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Supplement 3

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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 45 Related to ESBWR Design Certification Application -- Line Break Jet Impingement Loads -- RAI Numbers 3.6-13 and 3.6-18**

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) sent by NRC letter dated August 3, 2006 (Reference 1). RAI Numbers 3.6-13 and 3.6-18 are addressed in Enclosure 1.

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

Sincerely,

James C. Kinsey

James C. Kinsey
Vice President, ESBWR Licensing

D068
NRO

Reference:

1. MFN 06-271, Letter from U.S. Nuclear Regulatory Commission to David H. Hinds, GEH, *Request For Additional Information Letter No.45 Related to ESBWR Design Certification Application*, dated August 3, 2006

Enclosure:

1. Response to Portion of NRC Request for Additional Information Letter No. 45 Related to ESBWR Design Certification Application -- Line Break Jet Impingement Loads -- RAI Numbers 3.6-13 and 3.6-18

cc:	AE Cubbage	USNRC (with enclosure)
	GB Stramback	GEH/San Jose (with enclosure)
	RE Brown	GEH/Wilmington (with enclosure)
	DH Hinds	GEH/Wilmington (with enclosure)
	eDRF	0000-0075-1590, Rev. 2 (3.6-18 only)
	eDRF	0000-0075-1590, Rev. 4 (3.6-13 only)

Enclosure 1

MFN 06-299
Supplement 3

Response to Portion of NRC Request for

Additional Information Letter No. 45

Related to ESBWR Design Certification Application

Line Break Jet Impingement Loads

RAI Numbers 3.6-13 and 3.6-18

NRC RAI 3.6-13

The ANS 58.2 standard formulas for the spatial distribution of pressure through a jet cross-section are incorrect, as pointed out by Wallis and Ransom. In some cases,the standard's assumption that the pressure within a jet cross section is maximum at the jet centerline is correct (near the break, for instance), but far from the break, the pressure variation is quite different, often peaking near the outer edges of the jet. Applying the standard's formulas could lead to non-conservative pressures away from the jet centerline.

The applicant states the following on page 3.6-18 of Section 3.6.2 of ESBWR DCD Tier 2: "The jet impingement force is uniformly distributed across the crosssectional area of the jet and only the portion intercepted by the target is considered". The applicant also states that ANS 58.2 Appendix D is used, which defines variable (not uniform) pressures over the cross-section of an expanding jet (see comments above regarding the inaccuracies of ANS Appendix D). The standard does specify a uniform pressure over the cross-section of a non-expanding jet, so it appears that the applicant is mixing the methods of the standard, combining the shape of an expanding jet with the uniform pressure distribution of a non-expanding jet.

The applicant is requested to:

(a) Clarify which approach (variable pressure over an expanding jet cross-section as defined in Appendix D of ANS 58.2, or a uniform pressure distribution assumed in DCD) will be used to specify pressure distribution over an expanding jet cross section. In either case, the applicant should explain what analysis and/or testing has been used to substantiate use of the ANS 58.2 Appendix D and/or the formulas in DCD Tier 2 for defining conservatively the net jet impingement loading on SSCs in light of the information presented by Ransom and Wallis (ADAMS ML050830344,ADAMS ML050830341), which challenges the accuracy of the pressure distribution models presented in ANS 58.2.

(b) Submit a table of all postulated break types, along with the properties of the fluid internal and external to the ruptured pipe. The table should specify what type of jet the applicant assumes will emanate from each pipe break - incompressible nonexpanding jet, or compressible supersonic expanding jet - along with how impingement forces will be calculated for each jet. Specific examples of jet impingement loading calculations made using the ANS 58.2 standard and/or the methods in DCD Tier 2 for the postulated piping breaks in an ESBWR should be given, along with proof that the calculations lead to conservative impingement loads in spite of the cited inaccuracies and omissions in the ANS 58.2 models pointed out by Ransom and Wallis.

GEH Response

NRC item a) has questions in two parts:

Part i) *Clarify which approach (variable pressure over an expanding jet cross-section as defined in Appendix D of ANS 58.2, or a uniform pressure distribution assumed in DCD) will be used to specify pressure distribution over an expanding jet cross section*

As stated in ANS Standard 58.2, the pressure distribution on a target may be derived using variable as well as uniform distribution methods depending on the fluid and jet characteristics at the exit of the break. DCD Tier 2,Subsection 3.6.2.3.1 will be revised to identify that Appendix D methods will be used for the pressure distribution evaluations.

