GE Nuclear Energy

Sandra A. Delvin
Manager, ESBWR
Engineering & Technology

General Electric Company
175 Curtner Avenue, M/C 307 San Jose, CA 95125-1014
408 925-3900 (phone) 408 925-5490 (facsimile)

Project 717

MFN 03-117
October 20, 2003

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20852-2738

Attention: Chief, Information Management Branch
Program Management
Policy Development and Analysis Staff

Subject: **Response to Request for Additional Information (RAI) numbers (15, 259, 286, and 292) for ESBWR Pre-application Review - Supplementary Information**

In response to a request from the NRC, GE Nuclear Energy is submitting, in Enclosures 1 and 2, supplementary information in support of our response to Requests for Additional Information (RAI) numbers 15, 259, 286, and 292, which were originally provided in the referenced letters.

Enclosure 1 contains the supplementary information with GE proprietary information as defined by 10CFR2.790. GE customarily maintains this information in confidence and withholds it from public disclosure. A non-proprietary version of the information is provided in Enclosure 2.

The affidavit contained in Enclosure 3 identifies that the information contained in Enclosure 1 has been handled and classified as proprietary to GE. GE hereby requests that the information of Enclosure 1 be withheld from public disclosure in accordance with the provisions of 10 CFR 2.790 and 9.17.

If you have any questions about the information provided here, please let me know.

Sincerely,

Jim Fox for

Sandra A. Delvin
Manager, ESBWR
Engineering & Technology

D068

References:

1. MFN 03-079, Letter From Atam S. Rao (GE) to NRC, August 22, 2003, SUBJECT: RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION (RAI) NUMBERS (161, 162, 164, 176, 183, 184, 286, 292, 293, 295, 301, 323, 325, 339, and 382) FOR ESBWR PRE-APPLICATION REVIEW
2. MFN 03-083, Letter From Atam S. Rao (GE) to NRC, September 5, 2003, SUBJECT: RETRANSMITTAL OF RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION (RAI) NUMBERS (6, 15, 35, 45, 47, 48, 60, 65, 67, 77, 89-92, 94, 95, 97, 105, 159, 264, 271, 298, 299, 304, 305, 307, 310, 317, 321, 324, 326, 329, 331, 387, 388, 406, and 408) FOR ESBWSR PRE-APPLICATION REVIEW
3. MFN 03-101, Letter From Sandra A. Delvin (GE) to NRC, September 19, 2003, SUBJECT: RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION (RAI) NUMBERS (54, 79, 100, 101, 109, 259, 282, 309, 311, 333, and 383) for ESBWR Pre-application Review

Enclosures:

1. MFN 03-117 - Response to NRC RAI numbers (15, 259, 286, and 292) – Supplementary Information - Proprietary Information
2. MFN 03-117 - Response to NRC RAI numbers (15, 259, 286, and 292) – Supplementary Information - Non-proprietary Information
3. Affidavit, George B. Stramback, dated October 20, 2003

cc:	A. Cubbage	USNRC (with enclosure)
	J. Lyons	USNRC (w/o enclosure)
	G.B. Stramback	GE (with enclosure)

General Electric Company

AFFIDAVIT

I, George B. Stramback, state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and 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 the Enclosure 1 of GE letter MFN 03-117, Sandra A. Delvin to NRC, *Response to Request for Additional Information (RAI) numbers (15, 259, 286, and 292) for ESBWR Pre-application Review – Supplementary Information,* dated October 20, 2003. The proprietary information is in Enclosure 1, *Response to NRC RAI numbers (15, 259, 286, and 292) – Supplementary Information.* For text and text contained in tables, GE proprietary information is identified by a double underline inside double square brackets. 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.

