrees. The number of tubes contacting each other to completely cover the lower drywell floor should be approximately [[ ]] with the final number determined in detailed design.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-94

Question Summary: Tube diameters and inclinations affect on heat loads

Full Text:

[REFERENCE]

1. T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)

[QUESTION]

Reference [1] implies that the final BiMAC design may most likely choose [[ ]]. Please confirm this interpretation, and discuss the effects of differences in tube diameters and inclinations on the calculated heat loads.

GEH Response

The final option chosen was pipes with a nominal diameter of [[ ]] inches ([[ ]] cm), see Section 6 of [1]. The impacts of these choices have been noted in [1] on p.7 and we quote:

"The principal design variables in the full-scale tests were channel diameter and inclination. In the SAT report these were chosen to facilitate understanding during the SAT review process, in the absence of experimental data, at values of 0.1 m and 10 degrees respectively. During testing it became clear that coolability could not be challenged even for values as small as [[ ]] m ([[ ]] inches) and [[ ]] degrees and these specifications then became the principal focus of the experimental program.

An inclination of [[ ]] degrees is preferable (over 10 degrees) because it creates a smaller depth non-uniformity as illustrated in Figure 3.4. This allows space for the BiMAC to be buried deeper into the floor (an increase by [[...]] m) ([[ ]] inches)), which provides extra protection from mechanical impacts and steam explosion loads. In addition, a smaller diameter is more resistant to crushing loads, thus providing still greater protection against potential steam explosions. Finally a more nearly horizontal "dish" bottom would reduce the intensity of organized natural convection currents, such as those that gave rise to local peaking on the edge channels shown in Figure 3.2—see also Figure 3.7."

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-95

Question Summary Core melt situations where GDCS pools are depleted, preventing the deluge function

Full Text

The GDCS's main function is to serve as an emergency cooling supply to the core in any event that threatens the reactor coolant inventory. In addition, if the vessel fails, it is important to ensure that the GDCS can provide sufficient water to cool the debris in the lower drywell by utilizing the BiMAC. Please provide documentation of any core melt situations in which the GDCS pools have already been depleted by providing water to the vessel, and there is not sufficient inventory for ex-vessel cooling. Describe the amount of water that is required to sustain the BiMAC system.

GEH Response

A core melt situation with a depletion of the GDCS pools by providing water to the vessel requires a failure of containment heat removal. This sequence would be a Class II sequence.

The amount of water necessary for the BiMAC to function corresponds to a pool depth sufficient to cover the inlets to the BiMAC downcomers. The water level in the lower drywell would be greater than 10 m (33 ft) if the two smaller pools drained through the deluge lines assuming 502 m^3 (17,700 ft^3) of drainable volume in each smaller pool and a lower drywell area of 99 m^2 (1060 ft^2).

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-96

Question Summary: Correct values for heat loads

Full Text:

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

The calculated heat loads shown on Page 7 come from Figures 3.1, 3.2, and 3.3 [1]. It was difficult to verify the values because these figures display only the normalized values. For Figures 3.1 and 3.2 [1], the normalization value appears to be 100 kw/m^2, but for Figure 3.3 [1] it appears to be 300 kw/m^2. Please provide sufficient information to verify that these are the correct values.

GEH Response

Yes, these are the correct values as explained in detail in the original document [1]. There may be some confusion due to a typo in NEDO-33201 Section 21.5.4.3 4th paragraph. The second sentence should read "Clearly the relevant, yet extremely conservative, as explained just above, flux levels are at ~100 kW/m^2 (8.8 Btu/s.ft^2) on the lower boundary, and ~300 kW/m^2 (26 Btu/s.ft^2) on the side boundary of the BiMAC." The value of 300 kW/m^2 (26 Btu/s.ft^2) was incorrectly shown as 500 kW/m^2 (44 Btu/s.ft^2) in this sentence.

DCD Impact

No DCD changes will be made in response to this RAI.

LTR NEDO-33201, Rev 3 will be revised as described above to correct the typo.

NRC RAI 19.2-97

Question Summary: CFD simulations

Full Text

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

Please provide responses to the following questions, and include any additional clarifications on the CFD simulations:

(a) What is the rationale for choosing the volumetric heat generation rate and time into the accident, which were used during the CFD simulations in Reference [1]?