Part ii) *In either case, the applicant should explain what analysis and/or testing has been used to substantiate use of the ANS 58.2 Appendix D and/or the formulas in DCD Tier 2 for defining conservatively the net jet impingement loading on SSCs in light of the information presented by Ransom and Wallis (ADAMS ML050830344,ADAMS ML050830341), which challenges the accuracy of the pressure distribution models presented in ANS 58.2.*

GEH has committed, in the ESBWR DCD, to use of the approved standard ANS 58.2, as this standard has been accepted in pipe break evaluations in the nuclear plant design including prior BWR plant pipe rupture evaluations performed by GEH. It may be noted that GEH has made significant technical contributions to the development of this standard.

The GEH methodology used to demonstrate compliance with the standard is demonstrated and can be found in the example calculation "HPCF N16 Nozzle (200 mm) Terminal End Break Jet Impingement Loads." The calculation uses methodology that is representative of that which will be used for the ESBWR. This calculation is a proprietary document that can be made available to the NRC in the GEH offices in Washington, DC or Wilmington, NC.

This calculation illustrates the jet map geometries, various calculation steps in compliance with the methods stipulated in the standard and computes the pressure distribution as a function of distance from the break location based on a terminal end break at a nozzle. Although no net load on a target was determined, the calculation however provides resulting pressure at various distances from the break. The calculation conservatively determines the equivalent static loads on targets using 2.0 as a Dynamic Load factor (DLF) where applicable. Additionally, the calculation also discusses the determination of the pressure distribution in the radial direction of the jet for targets intercepted in the outer edge of the jet. The net load on a target is calculated using the jet pressure based on the distance of the target from the break and the intercepted area of the jet on the target. A target's shape factor ($K\phi$), may be required to be used as target's potential for changing the momentum of the jet in the net load on the target calculation.

In conclusion, the use of ANS Standard and design bases as described in the DCD Tier 2 Chapter 3.6 will be conservative and adequately address the protection against pipe failures for the ESBWR pipe rupture design/analysis.

(b) All ESBWR piping will be designed to minimize the stresses and fatigue usage factors such that piping intermediate break locations are avoided. Therefore, all postulated pipe break locations are the terminal end break at RPV and/or at the equipment nozzles. Conservatively, double-ended break is assumed for all breaks. Fluid pressure and temperature for an assumed break are the same as the applicable nozzles. For sub-cooled fluid condition, a non-expanding jet will be assumed otherwise an expanding jet will be used for the jet impingement. Based on the results from the pipe rupture analysis, the necessary protective devices will be designed and installed to mitigate the effects of the pipe break postulations in the high and moderate energy ESBWR piping systems.

DCD Impact

DCD Tier 2,Subsection 3.6.2.3.1 will be revised as noted in the attached markup.

NRC RAI 3.6-18

The applicant states at the top of page 3.6-18 of Section 3.6.2 of ESBWR DCD Tier 2 that 'Potential targets in the jet path are considered at the calculated final position of the broken end of the ruptured pipe'. However, ANS 58.2 Section 7.2 states that: "those targets which are close enough to the jet boundary of the model assumed such that with reasonable variations in the jet geometry or pipe movement parameters they could be impinged upon, shall be assumed to be impinged upon. "Justify this departure from the ANS 58.2 standard.

GEH Response

Consistent with ANS 58.2 Standard Section 7.2, the guidance provided will be used in selecting the potential targets interacting with jet from a ruptured pipe.

DCD Impact

DCD Tier 2, Subsection 3.6.2.3.1 will be revised as noted in the attached markup.

- Piping within the broken loop is no longer considered part of the RCPB. Plastic deformation in the pipe is considered as a potential energy absorber. Limits of strain are imposed which are similar to strain levels allowed in restraint plastic members. Piping systems are designed so that plastic instability does not occur in the pipe at the design dynamic and static loads unless damage studies are performed which show the consequences do not result in direct damage to any safety-related system or component.
- Components, such as vessel safe ends and valves which are attached to the broken piping system, do not serve a safety-related function. Components whose failure would not further escalate the consequences of the accident are not designed to meet ASME Code-imposed limits for safety-related components under faulted loading. However, if these components are required for safe shutdown or serve to protect the structural integrity of a safety-related component, limits to meet the Code requirements for faulted conditions and limits to ensure required operability would be met.