(3) In making this application for withholding of proprietary information of which it is the owner, GE 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 2.790(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 General Electric's competitors without license from General Electric 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 General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

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 2.790 (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 GE, 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 GE, 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. Access to such documents within GE 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 GE 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 details for licensing application of TRACG to the ESBWR passive safety system design of the BWR. This TRACG code has been developed by GE for over fifteen years, at a total cost in excess of three million dollars. The reporting, evaluation and interpretations of the results, as they relate to the ESBWR, was achieved at a significant cost, to GE.

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 GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE'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 GE.

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.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE 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 GE 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 GE 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 20th day of October 2003

George B. Stramback

George B. Stramback
General Electric Company

ENCLOSURE 2

MFN 03-117

Response to NRC RAI numbers (15, 259, 286, and 292) – Supplementary Information

Supplementary Information for RAI 15

Supplementary request:

Provide examples of bottom up phenomena found in the ESBWR experiments that were not expected in the top down scaling of the tests.

Response:

Bottom- Up Phenomena seen in Tests but not Considered in Top Down Scaling

	Phenomena	Test	Cause	Disposition
1	"Percolation" phenomenon in RPV upper plenum and standpipe	GIST	Non-prototypical upper plenum with single standpipe	Test facility distortion. Did not affect time-average behavior/ inventory in upper plenum/ core. Not seen in GIRAFFE/SIT tests. TRACG predicted occurrence for GIST, but not for ESBWR.
2	Light gas retention in lower drywell for extended period.	GIRAFFE/ Helium	Non-prototypical heat loss and condensation in lower drywell.	Test facility distortion. Affected containment pressure evolution but not final value. Valid data for PCCS performance with light noncondensibles were obtained.
3	Unequal inlet flows to the three PCC units.	PANDA-M	Small differences between PCC units and/or piping or in inlet conditions to the PCCs.	Possible phenomenon in plant. Does not affect total PCC heat removal. Demonstrated PCC capability to adapt to variable heat load.
4	Condensation in main vents and wetwell heatup.	PANDA-P	Non-prototypical main vent routing through wetwell gas space combined with a high heat load relative to PCC capacity maintained condensation in main vents.	Test facility distortion. Main vent closed off after reflooding of the vents to prevent non-prototypical behavior.
5	Oscillation in steam flow from RPV.	PANDA Test M7	Test started at low RPV level, low drywell temperature and high noncondensible load. RPV downcomer level got low enough (top of shroud) to produce oscillations in level and steaming. Detailed RPV geometry not scaled in PANDA.	Combination of low drywell temperature/low RPV level unlikely to occur in plant. Time-average response was not greatly affected. Free surface separation in PANDA likely aggravated oscillatory behavior when downcomer level got close to top of shroud. Oscillations were calculated with TRACG PANDA

	Phenomena	Test	Cause	Disposition
				model under similar conditions
6	Small flow reversals between RPV and GDCS pools over extended time periods.	PANDA Test P2	After early draining of GDCS pool, small backflow occurred through biased open check valve followed by subsequent draining, in response to RPV to WW pressure difference.	Possible phenomenon in plant, but of no consequence to overall response of containment or RPV. Resulted in one additional opening of vacuum breakers at about two hours from the start of the test.
7	Thermal stratification at top of wetwell gas space due to leakage flow from drywell	PANDA Test M6/8	Higher temperature steam leakage from drywell tended to stratify at top of wetwell	Possible effect in plant. Treated through conservative modeling process in TRACG.

Supplementary Information for RAIs 259 and 286

The purpose of this response is to address the issue of interactions between the major ESBWR volumes that was raised by the NRC staff and consultants. This is done by supplementing the derivations of the scaling equations in section 6 of the ESBWR Scaling Report. The terminology and nomenclature is the same as in the ESBWR Scaling Report. New terminology is defined in this response.

Interactions between the major ESBWR volumes (RPV, DW, SP and WW) occur as a result of flows between these volumes. The table below shows the important "external" flows that need to be considered during the various phases of the LOCA transient.