(b) Why a single combination chosen and no other possible variations were evaluated?

(c) What CFD code was used for the DCD analyses [1] and what turbulence model does it contain?

(d) How do the calculated steady-state temperatures in Reference [1] compare with the melt superheat on its first arrival into the LDW?

Was the presence of Zirconia credited during the CFD simulations reported in Reference [1], and if yes, what was the thickness and what is the basis for this value?

GEH Response

(a) As noted in the original document, the intent of these simulations and related estimates is to absolutely and highly conservatively bound the thermal loads. Thus we assume a whole-core melt pool, with no water on top, at the earliest possible time of vessel breach.

(b) Because as noted above, this is for an absolute upper bound estimate.....since it can be accommodated, we thought to avoid unnecessary arguments about more realistic choices.

(c) This was explained in the original document (Reference 1, Appendix 21D) dedicated to the validation question.

(d) As noted in the original report [1], because of the penetrations on the lower head, vessel breach will occur during the process of melting down, and prior to significant build-up of melt superheat. *"(a) by far the most likely mode of vessel failure would be via one or more of the numerous lower head penetrations, (b) the initial release would involve dominantly metallic melt, and (c) the remaining, mostly oxidic materials would be released gradually, over a rather long period of time, becoming quenched as they enter the water pool, and thus reaching an independently coolable state (not participating in the energy balance of interest to debris coolability). Thus the condition addressed here, that of a full-core molten pool that includes all possible metallic components is a grossly bounding state whose probability of occurrence is extremely small."* On the other hand, because of the conservative treatment of the ex-vessel pool, we have a bounding value of melt superheat that needs to build up so as to reject the thermal power generated in it. It was also noted that as long as the thermal loads are removed from the boundaries, the system is self-adjusting, and does not really care about what happens outside the inner liquidus boundary...the question of Zirconia is not relevant.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-98

Question Summary: Effects of crusts on heat loads

Full Text

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

The heat loads applied in Reference [1] were representative of decay heat in a full core melt pool with the boundary condition being the solidification temperature of the melt. If, however, there is formation of significant crust thickness all around the periphery, there could be a number of potential effects, as described below:

1. *The actual circulation patterns that affect the distribution may be constricted because of the smaller melt volume.*
2. *There is likely to be decay heat continued in the solidified crust regions.*
3. *Conduction in the crust regions could tend to alter the distribution.*

Please discuss the effects of crusts on heat loads, and the expected ranges of crust thicknesses.

GEH Response

Corium crusts are low-conducting, and any frozen material will subtract from the thermal loads we calculate. This is mentioned in [1] too. Moreover, at the relatively high decay heat levels under consideration, and, in the absence of water above the pool (conservative), boundary crusts cannot be sustained to thicknesses more than a few centimeters. There is no physically meaningful way that one could generate thermal loads higher than those bounds used in [1].

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-99

Question Summary: Structural integrity of Zirconia and impacts on heat loads

Full Text

Zirconia is a very brittle material subject to failure by thermal shock as a result of the monoclinic-to-tetragonal phase change at about 1470 K. Please discuss the structural integrity of Zirconia for thermal transient conditions expected in the lower drywell, and consequent effects on heat loads.

Please address the initial transient thermal loads on the Zirconia, and demonstrate that the BiMAC Zirconia structural integrity can be maintained under such transient conditions. In addition, address stabilization by the addition of materials such as MgO, CaO, and Y2O3, and evaluate the exothermic dissolution of these materials and consequent contributions to the transient heat loads. Include possible effects of the initial superheat.

GEH Response

As explained in the BiMAC report, we do not need any special provisions that led to the idea of using Zirconia in the original rendition of the design. The BiMAC is now protected by a very thick layer of concrete [[ ]] ([[ ]]). Further detail, including the possibility of using reinforcement will be provided in the detailed design.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-100

Question Summary: Thermal load boundary conditions used in the experiments justification

Full Text

The molten pool and core debris thermal state depends on the total mass, configuration and the boundary conditions at the outer edges. Please elaborate on the assumption of decoupling between the cooling afforded by BiMAC channels and molten pool thermal loads. Please justify the thermal load boundary conditions used in the experiments and the ESBWR BiMAC design.

