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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 08-630, Supplement 1

Docket No. 52-010

March 10, 2009

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. 281 Related to the ESBWR Design Certification – Reactor Building Mixing and Leakage Requirements – RAI Number 6.2-165 S01**

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 December 4, 2008. The initial RAI was provided in Reference 2 with GEH's initial response provided in Reference 3. GEH response to RAI Number 6.2-165 S01 is addressed 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 a non-proprietary version that 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.

D068
NRO

Sincerely,

Richard E. Kingston
Vice President, ESBWR Licensing

References:

1. MFN 08-952, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request For Additional Information Letter No. 281 Related To ESBWR Design Certification Application*, dated December 4, 2008
2. MFN 07-327, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request for Additional Information Letter No. 100 Related to ESBWR Design Certification Application*, dated May 30, 2007
3. MFN 08-630, Letter from Richard E. Kingston, GEH to the U.S. Nuclear Regulatory Commission, *Response to Portion of NRC Request for Additional Information Letter Nos. 100 and 181 Related to ESBWR Design Certification Application - Reactor Building Mixing and Leakage Requirements - RAI Numbers 6.2-165 and 15.4-26 S01, and Transmittal of Licensing Topical Report (LTR) Document No. 092-134-F-M-06000, "Reactor Building Gothic Mixing Model Calculation Report," Issue 1, May 27, 2008*, and Gothic Input Files, dated August 14, 2008

Enclosures:

1. Response to Portion of NRC Request for Additional Information Letter No. 281 Related to ESBWR Design Certification Application – Reactor Building Mixing and Leakage Requirements – RAI Number 6.2-165 S01 – GEH Proprietary Information
2. Response to Portion of NRC Request for Additional Information Letter No. 281 Related to ESBWR Design Certification Application – Reactor Building Mixing and Leakage Requirements – RAI Number 6.2-165 S01 – Public Version
3. Affidavit – David H. Hinds – March 10, 2009

cc:	AE Cubbage	USNRC (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	eDRFs	0000-0097-7387

Enclosure 3

MFN 08-630, Supplement 1

Response to Portion of NRC Request for Additional Information Letter No. 281 Related to ESBWR Design Certification Application

Reactor Building Mixing and Leakage Requirements

RAI Number 6.2-165 S01

Affidavit

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, **David H. Hinds,** state as follows:

(1) I am the General Manager, New Units Engineering, GE-Hitachi Nuclear Energy Americas LLC ("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 MFN 08-630, Supplement 1, Mr. Richard E. Kingston to U.S. Nuclear Regulatory Commission, *Supplemental Response to Portion of NRC Request for Additional Information Letter No. 281 Related to the ESBWR Design Certification – RAI Number 6.2-165 S01,* dated March 10, 2009. The information in the Enclosure 1, which is entitled "*Response to Portion of NRC Request for Additional Information Letter No. 281 Related to ESBWR Design Certification Application – Reactor Building Mixing and Leakage Requirements – RAI Numbers 6.2-165 S01 – GEH Proprietary Information*" contains proprietary information, and is identified by [[dotted underline inside double square brackets{3}]]. Figures and other large 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 or licensee, 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's 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 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 GEH ESBWR calculations and analyses assumptions and inputs related to Reactor Building Mixing and Leakage GOTHIC analyses application. Development of this GOTHIC analysis was achieved at a significant cost to GEH, and results in a significant economic and competitive advantage to a competitor, and 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 and obtaining 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 10th day of March, 2009.

