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Subject: Response to Portion of NRC Request for Additional Information Letter No. 116 Related to ESBWR Design Certification Application - Containment Systems - RAI Numbers 6.2-18 S02 and 6.2-23 S02

Enclosure 1 contains the GE Hitachi Nuclear Energy (GEH) response to the subject NRC RAI originally transmitted via the Reference 1 letter and supplemented by an NRC request for clarification in Reference 2.

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

References:

1. MFN 06-113, Letter from U.S. Nuclear Regulatory Commission to David H. Hinds, *Request for Additional Information Letter No. 18 Related to ESBWR Design Certification Application*, April 24, 2006
2. MFN 07-632, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, *Request for Additional Information Letter No. 116 Related to ESBWR Design Certification Application*, November 15, 2007

Enclosure:

1. MFN 08-270 - Response to Portion of NRC Request for Additional Information Letter No. 116 Related to ESBWR Design Certification Application - Containment Systems - RAI Numbers 6.2-18 S02 and 6.2-23 S02

cc:	AE Cubbage	USNRC (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	GB Stramback	GEH/San Jose (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	eDRF	0000-0080-9080

Enclosure 1

MFN 08-270

Response to Portion of NRC Request for Additional Information Letter No. 116 Related to ESBWR Design Certification Application

Containment Systems

RAI Numbers 6.2-18 S02 and 6.2-23 S02

NRC RAI 6.2-18 S02:

GEH's response to parts (A) and (C) are acceptable. Response to part (B) is unacceptable because incorrect mass flow rates were used (See RAI 6.2-23, Supplement No. 2). Please respond to part (B) using the correct mass flow rates.

GEH Response:

The statements in the response to RAI 6.2-18 S01 remain valid. No computer program was used to calculate mass and energy releases. A copy of the calculation is included in the response below to RAI 6.2-23 S02. The mass release rates are based on the following reference:

Moody, F. J. "Maximum Discharge Rate of Liquid-Vapor Mixtures from Vessels," General Electric Company, Report No. NEDO-21052, September 1975.

This reference will be added to DCD Tier 2, Subsection 6.2.9, as new reference 6.2-8, as described in the response to RAI 6.2-36 S01 (MFN 08-067, dated January 25, 2008). Additional changes will be made to DCD Tier 2, Subsections 6.2.1.2 and 6.2.1.2.3, to reflect the actual calculations performed.

DCD Impact:

DCD Tier 2, Subsections 6.2.1.2 and 6.2.1.2.3 will be revised as shown in the attached markup.

- GDC 50, as it relates to the subcompartments being designed with sufficient margin to prevent fracture of the structure due to pressure differential across the walls of the subcompartment. In meeting the requirements of GDC 50, the following specific criterion or criteria that pertain to the design and functional capability of containment subcompartments are used as indicated below.
  - The initial atmospheric conditions within a subcompartment are selected to maximize the resultant differential pressure. The model assumes air at the maximum allowable temperature, minimum absolute pressure, and zero percent relative humidity. For a restricted class of subcompartments, another model is used that involves simplifying the air model outlined above. For this model, the initial atmosphere within the subcompartment is modeled as a homogeneous water-steam mixture with an average density equivalent to the dry air model. This approach is limited to subcompartments that have choked flow within the vents. This simplified model is not used for subcompartments having primarily subsonic flow through the vents.
  - Subcompartment nodalization schemes are chosen such that there is no substantial pressure gradient within a node, that is, the nodalization scheme is verified by a sensitivity study that includes increasing the number of nodes until the peak calculated pressures converge to small resultant changes. The guidelines of Section 3.2 of NUREG-0609 are followed, and a nodalization sensitivity study is performed which includes consideration of spatial pressure variation, for example, pressure variations circumferentially, axially and radially within the subcompartment, for use in calculating the transient forces and moments acting on components.
  - When vent flow paths are used which are not immediately available at the time of pipe rupture, the following criteria apply:
    - The vent area and resistance as a function of time after the break are based on a dynamic analysis of the subcompartment pressure response to pipe ruptures.
    - The validity of the analysis is supported by experimental data or a testing program that supports this analysis.
    - In meeting the requirements of GDC 4, the effects of missiles that may be generated during the transient are considered in the safety analysis.
  - The vent flow behavior through all flow paths within the nodalized compartment model is based on a homogeneous mixture in thermal equilibrium, with the assumption of 100% water entrainment. In addition, the selected vent critical flow correlation is conservative with respect to available experimental data. An acceptable vent critical flow correlations are the "frictionless Moody" with a multiplier of 0.6 for water-steam mixtures, and the thermal homogeneous equilibrium model for air-steam-water mixtures.
  - A factor of ~~1.4~~<u>1.2</u> is applied to the peak differential pressure calculated for the subcompartment, structure and the enclosed components, for use in the design of the structure and the component supports. The as-built calculated differential pressure is not expected to be substantially different from the design value. However, improvements in the analytical models or changes in the as-built subcompartment may affect the available margin.