GEH Response

The BiMAC channels will absorb, in a self-adjusting manner all power delivered to them, unless this power exceeds the critical power (sufficient to cause burnout). Under this condition the pool boundary maintains a solid layer, and the inner surface of it is at the liquidus. These ideas, and the associated "decoupling", have been expounded and became standard knowledge and practice during the development of the in-vessel retention concept for PWRs.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-101

Question Summary: Clarification on the values of the driving head and assumed GDCS inventory

Full Text

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

The driving head for the BiMAC system cannot be easily deduced based on the documents cited here. Reference [1], on Page 23, states that "the BiMAC (will be) subjected to [[ ]] of gravity head" and on Page 48 states that "a good mean value of the pool height is [[ ]]". Based on the experimental facility design (Reference [1], Page 16), the driving head appears to be [[ ]]. Please provide the value for the driving head for the BiMAC system in the experiments and in the actual plant. Identify the GDCS inventory that is assumed while deriving the driving head for the plant.

GEH Response

On Page 48 the "pool height" refers to the corium/melt pool.

Referring to the water pool, gravity head and driving head are two different quantities and must not be confused. In the ESBWR the gravity head will be rather large, near 15 psi (100 kPa), and this would impose a minimum amount of subcooling at the BiMAC level of about 10 K (18°F). The gravity head in the experiment is much less. We have shown that the BiMAC operation is not significantly affected until water at the inlet comes in saturated. The driving head on the other hand is the difference in static pressure between the downcomer and riser portions of the BiMAC (as well as of the MAC experiment). This depends on the geometry and the power supplied to each one of the channels.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-102

Question Summary: Downcomer and riser elevations

Full Text:

[REFERENCE]

1. *GE-Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*
2. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

Table E.21.4-1 in Reference [1] mentions that the downcomer height is 1.8 m whereas the height of the vertical section of the riser is 0.83 m. If the height due to the inclination (at a 10° angle) is considered the total height of the vertical portion from the bottom of the LDW would be ~1.7 m. Therefore, this would make the elevation of the downcomer higher than the vertical section of the riser. Further, the experimental arrangement [2] shows that the 'downcomer' inlet is [[ ]] lower than the vertical section. Please provide information regarding the elevations of the downcomer and riser (vertical) sections of the BIMAC in the plant.

GEH Response

In the experiments we focused on the final choice of the design parameters (diameter and inclination) and this is why the numbers are different than those in [1]. However, it should be clear that BiMAC operation is not affected by downcomer height. In the experiments we made sure that the (single-phase) pressure drop in the downcomer at maximum load conditions was negligible, and in the final design this consideration is to be observed too. This had already been noted in [1]: *"The designed pressure drop in the header and in these downcomers will be insignificant in comparison to the two-phase pressure drop of a fully-loaded BiMAC."*

1. The total length of the inclined section was [[ ]].
2. The total length of the riser (vertical section) was [[ ]]—[[ ]] ([[ ]]) below the tank and [[ ]] inches ([[ ]]) inside the tank.

In the plant, the risers will be about [[ ]] ([[ ]]) in length, and the downcomers [[ ]] ([[ ]]) longer [[ ]].

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-103

Question Summary: Verification of the assumed extent of subcooling

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

Full Text

[QUESTION]

Reference [1] (Page 23) notes that the subcooling, once the LDW pool reaches saturation, will be [[ ]] with the BiMAC subjected to [[ ]] of gravity head. Please provide details as to how these numbers were arrived at.

GEH Response

These values were derived from the depth of the water pool in the LDW and the water temperature in it as provide by Level 2 calculations (MAAP) in NEDO-33201 Chapter 9.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-104

Question Summary: Scaling relations

Full Text:

The scaling base of the MAC multi-channel test is not clear. Please explain how the multi-channel test is scaled relative to the prototype and what the scaling relations are.

GEH Response

Simple geometric scaling (1/2-scale). The principle consideration is that both pressure drop and steam quality in the channel scale with L/D, and this is the basis for our ½-scale design. For the same heat flux levels we would expect somewhat more conservative depiction of flow instability at ½-scale because the phase-coupling would be somewhat "tighter" at ½-scale.