[[

]]

In the above table, the flow terms shown in red (bold) represent interaction terms, which are calculated from corresponding pressure differences between the participating volumes. The other flows are either choked or driven by decay heat or PCC condenser capacity. For the latter, the pressure difference between the volumes becomes the dependent quantity based on the flow rate. In the long term the PCC vent flow consists primarily of noncondensibles that end up in the wetwell gas space. The integrated flow of noncondensible flowing out of the PCC vent is slightly less than the noncondensibles flowing into the PCCS. This is because the PCCS maintains (on average) a nearly constant noncondensible inventory such that the

condensing capacity matches the decay heat. The temperature of the noncondensibles is close to the PCC secondary temperature of 100 C, so very little sensible energy is added to the suppression pool as the noncondensibles flow through to the wetwell gas space.
The terminology NC ~95% implies that 95% of the noncondensible initially in the drywell are pushed into the wetwell gas space in the early blowdown transient. Most of the remaining 5% will be transported before the GDCS phase. During the GDCS phase vacuum breaker openings occur and some of the noncondensibles are returned to the drywell. These are assumed to be of the order of no more than 5% of the original drywell noncondensible content, and are re-transported to the wetwell in the long term phase.

The Scaling Report expresses the conservation equations for liquid mass, pressure rate and the energy equation in non-dimensional form to examine the correspondence of the dominant phenomena between the ESBWR and the relevant test facilities. In these equations, interactions between the major volumes (RPV, drywell, SP and wetwell) are represented through the flows between the regions. The flow terms were non-dimensionalized with respect to reference values of the flows. In the following, the flows that are driven by pressure difference are explicitly expressed in terms of these pressure differences, resulting in cross terms involving pressures in connecting volumes. Non-dimensionalized values of the pressure differences are used in the reference terms. The corresponding PI groups indicate the importance of these terms in the scaling of the test facilities.

<u>Liquid Mass:</u>

$$\frac{dM_l}{dt} = -\sum_i \frac{\dot{Q}_i}{h_{fg}} + \sum_i W_{l,i} + \sum_i \frac{\Delta h_{sub} W_{l,i}}{h_{fg}} - \frac{1}{h_{fg}}\left[V_{RPV}\left(1-\rho_g h'_g\right) + M_l\left(\frac{\rho_g}{\rho_l} h'_g - h'_f\right)\right]\frac{dP_R}{dt} \quad \text{...(1)}$$

(Equation 3.1-11 of ESBWR Scaling Report)

Some external flows can be related to pressure differences between regions through the momentum equation (except for break and DPV flows that are choked in the blowdown phase, and are not dependent on the receiver pressure and involve no coupling between volumes):

$$\left(\frac{L}{a}\right)\frac{dW_i}{dt} = \Delta P_{ij} - \rho g H_{ij} - \left(\frac{F}{a^2}\right)\frac{W_i^2}{2\rho} \quad \text{....................(2)}$$

(Equation 3.2-3 of ESBWR Scaling Report)

In general, it can be shown that for the ESBWR transients being considered, the inertial terms for the flow paths are negligible in magnitude relative to the other terms. Hence, the momentum equation can be solved for the flow as:

$$W_i = \sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij} - \rho g H_{ij}\right)} \quad \text{..................(3)}$$

Substituting for the flow rates in the liquid mass equation (1):

$$\frac{dM_l}{dt} = -\sum_i \frac{\dot{Q}_i}{h_{fg}} + \sum_i \sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij} - \rho g H_{ij}\right)} + \sum_i \frac{\Delta h_{sub}\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij} - \rho g H_{ij}\right)}}{h_{fg}} \quad \text{.....(4)}$$
$$-\frac{1}{h_{fg}}\left[V_{RPV}\left(1-\rho_g h_g'\right) + M_l\left(\frac{\rho_g}{\rho_l}h_g' - h_f'\right)\right]\frac{dP_R}{dt}$$