6.2.1.2.1 Design Bases

The design of the containment subcompartments is based upon a postulated DBA occurring in each subcompartment.

For each containment subcompartment in which high energy lines are routed, mass and energy release data corresponding to a postulated double ended line break are calculated. The mass and energy release data, subcompartment free volumes, vent path geometry and vent loss coefficients are used as input to an analysis to obtain the pressure/temperature transient response for each subcompartment. At least 15% margin above the analytically determined pressures is applied for structural analysis.

6.2.1.2.2 Design Features

The DW and WW subcompartments are described in Subsection 6.2.1.1. The remaining containment subcompartments are as follows.

Drywell Head Region

The DW head region is covered with a removable steel head, which forms part of the containment boundary. The DW bulkhead connects the containment vessel flange to the containment and represents the interface between the DW head region and the DW. There are no high energy lines in the DW head region.

Reactor Shield Annulus

The reactor shield annulus exists between the Reactor Shield Wall (RSW) and the RPV. The RSW is a steel cylinder surrounding the RPV and extending up close to the DW top slab, as shown in Figure 6.2-1. The opening between the RSW and the DW top slab provides the vent pathway necessary to limit pressurization of the annulus due to a high energy pipe rupture inside the annulus region. The shield wall is supported by the reactor support structure.

Several high energy lines extend from the RPV through the reactor shield wall. There are also penetrations in the RSW for other piping, vents, and instrumentation lines. The reactor shield wall is designed for transient pressure loading conditions from the worst high energy line rupture inside the annulus region.

6.2.1.2.3 Design Evaluation

FWL or RWCU line break within the Reactor Shield Annulus are identified to be the accident with most severe consequences. Mass and Energy releases from the postulated pipe breaks are based on the reactor operating condition prior to the break. It was assumed that the reactor is operating at full power and the containment is filled with dry air at atmospheric pressure and 100°C when the postulated pipe break occurs. The mass release rates are determined with Moody's ~~Frictionless Critical Flow Model~~Critical Flow Model for Homogenous Equilibrium Mixture (Reference 6.2-~~5~~8). ~~Analyzed with TRACG, the peak subcompartment pressure responses were found to be below the design pressure for postulated pipe break accidents.~~The subcompartment pressure responses were analyzed with TRACG. The integrity of Reactor Shield Wall is discussed in DCD subsection 3G.1.5.4.2.3.

NRC RAI 6.2-23 S02:

In GEH's response to RAI 6.2-23, Supplement No. 1, Attachment 3, provided detailed calculations of the break boundary conditions for the feedwater line and RWCU/SDC line breaks. For the feedwater line break, page 2 of this attachment indicates that the calculated break velocity is 55.207 m/s for the feedwater line break. Similarly, page 3 of this attachment indicates that the calculated break velocity for the RWCU/SDC line break is 31.764 m/s. The velocity calculations used half the break flow to accommodate the 180° model of the shield wall annulus; however, the full break area, instead of half the break area, was used in the velocity calculations. Consequently, the calculated break velocities were in error by a factor of 2. The correct feedwater break velocity is 110.414 m/s and the correct RWCU/SDC break velocity is 63.528 m/s. These break velocities were directly used in the inputs for the shield wall pressurization analyses provided in Attachments 1 and 2. Please correct the velocity input errors and resubmit the corrected shield wall pressurization analyses for the feedwater and RWCU line breaks.

GEH Response:

In the revised annulus pressurization analysis using TRACG computer program, a control block to model the break flow was added to replace the velocity input in the FILL component. In addition, the PIPE component between the VSSL and FILL was removed since this artificially added component was not necessary in the current TRACG version. Only the final cases were rerun and updated since the conclusions from the sensitivity study were not affected.

The reactor water cleanup (RWCU) and feedwater (FW) line pipe break critical mass flow rates are calculated in the updated Attachment 3 below. The total blowdown break flow into the annulus consists of two components, one from the reactor pressure vessel (RPV) side of the break and the other from the pipe side of the break. A critical flow inventory multiplier of 0.5 (Reference 1) was applied in the blowdown break flow on the pipe side of the break. There is no change on the RPV side. The break is modeled in TRACG as a FILL component with a control block providing constant break flow rate. Modifications to the input files for the final RWCU and FW cases are presented in Attachments 1 and 2 below.