The exact scaling relations (meaning ability to match one-to-one) for flow and pressure drop are not known, because this "exotic" geometry gives rise to non-equilibrium (both thermal and mechanical) that is beyond anyone's capability of prediction. This is why we insisted from the beginning to: (a) make conservative estimates of flow and quality build-up in the channel using analysis in NEDO-33201 Chapter 21 [1], and (b) carry out the main tests at full prototypic scale in all respects in NEDE-33392P [2]. These (single-tube) tests already demonstrated what is needed for assessing BiMAC performance—stable operation, much higher flow and sensible energy transfer than expected from the original conservative estimates, and self-adjusting flow behavior to power levels. As noted in [2] the multi-channel tests were done as a matter of original commitment.

Having said that, we point out that in the experiments we reached twice the base power relevant to BiMAC (100 kW/m^2 or 8.8 Btu/s.ft^2):

"There is a total of [[ ]] m and [[ ]] m of running lengths in the inclined and riser portions of the pipe array, and a total equivalent (coverage) area of [[ ]] m^2. So at [[ ]]% power to the band heaters (and a similar heat flux by the copper blocks in pipe #20) we would have an average heat flux of [[ ]] kW/m^2. In the experiments we reached up to [[ ]]% of rated power and so up to ~ [[ ]] kW/m^2. The copper blocks are applied over a pipe length of [[ ]] m, the heated area is [[ ]] m^2, and so that the maximum available heat flux is [[ ]] MW/m^2. In the experiments we reached up to ~33% of rated power which corresponds to a peak heat flux of ~ [[ ]] kW/m^2."

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-105

Question Summary: Near-edge tubes no tests

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

It appears that the single tube tests were only for the mid-section tubes. Please identify the relevant tests for the near-edge tubes that are shorter but have less margin to burnout as indicated by Figure 21.5.4.5.2 [1]. If there are none, justify why the existing test data are sufficient.

GEH Response

The margins to burnout in Figure 21.5.4.5.2 [1] are superseded, and in fact they are shown to be much greater, by the directly relevant tests conducted in the MAC experiment. The mid-section tubes show that with any, even small, amount of subcooling at the inlet we cannot affect BiMAC performance even at much higher levels of power than those bounding levels that defined our design criteria. These tests also showed that the only way that we could (arbitrarily) violate operation was by allowing inlet subcooling to go to zero, thusly allowing a significant amount of vapor fraction to develop in the inclined portion of the pipe. Near edge channels have somewhat higher local fluxes at the very end of the inclined portion, but the total power delivered to them is much smaller. Moreover, as noted in NEDE-33392P [2] these fluxes will be lower under the [[ ]]-degree inclination.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-106

Question summary: Heat flux doubling

Full Text:

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

For the 20 tube experiments, as the length of the tubes were ½ full-length [1], it appears that the applied heat fluxes should be twice the calculated values for the full scale. Please explain why the heat fluxes do not need to be doubled.

GEH Response

However, the diameter is also ½ of the full scale, and as noted in the response to RAI 19.2-104, the proper scaling is by L/D, which remains the same between full-scale and ½-scale. So the correct heat flux to match BiMAC is 100 kW/m^2 (8.8 $Btu/s.ft^2$). In the tests we reached twice this "base" value before any flow instability, and even then only when inlet subcooling was let fall to a few degrees.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-107

Question summary: Effects of subcooling and void fractions on flow rate

Full Text:

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

It is presumed that there is a significant driving force in natural convection because a significant void fraction is developed in the tubes. However, the result shown in Figure 5.1 in Reference [1] indicates that, up to an achieved flow rate of [[ ]], the exit void fraction was still zero. However, the flow rate decreased markedly as inlet subcooling decreased down to [[ ]] over the flow range up to [[ ]]. Please explain this behavior.

GEH Response

(a) Actually the void fractions are small until inlet subcooling decreases to rather low values. We noted in the report [1] that single-phase heating and a small amount of even transient voids can drive significant flows, and that as a result the amount of sensible heat carried out of the channel is a rather large fraction of the heat supplied. This was not reflected (conservatively) in our original calculations in NEDO-33201 Chapter 21 and as a result the margins are much greater than originally envisioned.