An analysis for pipe whip restraint selection using the piping design analysis (PDA) computer program and a pipe break modeling program (ANSYS) are performed as described in Appendix 3D, which predicts the response of a pipe subjected to the thrust force occurring after a pipe break. The program treats the situation in terms of generic pipe break configuration which involves a straight, uniform pipe fixed at one end and subjected to a time-dependent thrust force at the other end. A typical restraint used to reduce the resulting deformation is also included at a location between the two ends. Nonlinear and time-independent stress strain relationships are used to model the pipe and the restraint. Using a plastic-hinge concept, bending of the pipe is assumed to occur only at the fixed end and at the location supported by the restraint.

Effects of pipe shear deflection are considered negligible. The pipe-bending moment-deflection (or rotation) relation used for these locations is obtained from a static nonlinear cantilever-beam analysis. Using the moment-rotation relation, nonlinear equations of motion of the pipe are formulated using energy considerations and the equations are numerically integrated in small time steps to yield time-history of the pipe motion.

The piping stresses in the containment penetration areas are calculated by the ANSYS computer program, a program as described in Appendix 3D. The program is used to perform the non-linear analysis of a piping system for time varying displacements and forces due to postulated pipe breaks.

3.6.2.3 Dynamic Analysis Methods to Verify Integrity and Operability

3.6.2.3.1 Jet Impingement Analyses and Effects on Safety-Related Components

The methods used to evaluate the jet effects resulting from the postulated breaks of high-energy piping are described in Appendices C and D of ANSI/ANS 58.2 and presented in this subsection.

The criteria used for evaluating the effects of fluid jets on safety-related structures, systems, and components are as follows:

- Safety-related structures, systems, and components are not impaired so as to preclude safety-related functions. For any given postulated pipe break and consequent jet, those safety-related structures, systems, and components needed to safely shut down the plant are identified.

- Safety-related structures, systems and components which are not necessary to safely shut down the plant for a given break, are not protected from the consequences of the fluid jet.
- Safe shutdown of the plant caused by postulated pipe ruptures within the RCPB is not aggravated by sequential failures of safety-related piping and the required emergency cooling system performance is maintained.
- Off-site doses comply with 10 CFR 50.34(a).
- Postulated breaks resulting in jet impingement loads are assumed to occur in high-energy lines at 102% power operation of the plant.
- Through-wall leakage cracks are postulated in moderate-energy lines and are assumed to result in wetting and spraying of safety-related structures, systems, and components.
- Reflected jets are considered only when there is an obvious reflecting surface (such as a flat plate) which directs the jet onto safety-related equipment. Only the first reflection is considered in evaluating potential targets.
- ~~Potential targets in the jet path are considered at the calculated final position of the broken end of the ruptured pipe. This selection of potential targets is considered adequate due to the large number of breaks analyzed and the protection provided from the effects of these postulated breaks.~~Potential targets, or portion of a large target, which are close enough to the jet boundary of the model assumed such that with reasonable variations in the jet geometry or pipe movement parameters they could be impinged upon, are assumed to be impinged upon. RAI 3.6-18

The analytical methods used to determine which targets could be impinged upon by a fluid jet and the corresponding jet impingement load include:

- The direction of the fluid jet is based on the arrested position of the pipe during steady-state blowdown.
- The impinging jet proceeds along a straight path.
- The total impingement force acting on any cross-sectional area of the jet is time and distance invariant with a total magnitude equivalent to the steady-state fluid blowdown force given in Subsection 3.6.2.2 and with jet characteristics shown in Figure 3.6-1.
- The jet impingement force on the target is calculated according to Appendix D of ANSI/ANS 58.2.~~is uniformly distributed across the cross-sectional area of the jet and only the portion intercepted by the target is considered.~~ RAI 3.6-13
- The break opening is assumed to be a circular orifice of cross-sectional flow area equal to the effective flow area of the break.
- The jet impingement force is equal to the steady-state value of the fluid blowdown force calculated by the methods described in Subsection 3.6.2.2.
- The distance of jet travel is divided into two or three regions. Region 1 (Figure 3.6-1, items a, b and c) extends from the break to the asymptotic area. Within this region the discharging fluid flashes and undergoes expansion from the break area pressure to the atmospheric pressure. In Region 2 the jet expands further. For partial-separation

circumferential breaks, the area increases as the jet expands. In Region 3, the jet expands at a half angle of 10 degrees (Figure 3.6-1, items a and c).