The nondimensional form of the equation is

$$h_{fg}^+ \frac{dM_\ell^+}{dt^+} = -\sum_k \Pi_{M,\dot{Q},k}\dot{Q}_k^{\,+} + h_{fg}^+ \sum_i \Pi_{M,W,i}\sqrt{\Delta P^+{}_{ij}} + \sum_i \Pi_{M,sub,i} h_{sub,i}^+ \sqrt{\Delta P_{ij}^+} \quad \text{...........(5)}$$
$$-\left[\Pi_{M,\dot{P}1} V_{RPV}^+ f_3^+ + \Pi_{M,\dot{P}2} f_4^+ M_\ell^+\right]\frac{dP^+}{dt^+}$$

where

$f_3 = 1 - \rho_g h_g'$; $f_4 = \dfrac{\rho_g}{\rho_l} h_g' - h_f'$ are thermodynamic properties,

$$\Pi_{M,\dot{Q},k} = \frac{\dot{Q}_{k,o}}{h_{fg,o}}\frac{t_r}{\Delta M_{\ell,r}}$$
$$\Pi_{M,W,i} = \sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}\frac{t_r}{\Delta M_{\ell,r}}$$
$$\Pi_{M,sub,i} = \frac{\Delta h_{sub,i,o}}{h_{fg,o}}\frac{\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}\,t_r}{\Delta M_{\ell,r}}$$
$$\Pi_{M,\dot{P}1} = \frac{V_{RPV,o} f_{3,o}}{h_{fg,o}}\frac{\Delta P_r}{\Delta M_{\ell,r}} \quad \text{...........................(6)}$$
$$\Pi_{M,\dot{P}2} = \frac{f_{4,o}\Delta P_r}{h_{fg,o}}\frac{M_{\ell,o}}{\Delta M_{\ell,r}}$$

are PI numbers, and

$$\Delta M_\ell^+ = \frac{M_\ell - M_{\ell,o}}{\Delta M_{\ell,r}};\ t^+ = \frac{t}{t_r};\ \dot{Q}_k^{\,+} = \frac{\dot{Q}_k}{\dot{Q}_{k,o}};\ \Delta P_{ij}^+ = \frac{\Delta P_{ij} - \rho g H_{ij}}{\Delta P_{ij,0} - \rho g H_{ij,0}};\ h_{sub,i}^+ = \frac{\Delta h_{sub,i}}{\Delta h_{sub,i,o}};$$
$$M_\ell^+ = \frac{M_\ell}{M_{\ell,o}};\ \mathrm{P}^+ = \frac{P - P_o}{\Delta P_r};\ h_{fg}^+ = \frac{h_{fg}}{h_{fg,o}};\ f_3^+ = \frac{f_3}{f_{3,o}};\ f_4^+ = \frac{f_4}{f_{4,o}} \quad (7)$$

are the nondimensional variables. A standard nomenclature for the Π groups is adopted where the first subscript indicates the equation to which the term applies (i.e. mass, pressure), the second one indicates the phenomena represented and the third one indicates the flow path or source. Note that not all flows are replaced by driving head terms (see table on page 1). Some flow based PI groups will remain in the equation as shown in the original equation 6.1-1 of the scaling report. These are not shown here to reduce the complexity of the equation.

[[

]]

Temperature (Energy) Equation:

The temperature of the suppression pool is important to the steam partial pressure in the WW gas space. The temperature change is of course dependent on the energy in the pool. The dimensional form of the full equation is

$$M\frac{de}{dt} = -p\frac{dV}{dt} + \dot{Q} + \sum W_i\left(h_{o,i} - h_o\right) + {}^{p}\!/_{\rho}\sum W_i \quad \text{.........................(10)}$$

(Equation 3.1-6 of the ESBWR Scaling Report)