(b) In addition, the flow rate increased (NOT decreased) markedly as inlet subcooling "decreased down to [[ ]] K" ([[ ]]°F). The behavior in Figure 5.1 is straightforward and is explained sufficiently in the report [1]:

"At the relevant and available in the experiment power levels, it was not possible to reach (Ledineg type) flow instability. This is in contrast to the theoretical prediction (Figure 3.6) according to which configuration [[ ]] should be barely acceptable—in fact this was the basis for selecting configuration [[ ]]. The reason for this discrepancy is that in the calculation we assumed saturated fluid at the inlet, while the experiments show that even a very small amount of subcooling provides for very effective cooling mechanism; as the void fraction in the channel in increased with increasing power the flow rate increases too, thus

compensating by increasing amounts of sensible heat transport. Indeed the experimental data show that in this system the flow adjusts to the cooling requirement at any heat loading up to an extent that covers the relevant power levels to ESBWR (this range is discussed in Section 6 and shown in Figure 6.1). This is the basis for the above-made statement that the [[ ]] experiments are to be pursued only as a matter of completeness, or satisfying the commitment made to the NRC."

"*The flow-subcooling relationship as deduced from all tests is illustrated in Figure 5.1. We can see that all data, with two different positions of the high flux regions and power levels that cover a rather wide span [[ ]] to [[ ]] kW, Figure 6.1), collapse into one unified trend—the flow accelerates with decreasing subcooling down to a value of [[ ]] K, at which point vapor quality develops (Figure 5.1b), and two-phase pressure loss begins to interfere with flow development. As seen in Figure 5.1b, the effect of power level and possibly the position of both high flux regions on the riser (see Figure 6.1) is a somewhat delayed development of this flow interference. However in all conditions tested there was no evidence of flow instability, and mild changes in pressure distribution in the test section were principally the result of slight changes in gravity head due to voids build-up in the riser (Figure 5.2)."*

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-108

Question Summary: Effects on location of downcomer on flow distribution in the tubes

Full Text

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

The SE test apparatus (Figure 4.4 of Reference [1]) shows the downcomer entering the mid section of the distributor instead of at one end. Please explain how this affects the flow distribution in the tubes.

GEH Response

This is not significant because, as we stated in the response to RAI 19.2-102, the pressure drop over the downcomer is negligible and this low pressure drop will be assured for the actual BiMAC also.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-109

Question summary: Heat flux not increased beyond [[ ]]

Full Text

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

Please confirm if the following interpretation of the single tube experiments (SC series), based on information in Reference [1], is correct:

A uniform heat flux of [[ ]] was applied for which stable behavior was observed. At the increased e heat flux of [[ ]] using double-stacked copper band heaters), temperature oscillations were observed. No measurements for values between [[ ]] and [[ ]] were performed. In addition, heat fluxes exceeding [[ ]] were not tested.

If this interpretation is correct, explain why the heat flux was not increased beyond [[ ]] to determine the boundary for onset of instabilities, and whether the limit of [[ ]] was imposed due to limitation of copper heaters or based on CFD results. In addition, explain why heat fluxes higher than [[ ]] were not tested.

GEH Response

The relevant paragraph is in page 24 of the report:

> "burnout was rather difficult to achieve within the relevant and attainable in experiment heat flux levels, and at no time did it become necessary to scram the power supply. Thus, to test the coolability limits we had to increase steam quality to higher than normally appropriate levels, and this we did by doubling up the heating elements over the section supplied by the band heaters. More specifically, the quoted heat flux of [[ ]] kW/m^2 in Tables 5.1 to 5.5 was actually applied over a doubled-up row of band heaters thus producing the equivalent of [[ ]] kW/m^2 of thermal load in BiMAC. At these conditions and at sufficiently high power levels in the peak flux regions, deficient cooling could be seen by high-amplitude ([[ ]] K) temperature oscillations, as shown for example in Figure 5.3. Even these cases however remain bounded, presumably by highly effective cooling in convective transition/film boiling (see detailed data in the appendices), and normal operation was easily recoverable by modest decreases in power level as illustrated for example in Figure 5.4."