- The analytical model for estimating the asymptotic jet area for subcooled water and saturated water assumes a constant jet area. For fluids discharging from a break that are below the saturation temperature at the corresponding room pressure or have a pressure at the break area equal to the room pressure, the free expansion does not occur.
- The distance downstream from the break where the asymptotic area is reached (Region 2) is calculated for circumferential and longitudinal breaks.
- Both longitudinal and fully separated circumferential breaks are treated similarly. The value of fL/D used in the blowdown calculation is also used for jet impingement.
- Circumferential breaks with partial (i.e., h<D/2) separation between the two ends of the broken pipe not significantly offset (i.e., no more than one pipe wall thickness lateral displacement) are more difficult to quantify. For these cases, the following assumptions are made.
  - The jet is uniformly distributed around the periphery.
  - The jet cross-section at any cut through the pipe axis has the configuration depicted in Figure 3.6-1, item b. The jet regions are also shown.
  - The jet force F_j = total blowdown.

  The pressure at any point intersected by the jet (P_j) is:

$$P_j = \frac{F_s}{A_R} \tag{3.6-1}$$

  where

  A_R = the total 360° area of the jet at a radius equal to the distance from the pipe centerline to the target

  F_s = Steady State blowdown force

  - The pressure of the jet is then multiplied by the area of the target submerged within the jet.
- Target loads are determined using the following procedures:
  - For both the fully separated circumferential break and the longitudinal break, the jet is studied by determining target locations vs. asymptomatic distance and applying ANSI/ANS 58.2, Appendices C and D.
  - For circumferential break limited separation, the jet is analyzed by using different equations of ANSI/ANS 58.2, Appendices C and D and determining respective target and asymptomatic locations.

  After determination of the total area of the jet at the target, the jet pressure is calculated by:

$$P_I = \frac{F_j}{A_x} \tag{3.6-2}$$

where

P_I = incident pressure

A_x= area of the expanded jet at the target intersection.

Target shape factors are included in accordance with ANS 58.2.

If the effective target area (A_{te}) is less than the expanded jet area ($A_{te} < A_x$), the target is fully submerged in the jet and the impingement load is equal to (P_I) (A_{te}). If the effective target area is greater than the expanded jet area ($A_{te} > A_x$), the target intercepts the entire jet and the impingement load is equal to (P_I) (A_x) = F_j. The effective target area (A_{te}) for various geometries follows:

- Flat Surface — For a case where a target with physical area A_t is oriented at angle ϕ with respect to the jet axis and with no flow reversal, the effective target area A_{te} is:

$$A_{te} = (A_t)(\sin\phi) \tag{3.6-3}$$

- Pipe Surface — As the jet hits the convex surface of the pipe, its forward momentum is decreased rather than stopped; therefore, the jet impingement load on the impacted area is expected to be reduced. For conservatism, no credit is taken for this reduction and the pipe is assumed to be impacted with the full impingement load. However, where shape factors are justifiable, they may be used. The effective target area A_{te} is:

$$A_{te} = (D_A)(D) \tag{3.6-4}$$

where

D_A = diameter of the jet at the target interface

D = pipe OD of target pipe for a fully submerged pipe

When the target (pipe) is larger than the area of the jet, the effective target area equals the expanded jet area

$$A_{te} = A_x \tag{3.6-5}$$

- For all cases, the jet area (A_x) is assumed to be uniform and the load is uniformly distributed on the impinged target area A_{te}.

3.6.2.3.2 Pipe Whip Effects on Safety-Related Components

This subsection provides the criteria and methods used to evaluate the effects of pipe displacements on safety-related structures, systems, and components following a postulated pipe rupture.

Pipe whip (displacement) effects on safety-related structures, systems, and components can be placed in two categories: (1) pipe displacement effects on components (nozzles, valves, tees, etc.) which are in the same piping run that the break occurs in; and (2) pipe whip or controlled