Results show the RWCU line break to be limiting, with a peak annulus pressure of 1.2124 MPa reached at 1.5 msec after the break, compared to 1.521 MPa at 3 msec from the previous analysis. For FW line break, the peak pressure is 0.8852 MPa and occurs at 13 msec into the transient, compared to 0.877 MPa at 3 msec from the previous analysis.

References

1. NEDO-20533-1, "The General Electric Mark III Pressure Suppression Containment System Analytical Model Supplement 1," Appendix B, September 1975.

DCD Impact:

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

Attachment 1 Modifications to final RWCU case input file

```
*Followings are modifications from DRF Section 0000-0036-5118 Revision 1
*****         PIPE
*
*PIPE02000    2    "RWCU BREAK AND VESSEL"
*            NCELLS   NODES    JUN1     JUN2      MAT
*PIPE02010     1        0        1        2        0
*PIPE02DX0              0.355           E
*PIPE02VOL0             0.0233          E
*PIPE02TL0              545.5          E
*PIPE02TV0              545.5          E
*PIPE02P0               7.235E+06       E
*PIPE02PA0              0.0             E
*PIPE02ALP              0.0             E
*PIPE02FRICN0    0.0        1.0         E
*PIPE02FRICP0    0.0        0.0         E
*PIPE02FA0       0.0656     0.0656      E
*PIPE02VL0       0.0        0.0         E
*PIPE02VV0       0.0        0.0         E
*PIPE02ICHOKE0   0          0           E
*
*              DSTEP     TIMET       STDYST   TRANSI   NCOMP   NJUN   IPAK
MAIN00           0      0.0000E+00     0        1        2       1      1
*              SITMAX   NTRX    NDMPTR    ICTR    IBORC   IOPTCD     CMULT
MAIN02          10        0       0         1       0       2       1.0000E+02
******    COMPONENT LIST CARDS
COMPLIST00   99   01
*                       ISRL    ISRC    ISRF           JUNS           ZJN
VSSL9900140               8      10      -3              1            0.5
*            JUN1     IFTY     IFTR     NFTX
FILL01010      1        1        0        0
*            DXIN     VOLIN     ALPIN    VIN     TIN     PIN     BORCIN
FILL01011    0.355    0.0233    0.0      0.0     545.5 7.235E+06  0
*--------------------------------------------------------------------------------
*Added a control block
*CONTROL SYSTEM DATA
*CONTROL SYSTEM SIMPLE PARAMETERS CARD,CNTRL01000
*              NIOD        NCB        NFT       DELTCN
CNTRL010000      2           1          1         1.0
*CONTROL SYSTEM SIMPLE I/O DATA CARDS, CNTRL10XXX, NIOD CARDS
*              IOVAR       IOCMP      IOLEV     IOCEL
CNTRL100001     TIME         0          0         0
CNTRL100002     MDOT         1          0         1
*              ICBTYP      NCBI1      NCBI2     NCBI3    NCBOUT   CBNAM
CNTRL200001     FNG1        -1          1         0        -2       "mass flow rate"
*              CBIV        CON1       CON2      CBGAIN   CBMAX    CBMIN
CNTRL210001    0.0         0.0        0.0       1.0      1.E07    0.0
*CONTROL SYSTEM FUNCTION TABLE, CNTRL400XXX
*              NFTP        FTNAM
CNTRL400001      2      "mass flow rate"
*CONTROL SYSTEM FUNCTION TABLE DATA CARDS, CNTRL41XXXY
*              CBFUN, NFT TABLES OF 2*NFTP VALUES
CNTRL410011    0.0    2395.06        9.0 2395.06
*--------------------------------------------------------------------------------
```