Substituting for the external flows as before in (10):

$$\begin{aligned} M\frac{de}{dt} = -p\frac{dV}{dt} + \dot{Q} + \sum\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij} - \rho g H_{ij}\right)}\left(h_{o,i} - h_o\right) \\ + {}^{p}\!/_{\rho}\sum\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij} - \rho g H_{ij}\right)} \end{aligned} \quad \text{..................... (11)}$$

Non-dimensionalizing:

$$\begin{aligned} M^+\frac{de^+}{dt^+} = -\Pi_{e,\dot{V}}P^+\frac{dV^+}{dt^+} + \sum_k \Pi_{e,\dot{Q},k}\dot{Q}_k^+ + \sum_i \Pi_{e,Wh,i}\sqrt{\Delta P_{ij}^+}\,h_i^+ \\ + {}^{P^+}\!/_{\rho^+}\sum_i \Pi_{e,mech,i}\sqrt{\Delta P_{ij}^+} \end{aligned} \quad \text{.. .... (12)}$$

where:

$$\Pi_{e,\dot{V}} = \frac{P_o \Delta V_r}{M_o \Delta e_r}$$

$$\Pi_{e,\dot{Q},k} = \frac{\dot{Q}_{k,o}t_r}{M_o \Delta e_r}$$

$$\Pi_{e,Wh,i} = \frac{\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}\Delta h_{i,o}t_r}{M_o \Delta e_r} \quad \text{.................................(13)}$$

$$\Pi_{e,\,mech,\,i} = \frac{P_o\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}t_r}{M_o \Delta e_r \rho_o}$$

and

$$e_i^+ = \frac{e - e_o}{\Delta e_r};\quad P^+ = \frac{P}{P_o};\quad dV^+ = \frac{dV}{\Delta V_r};\quad t^+ = \frac{t - t_o}{t_r};$$

$$\dot{Q}_k^+ = \frac{\dot{Q}_k}{\dot{Q}_{i.o}};\quad \Delta P_{ij}^+ = \frac{\Delta P_{ij} - \rho g H_{ij}}{\Delta P_{ij,0} - \rho g H_{ij,0}};\quad h_i^+ = \frac{h_i - h}{\Delta h_{i.o}}; \quad \text{.....................(14)}$$

$$\rho^+ = \frac{\rho}{\rho_o};\quad M^+ = \frac{M}{M_o}$$

are nondimensional variables.

Time Rate of Pressure Change

The dimensional form of the equation is

$$Vf_2 \frac{dp}{dt} = \sum_i \left[W_i\left(h_{o,i} - h_o\right)\right] + \sum_i W_i p^* / \rho + \dot{Q} - p^* \frac{dV}{dt} - V \sum_j \left[f_{l,j} \frac{dy_j}{dt}\right] \quad \text{.....................(15)}$$

(Equation 3.1-7 of the ESBWR Scaling Report)

The right side of the equation contains terms for energy increase due to enthalpy and heat additions, pressurization due to volume changes and fluid addition and changes in constituent fractions.
Substituting for the flow rates in terms of the driving heads in (15):

$$\begin{aligned} \mathrm{Vf_2} \frac{\mathrm{dp}}{\mathrm{dt}} &= \sum_{\mathrm{i}} \left[\sqrt{\left(\frac{2\rho a^2}{\mathrm{F}}\right)\left(\Delta \mathrm{P_{ij}} - \rho g \mathrm{H_{ij}}\right)} \left(\mathrm{h_{o,i}} - \mathrm{h_o}\right) \right] \\ &+ \sum_{\mathrm{i}} \frac{\mathrm{p}^*}{\rho} \sqrt{\left(\frac{2\rho a^2}{\mathrm{F}}\right)\left(\Delta \mathrm{P_{ij}} - \rho g \mathrm{H_{ij}}\right)} + \dot{\mathrm{Q}} - \mathrm{p}^* \frac{\mathrm{dV}}{\mathrm{dt}} - \mathrm{V} \sum_{\mathrm{j}} \left[\mathrm{f_{l,j}} \frac{\mathrm{dy_j}}{\mathrm{dt}}\right] \end{aligned} \quad \text{.............(16)}$$