The [[ ]] was based on total heated area, while the [[ ]] one on an equivalent BiMAC area, that is per unit area of floor. These fluxes were applied over the whole inclined section, and they represent what we call the "base load". The oscillations in temperature appeared only "**at the sufficiently high power levels in the peak flux regions**" and only when subcooling has been reduced to just a few degrees.

The intent of this paragraph was to convey how far past normal levels one needs to go to even begin to challenge the system! The thermal fragility of BiMAC can be found in Table 5.6.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-110

Question Summary: oscillation and flow reversal for multiple tube experiments

Full Text:

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

From the multiple tube experiments, in particular Run # [[ ]] [1], oscillations and flow reversal have been observed for heat fluxes higher than [[ ]] along the inclined section in the presence of subcooling. Please explain the oscillation and flow reversal for the multiple tube experiments. In addition, provide the margin to oscillatory behavior for the BiMAC system, using the heat fluxes obtained from the CFD study as reference.

GEH Response

The oscillations mentioned were obtained at around [[ ]] s, when inlet subcooling was just a few degrees, and the heat fluxes were well beyond conditions of interest to BiMAC—as can be deduced from the data given in Appendix F, pipe 20 average (floor-equivalent) heat flux [[ ]] kW/m^2 ([[ ]] Btu/s.ft^2), pipe 18, [[ ]] kW/m^2 ([[ ]] Btu/s.ft^2). But these are not to be mistaken as the true margins (from the [[ ]] kW/m^2 ([[ ]] Btu/s.ft^2) taken as a "base" value for the ESBWR), they are much greater and beyond the need to be quantified, because as shown by the data subcooling has a profound effect in removing heat by sensible energy transport.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-111

Question Summary: Locations of probes and pressure transducers

Full Text:

[REFERENCE]

1. *T. G. Theofanous, "The MAC Experiments Fine Tuning of the BiMAC Design", NEDE-33392P Rev. 0 (March 2008)*

[QUESTION]

It is stated in Reference [1] that the void fraction measurement for single tube experiments was performed using traversing conductivity probe at the exit of the riser section. Please confirm that the location is at the exit of the single tube (at an elevation of [[ ]] from the bottom of the tank) and not at (or near) the bottom of the tank (at an elevation of [[ ]] from the beginning of the vertical section). Also provide the location of the pressure transducers used for measuring the inlet and exit pressures.

GEH Response

1. The inlet pressure transducer was [[ ]] inches ([[ ]] cm) from the upstream end of the pipe.
2. The exit pressure transducer was just below the bottom of the tank; that is [[ ]] inches ([[ ]] cm) from the bottom of the riser.
3. There was also an intermediate pressure transducer, near the exit of the inclined section, [[ ]] inches ([[ ]] cm) from where the inclined and vertical sections join.
4. The void fraction probe was [[ ]] inches ([[ ]] cm) above the exit pressure transducer ([[ ]] inches ([[ ]] cm) from the bottom of the riser).
5. The total length of the inclined section was [[ ]] feet (about [[ ]] meters, heated length [[ ]] m ([[ ]] ft)).
6. The total length of the riser (vertical section) [[ ]] feet (about [[ ]] meters, heated length [[ ]] m ([[ ]] in)).

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-112

Question Summary: Results for near-edge tubes

Full Text:

The failure modes evaluated in the tests were the potential for burnout and dryout of the tubes as a result of any deficient natural convection cooling at the applied heat loads. Although the vertical piping may have a higher heat flux peaking, it is important to demonstrate that the near edge piping sections also have sufficient margin for coolability. For the MAC tests to be conclusive in establishing robustness with respect to these failure modes, it appears that a single tube test of the near-edge tubes is needed. Please indicate which tests in the existing test matrix address near-edge effects, and what the pertinent results are.. Otherwise, please carry out such a test or justify why it is not necessary.

GEH Response

Such a test is clearly not necessary because the MAC data show that the potential for burnout arises only in extreme and unrealistic conditions where inlet subcooling is reduced to zero and total power to the channel is increased significantly, so as to produce (steam) quality in the channel. Accordingly these "bounds" were explored with the longest (mid-section) channels and power levels reached under these conditions (both locally and in total) cover those of interest in near-edge channels (much shorter, much less total power, much less steam quality). This can also be seen by the flow performance of each channel (long vs. short) in the SE series of tests.