Attachment 2 Modifications to final FW case input file

```
*Followings are modifications from DRF Section 0000-0036-5118 Revision 1
*****          PIPE
*
*PIPE02000    2    "FW BREAK AND VESSEL"
*           NCELLS    NODES     JUN1      JUN2      MAT
*PIPE02010     1         0         1         2         0
*PIPE02DX0             0.355             E
*PIPE02VOL0            0.0166            E
*PIPE02TL0             488.75            E
*PIPE02TV0             488.75            E
*PIPE02P0              7.305E+06         E
*PIPE02PA0             0.0               E
*PIPE02ALP             0.0               E
*PIPE02FRICN0     0.0        1.0         E
*PIPE02FRICP0     0.0        0.0         E
*PIPE02FA0        0.0468     0.0468      E
*PIPE02VL0        0.0        0.0         E
*PIPE02VV0        0.0        0.0         E
*PIPE02ICHOKE0    0          0           E
*
*                DSTEP     TIMET       STDYST    TRANSI    NCOMP    NJUN    IPAK
MAIN00             0     0.0000E+00      0          1         2        1       1
*                SITMAX    NTRX    NDMPTR    ICTR    IBORC    IOPTCD      CMULT
MAIN02             10        0       0         1       0        2      1.0000E+02
******     COMPONENT LIST CARDS
COMPLIST00    99   01
*                        ISRL    ISRC    ISRF            JUNS            ZJN
VSSL9900140                13      10      -3               1             0.5
*           JUN1     IFTY     IFTR     NFTX
FILL01010     1        1        0        0
*           DXIN     VOLIN     ALPIN     VIN     TIN     PIN     BORCIN
FILL01011   0.355    0.0166    0.0       0.0    488.75 7.305E+06  0
*-------------------------------------------------------------------------------
*Added a control block
*CONTROL SYSTEM DATA
*CONTROL SYSTEM SIMPLE PARAMETERS CARD,CNTRL01000
*              NIOD        NCB        NFT        DELTCN
CNTRL010000     2           1          1          1.0
*CONTROL SYSTEM SIMPLE I/O DATA CARDS, CNTRL10XXX, NIOD CARDS
*              IOVAR       IOCMP      IOLEV      IOCEL
CNTRL100001     TIME         0          0          0
CNTRL100002     MDOT         1          0          1
*              ICBTYP      NCBI1      NCBI2      NCBI3    NCBOUT    CBNAM
CNTRL200001     FNG1        -1          1          0        -2        "mass flow rate"
*              CBIV        CON1       CON2       CBGAIN   CBMAX     CBMIN
CNTRL210001    0.0         0.0        0.0        1.0      1.E07     0.0
*CONTROL SYSTEM FUNCTION TABLE, CNTRL400XXX
*              NFTP        FTNAM
CNTRL400001     2      "mass flow rate"
*CONTROL SYSTEM FUNCTION TABLE DATA CARDS, CNTRL41XXXY
*              CBFUN, NFT TABLES OF 2*NFTP VALUES
CNTRL410011    0.0     2854.26        9.0 2854.26
      *-------------------------------------------------------------------------------
      -
```

Attachment 3 - Break Boundary Conditions

Feedwater Line Break

The FW line break flow is from both sides of the break. From ref. 2, attachment 2, the RPV side break area is limited by the sum of nozzle areas attached to the feedwater sparger. The flow feeding the feedwater line sees a limiting flow area at the break between the RPV and RSW.

The feedwater line thermal hydraulic conditions are obtained from the reactor heatbalance of reference 3. The pressure at the feedwater line break is based on the steady state TRACG calculation in reference 3 for nominal conditions, (from reference 4 the feedwater component is tee 0061, cell 10 connects to the vessel and represents the safe end break location).

$A_1 := 0.0280 m^2$	$A_1 = 0.301 ft^2$	RPV side - 18 sparger nozzle areas (ref. 2)
$A_2 := 0.0656 m^2$	$A_2 = 0.706 ft^2$	RSW side - FW pipe flow area (ref. 2)
$A := \frac{(A_1 + A_2)}{2}$		Combined flow area is 1/2 actual flow area since we are modeling only 1/2 the annulus.
$A = 0.0468 m^2$	$A = 0.504 ft^2$	
$P := 7.305 \cdot 10^6 \cdot Pa$	$P = 1060 psi$	FW line pressure, from ref. 3, TRACG component TEE0061, cell 9.
$h := 0.925 \cdot 10^6 \cdot \frac{joule}{kg}$	$h = 397.7 \frac{BTU}{lb}$	FW enthalpy (ref. 3)
$T := 488.75K$		FW temperature (ref. 3)
$v_f := 1.176 \cdot 10^{-3} \frac{m^3}{kg}$	$v_f = 0.0188 \frac{ft^3}{-}$	specific volume from steam tables (ref. 6)
$P_{annulus} := 0.101325 \cdot 10^6 Pa$	$P_{annulus} = 14.7 psi$	

The critical mass flux may be used to find the mass flow rate through the break.

$G_c := 9.389 \times 10^4 \cdot \frac{kg}{s \cdot m^2}$ $G_c = 19230 \frac{lb}{s \cdot ft^2}$ From reference 7 using above input

Note: in the ref. 1 analysis, the critical mass flow rate has been adjusted by correcting for the over-prediction of the critical mass flux during inventory depletion. This was done by applying a critical flow inventory multiplier, f (see reference 5). ~~For conservatism, the reduction multiplier is not applied for the ESBWR analysis (value set to 1.0). If the multiplier had been included, the break flow would be significantly reduced, thus lowering the peak AP load.~~
Similar approach was adopted in Revision 2 of this analysis.