Non-dimensionalizing:

$$\begin{aligned} \mathrm{f_2^+ V^+} \frac{\mathrm{dP^+}}{\mathrm{dt^+}} &= \sum_{\mathrm{k}} \Pi_{\mathrm{P},\dot{\mathrm{Q}}\mathrm{k}} \mathrm{Q_k^+} - \Pi_{\mathrm{P},\dot{\mathrm{V}}} \mathrm{P^{*+}} \frac{\mathrm{dV^+}}{\mathrm{dt^+}} + \sum_{\mathrm{i}} \Pi_{\mathrm{P,Wh,i}} \sqrt{\Delta \mathrm{P_{ij}^+}}\, \mathrm{h_i^+} \\ &+ \frac{\mathrm{P^{*+}}}{\rho^+} \sum_{\mathrm{i}} \Pi_{\mathrm{P,mech,i}} \sqrt{\Delta \mathrm{P_{ij}^+}} - \mathrm{V^+} \sum_{\mathrm{j}} \Pi_{\mathrm{P,y,j}} \left(\mathrm{f_{1,j}^+} \frac{\mathrm{dy_j^+}}{\mathrm{dt^+}}\right) \end{aligned} \quad \text{...............(17)}$$

where

$$P^* = P + \left.\frac{\partial e}{\partial v}\right|_{P,y_j}$$

$$f_{1,j} = \frac{1}{v}\left.\frac{\partial e}{\partial y_j}\right|_{P,v,y}$$

$$f_2 = \frac{1}{v}\left.\frac{\partial e}{\partial P}\right|_{v,y_j}$$

are thermodynamic properties, and

$$\Pi_{P,\dot{Q},k} = \frac{\dot{Q}_{k,o}}{V_o f_{2,o}}\frac{t_r}{\Delta P_r}$$

$$\Pi_{P,\dot{V}} = \frac{P_o^* \Delta V_r}{\Delta P_r V_o f_{2,o}}. \qquad \text{..............................} (18)$$

$$\Pi_{P,Wh,i} = \frac{\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}\Delta h_{i,o}}{V_o f_{2,o}}\frac{t_r}{\Delta P_r}$$

$$\Pi_{P,mech,i} = \frac{\sqrt{\left(\frac{2\rho a^2}{F}\right)\left(\Delta P_{ij,0} - \rho g H_{ij,0}\right)}P_o^*}{V_o f_{2,o}\rho_o}\frac{t_r}{\Delta P_r}$$

$$\Pi_{P,y,j} = \frac{f_{1,j,o}\Delta y_{j,r}}{\Delta P_r f_{2,o}}$$

are PI numbers, and

$$P^+ = \frac{P - P_o}{\Delta P_r};\quad V^+ = \frac{V}{V_o};\quad dV^+ = \frac{dV}{\Delta V_r};\quad t^+ = \frac{t - t_o}{t_r};$$

$$\dot{Q}_k^+ = \frac{\dot{Q}_k}{\dot{Q}_{k,o}};\quad \Delta P_{ij}^+ = \frac{\Delta P_{ij} - \rho g H_{ij}}{\Delta P_{ij,0} - \rho g H_{ij,0}};\quad h_i^+ = \frac{h_i - h}{\Delta h_{i,o}};\quad y_j^+ = \frac{y_j - y_{j,o}}{\Delta y_{i,r}}; \qquad \text{...........}(19)$$

$$P^{*+} = \frac{P^*}{P_o^*};\quad \rho^+ = \frac{\rho}{\rho_o};\quad f_{1,j}^+ = \frac{f_{1,j}}{f_{1,j,o}};\quad f_2^+ = \frac{f_2}{f_{2,o}}$$

are nondimensional variables. This equation is used for the RPV for the late blowdown and GDCS transition phases and in the containment regions for the long-term phase.