In addition, it should be kept in mind that: "Finally a more nearly horizontal "dish" bottom would reduce the intensity of organized natural convection currents, such as those that gave rise to local peaking on the edge channels shown in Figure 3.2—see also Figure 3.7." [MAC test report].

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-113

Question Summary: Draining of water from GDCS pools

Full Text: The MAC tests address the period after both sets of deluge lines have been activated and the system has reached a quasi steady state. Please identify what fraction of the water in the GDCS pool would be drained into the lower drywell and BiMAC tubes, and what the resulting depth of the overlying water pool would be. What is the minimum depth that would ensure effective natural convection capability of the BiMAC?

GEH Response

See response to RAI 19.2-95 for discussion on GDCS water drained into the lower drywell and resulting depth in the lower drywell.

At this stage, if there is no water coming in directly from GDCS pools into the BiMAC, the minimum level in the pool should be sufficient to cover the downcomer inlets.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-114

Question Summary: Results documentation of calculation of melt jet impingement

Full Text:

[REFERENCE]

1. *GE-Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

The Saito correlation is appropriate for evaluating the melt jet impinging on a flat surface. The value of 13 MW/m^2 for heat flux [1] was not reproducible. Please provide the results of the calculation with the appropriate units.

GEH Response

Saito (1989) correlation:

$$Nu = h\ d/k = 0.0027\ Re.Pr = 0.0027\ Pe = 0.0027\ U\ d/\alpha$$

Therefore, the heat transfer coefficient is:

$$h = 0.0027\ U\ d/\alpha\ .\ (k/d) = 0.0027\ U\ \rho\ C$$

and the heat flux:

$$q = \Delta T\ \ h = \ 0.0027\ U\ \rho\ C\ \Delta T \qquad (1)$$

The substrate-ablation rate V_S is then determined as

$$V_S = q/(L_S.\ \rho_S)\ = 0.0027\ U\ \rho\ C\ \Delta T\ \ /(L_S.\ \rho_S) \qquad (2)$$

Parameter	Unit		Explanation
Jet velocity, U	m/s	40	
Density, ρ	kg/m^3	8000	
Heat capacity, C	J/kg.K	300	
Heat of fusion of Zirconia substrate, L_S	J/kg	1.7x10^6	
Density of	kg/m^3	6100	

Zirconia, ρ_S			
Ablation rate, V_S	m/s	0.002499	this is the 2.5 mm/s in the report
Heat flux, q	MW/m^2	25.9	Using formula (1)

The ablation rate in the report is correct. The heat flux number quoted in this question, is an intermediate value, which was originally based on 50 K (90°F) superheat, and it was inadvertently not updated when the final choice of superheat for this evaluation was made as 100 K (180°F). The heat flux in [1] will be corrected to 26 MW/m^2 (2280 $Btu/s.ft^2$).

DCD Impact

No DCD changes will be made in response to this RAI.

LTR NEDO-33201, Rev 3 will be revised as described above to correct the typo.

NRC RAI 19.2-116

Question Summary: Clarification of success criteria for number of deluge lines

Full Text:

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

On Page 21.5-3 of Reference [1] is this note: "The lines [deluge] are sized so that any three of them would be sufficient to ensure proper BiMAC functioning ...". Was this meant to say: "...any one of the three..."?

GEH Response

This was a way to express the reliability required as described in Reference 1, Section 21.5.2. In the new design choices supported by the MAC tests, the water supply requirements are more flexible and they will be optimized under the reliability criteria specified.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-116

Question Summary: Clarification of success criteria for number of deluge lines

Full Text:

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

On Page 21.5-3 of Reference [1] is this note: "The lines [deluge] are sized so that any three of them would be sufficient to ensure proper BiMAC functioning ...". Was this meant to say: "...any one of the three..."?

GEH Response

This was a way to express the reliability required. In the new design choices supported by the MAC tests the water supply requirements are more flexible, and they will be optimized under the reliability criteria specified.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-117

Question Summary: Line feed into downcomers

Full Text:

There are apparently six (6) deluge lines coming from the GDCS. Do three feed the BiMAC tubes and three feed the direct deluge? If three feed the BiMAC tubes, explain how the three lines are fed into the two downcomers.