$f_1 := 1.0$ subscript 1 is the RPV side

$f_2 := \cancel{1.0}\ 0.5$ subscript 2 is the FW supply side

$m_1 := f_1 \cdot G_c \cdot A_1$

$m_2 := f_2 \cdot G_c \cdot A_2$

$m_t = 0.5(G_c A_1 + 0.5 G_c A_2) = 2854.26 \text{ kg/s}$

$m_1 = 2629 \frac{kg}{s}$

$m_2 = 6159 \frac{kg}{s}$

The total mass flow rate is found by combining the flow from the two sources. Since we are modeling only 1/2 the annulus, the total mass flow rate entering the model is 1/2 the total flow rate.

$m_{tot} := \frac{1}{2}(m_1 + m_2)$

$m_{tot} = 4394 \frac{kg}{s}$

$V := \frac{m_{tot} \cdot v_f}{(A_1 + A_2)}$ velocity at break

$V = 55.207 \frac{m}{s}$ value applied to TRACG boundary condition (component FILL01)

<u>RWCU/SDC Line Break</u>

The RWCU/SDC line break flow is from both sides of the break. The flow area is based on the piping ID from ref. 2, attachment 2

The RWCU line thermal hydraulic conditions RWCU are obtained from the reactor heatbalance of reference 3. The pressure at the feedwater line break is based on the conditions in the downcomer at the elevation of the RWCU/SDC line. This is obtained from the steady state TRACG calculation in reference 3 for nominal conditions, (VSSL level 15, theta node 19).

$A_1 := 0.0656 m^2$	$A_1 = 0.706 ft^2$	RPV side - 18 sparger nozzle areas (ref. 2)
$A_2 := 0.0656 m^2$	$A_2 = 0.706 ft^2$	RSW side - FW pipe flow area (ref. 2)
$A := \frac{(A_1 + A_2)}{2}$		Combined flow area is 1/2 actual flow area since we are modeling only 1/2 the annulus.
$A = 0.0656 m^2$	$A = 0.706 ft^2$	
$P := 7.235 \cdot 10^6 \cdot Pa$	$P = 1049 psi$	Downcomer pressure at RWCU elevation (ref 3)
$h := 1.1967 \cdot 10^6 \cdot \frac{joule}{kg}$	$h = 514.5 \frac{BTU}{lb}$	Downcomer enthalpy at RWCU elev. (ref. 3)
$T := 545.5K$		RWCU FW temperature (ref. 3)
$v_f := 1.305 \cdot 10^{-3} \frac{m^3}{kg}$	$v_f = 0.0209 \frac{ft^3}{lb}$	specific volume from steam tables (ref. 6)
$P_{annulus} := 0.101325 \cdot 10^6 Pa$	$P_{annulus} = 14.7 psi$	

The critical mass flux may be used to find the mass flow rate through the break.

$G_c := 4.868 \cdot 10^4 \cdot \frac{kg}{m^2 s}$ $\quad G_c = 9970 \frac{lb}{s \cdot ft^2}$ From reference 7 using above input.

Note: in the ref. 1 analysis, the critical mass flow rate has been adjusted by correcting for the over-prediction of the critical mass flux during inventory depletion. This was done by applying a critical flow inventory multiplier, f (see reference 5). ~~For conservatism, the reduction multiplier is not applied for the ESBWR analysis (value set to 1.0). If the multiplier had been included, the break flow would be reduced, thus lowering the peak AP load.~~
Similar approach was adopted in Revision 2 of this analysis.

$f_1 := 1.0$ subscript 1 is the RPV side

$f_2 := \cancel{1.0}\ 0.5$ subscript 2 is the FW supply side

$m_1 := f_1 \cdot G_c \cdot A_1$

$m_2 := f_2 \cdot G_c \cdot A_2$

$m_1 = 3193 \frac{kg}{s}$

$m_2 = 3193 \frac{kg}{s}$

The total mass flow rate is found by combining the flow from the two sources. Since we are modeling only 1/2 the annulus, the total mass flow rate entering the model is 1/2 the total flow rate.

$m_{tot} := \frac{1}{2}(m_1 + m_2)$

$m_{tot} = 3193 \frac{kg}{s}$

$V := \frac{m_{tot} \cdot v_f}{(A_1 + A_2)}$ velocity at break

$V = 31.764 \frac{m}{s}$ value applied to TRACG boundary condition (component FILL01)

$m_t = 0.5(G_c A_1 + 0.5 G_c A_2) = 2395.06\ kg/s$