[[

]]

[[

]]

[[

]]

[[

]]

292. The 1/3 - 3 criterion for acceptance is meaningless unless one can relate the effect of such distortion range on the figure of merit. Presumably the figure of merit is core coolability. Therefore, it is necessary to show that when a given non-dimensional group is within the acceptability range, its effect on core coolability is within the acceptable range of uncertainties. Provide a detailed justification on the 1/3 – 3 criterion that is based on the impact that the distortions of important parameters have on the figure of merit.

__Supplemental response to RAI 292__

There was a remaining concern that the range of 1/3 to 3 for the ratio of PI groups was not an adequate criteria without further supporting information. This supplemental response addresses that concern.

[[

]]

Following the work of diMarzo [1], a simplified model of the RPV blowdown behavior is used to predict the plant and test performance, including only the key variables needed to predict the behavior with reasonable accuracy. The simplified models were compared against TRACG predictions for the ESBWR, and test data for the test facilities to assure that they are reasonably accurate.

The details of the simplified model approach and implementation are summarized in the paper by diMarzo. The specific application to the ESBWR and test facilities is summarized below. There are several differences and added complications in the ESBWR compared to the situation in diMarzo's paper. For application to the ESBWR and test facilities, a GDCS line break is used since this is the limiting break for RPV liquid inventory. This is also the break considered for the RPV liquid mass in the ESBWR scaling report. For this break, the ESBWR has both steam flow from the vessel due to ADS flow and liquid flow from the broken GDCS line. In addition, the minimum liquid inventory occurs a short time after ECCS injection flow from the GDCS system initiates. The GDCS flow rate is highly dependent on the RPV pressure. Therefore a simple model of the GDCS flow is needed.

The simplified model results in a system of equations for the pressure and inventory in the vessel,

[[

]]

where the following variables are used

P = pressure in vessel
t = time
$I = M_l/M_o$ = liquid inventory in vessel divided by initial inventory
M_l = liquid inventory
W_{GDCS} = GDCS injection flow rate
$Q_{decheat}$ = decay heat
Q_{stored} = stored energy release from vessel wall

In addition the following values are held constant

M_o = Initial inventory in vessel (steam and liquid)
ρ_l = liquid density
V = RPV non solid volume
F = Discharge coefficient for liquid flows out of the vessel
D = Discharge coefficient for vapor flows out of vessel
R = Gas constant
T = temperature in vessel
h_s = GDCS pool subcooling relative to RPV ($h_{pool} - h_{GDCS}$)
h_{fg} = enthalpy of vaporization
$a = h_{fg}/RT$
C_p = Specific heat
A = critical flow area

[[

]]

where

P_{RPV} = RPV pressure (P in the equations above)
P_{DW} = drywell pressure (held constant)
H_{GDCS} = hydrostatic head for the GDCS line
$H_{mainvent}$ = submergence of the main vent
$W_{GDCSrated}$ = rated GDCS flow when the RPV and drywell are at the same pressure
g = acceleration due to gravity constant

[[

]]

The last term in equation 292-2, representing the mass stored in the gas space, has been dropped in equation 292-7. This term has a very small impact on the inventory calculation and adds undesirable complexity to the calculation since it contains the pressure derivative.

The non-dimensional variables in equation 292-6 and 292-7 are all in the form,

$$X^{+} = \frac{X}{X_o} \qquad (292\text{-}8)$$

where X is the variable of interest and X_o is the reference value for the variable. For all variables except time and areas, the initial values are used as the reference values. For the ADS area, which varies with time, the maximum area is used. The determination of the time reference value is described in a later section.

The PI groups are defined as,

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

References:

1. di Marzo, Marino, 2001, "A Simplified Model of the BWR Depressurization Transient," Nuclear Engineering Design, **205,** 107-114.