GEH Response

As shown in DCD Tier 2 Chapter 6 Figure 6.3-1, there are 4 deluge lines coming from the GDCS, each connected to 3 deluge valves. The interface between the deluge lines and BiMAC downcomers and lower drywell deluge will be determined in the detailed design phase.

In the new design choices supported by the MAC tests the water supply requirements are more flexible, and they will be optimized under the reliability criteria specified in NEDO-33201 Revision 3, Section 21.5.2.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-118

Question Summary: Values for driving head and length of pipe

Full Text:

[REFERENCE]

1. *GE-Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric-Hitachi (GEH) (May 2008)*

[QUESTION]

Please provide the values for the driving head and length of the pipe used for the theoretical analysis in of Reference [1] to obtain the mass flow rate versus the heat flux curves for different pipe sizes.

GEH Response

These were for mid-section conditions. The driving head is a result not an input. It depends on the amount of void in the pipe.

DCD Impact

No DCD changes will be made in response to this RAI.

No changes to NEDO-33201 or NEDE-33392P will be made in response to this RAI.

NRC RAI 19.2-119

Question Summary: Correlation used for "correction of inclination"

Full Text:

[REFERENCE]

1. *GE Hitachi ESBWR NEDO 33201 Rev. 3, Chapter 21, General Electric- Hitachi (GEH) (May 2008)*

[QUESTION]

With regard to the two-phase natural circulation model (Table E.21.2-1 in of Reference [1]) please provide details of the correlation used for 'correction for inclination' including a nomenclature of the terms involved.

GEH Response

The 'correction for inclination' is shown in Table E.21.2-1 as equation E.21.3. There is a typo in the second paragraph of Section 21E.2. (The last sentence should refer to E.21.3 instead of E.3.)

This was based on a correlation obtained from a Russian handbook that is not widely available. We can think of it for our purposes as an empirical correction used as a first approximation. At this time this is superceded by the MAC data that show the model to be very conservative.

All the terms involved in this "correction for inclination" are already given in Nomenclature subsection at the end of the Appendix or explicitly defined in the Table. The only exception is u_o, which is defined as usual: $u_o = G/\rho_W$.

DCD Impact

No DCD changes will be made in response to this RAI.

LTR NEDO-33201, Rev 3 will be revised as described above to correct the typo.

MFN 08-801

Enclosure 3

Affidavit

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, David H. Hinds, state as follows:

(1) I am the Manager, New Units Engineering, GE Hitachi Nuclear Energy ("GEH"), have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Enclosure 1 of GEH letter MFN 08-801, Mr. Richard E. Kingston to U.S. Nuclear Regulatory Commission, *Response to Portion of NRC Request for Additional Information Letter No. 230 Related to ESBWR Design Certification Application ESBWR RAI Numbers 19.2-93 through 19.2-119,* dated November 3, 2008. The GEH proprietary information in Enclosure 1, *Response to Portion of NRC Request for Additional Information Letter No. 230 Related to ESBWR Design Certification Application Probabilistic Risk Assessment RAI Numbers 19.2-93 through 19.2-119 - GEH Proprietary Information,* is delineated by a [[dotted underline inside double square brackets.{3}]]. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination. A non-proprietary version of this information is provided in Enclosure 2, *Response to Portion of NRC Request for Additional Information Letter No. 330 Related to ESBWR Design Certification Application Probabilistic Risk Assessment RAI Numbers 19.2-93 through 19.2-119 - Non-Proprietary Version.*

(3) In making this application for withholding of proprietary information of which it is the owner, GEH relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret," within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GEH competitors without license from GEH constitutes a competitive economic advantage over other companies;
b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future GEH customer-funded development plans and programs, resulting in potential products to GEH;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., and (4)b, above.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GEH, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GEH, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or subject to the terms under which it was licensed to GEH. Access to such documents within GEH is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GEH are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it identifies detailed GE ESBWR design information for the BiMAC. GE utilized prior design information and experience from its fleet with significant resource allocation in developing the system over several years at a substantial cost.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GEH asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GEH.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GEH would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GEH of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 3rd day of November 2008.

David H. Hinds
GE-Hitachi Nuclear Energy Americas LLC