David H. Hinds
GE-Hitachi Nuclear Energy Americas LLC

Enclosure 2

MFN 08-630, Supplement 1

Response to Portion of NRC Request for Additional Information Letter No. 281 Related to ESBWR Design Certification Application

Reactor Building Mixing and Leakage Requirements

RAI Number 6.2-165 S01

Public Version

NRC RAI 6.2-165 S01:

Through the review of GEH's response to RAI 6.2-165, the supporting GOTHIC analysis, the LTR NEDE-33279P Revision 2, and discussions with GEH on the telephone, the staff has determined that there is considerable uncertainty in the GOTHIC analysis assumptions and results. The staff requests that GEH address the uncertainties in the analysis, some of which are characterized below. The staff is reluctant to request additional analysis because it is not clear that additional analysis will be on a success path to remove uncertainties. In fact, additional analysis could introduce new uncertainties. This being said, the staff will consider additional analyses, if submitted, that demonstrate the results as bounding and conservative. The staff will also consider the inclusion of a safety factor to address uncertainties. The staff will also consider a change in ex-filtration rate to the NUREG-1242 recommended 25 percent per day and a reduction of mixing volume to a lower value than currently submitted. Please provide a plan for addressing the uncertainties in the GOTHIC analysis in a preliminary response to this supplement and the results of implementing the plan in the final response to this supplement.

The staff would like to clarify that both the REPAVS volume and the CLAVS volume are not part of the safety envelope. Although these volumes are isolated to some degree, they are not tested and as such, should not be used as hold up volumes in any dose assessment affecting off site dose such as CR, EAB, or LPZ doses. On the other hand any release to these volumes could affect the dose inside the volume on equipment qualification, access and operator exposure. As such, if there are releases to these volumes, the volumes should be considered 100 percent holdup for the purpose of evaluating the impact on equipment and personnel inside these volumes.

The staff is considering a number of uncertainties and this is by no means a complete list:

1. The distribution of primary leakage on the basis of process pipe diameters in mechanical penetration. Considering all the leakage going into one or two penetration rooms, electrical penetration leakage, and a closer proximity to ex-filtration paths would be more conservative.

2. Initial conditions outside the range of positive ¼-inch wg to negative ¼-inch wg. The staff was unable to explain initial pressures of negative 1.67 inches and positive ¾ inches for certain rooms.

3. Use of abnormally high K values to block flow to CLAVS area. Staff believes a realistic K value should be used with an external pressure of negative or positive ¼ inch as a boundary condition. The flow would be then determined by the GOTHIC analysis. The staff noted that some other K values of 1.2 and 2.77 that seem to have been included to restrict flow.

4. Use of a single point ex-filtration or in-filtration location. Each potential location of a leakage should be evaluated with a boundary condition of negative or positive ¼-inch wg applied. GOTHIC should determine all flows. If the GOTHIC program predicts the ex-filtration flows based on the real physical conditions, a test program that confirms these flows would reduce the level of uncertainty.

5. Door gap sizes should be based on design records and can be verified by ITAAC. Any change from the design for the purpose of the analysis needs to be clearly identified and the impact of the change evaluated. GOTHIC is assumed to be a best estimate analysis based on actual physical constructions.

6. Physical parameters must also support HVAC operation for both normal and after 72-hour operations.

7. A validation model for GOTHIC that is similar to the current application. The staff wants to review the differences in the validation model and the current application.

GEH Response:

GEH's plan for addressing the uncertainties in the GOTHIC analysis is provided in Appendix A. The resulting plan implementation and the final response to this supplement will be provided by May 1, 2009.

To address NRC's request for a safety factor, GEH will make a change to reduce the credited mixing volume in the dose analysis to add conservatism to the amount of hold up predicted by RADTRAD. Adding conservatism to the hold up predicted by RADTRAD adds assurance that the uncertainties in the hold up predicted by the GOTHIC analysis are appropriately bounded. A reduction in the primary containment leakage value will be made such that the doses with the lower holdup/mixing are approximately the same. A change in the Reactor Building exfiltration rate was considered by GEH, but reduction in primary containment leakage was the preferred option to allow operating experience of similar containments to be applied.

The Refuel and Pool Area Ventilation Subsystem (REPAVS) and Clean Area Ventilation Subsystem (CLAVS) areas are not part of the safety envelope and are not credited as hold up in the dose analysis. Doses with respect to equipment qualification, access and operator exposure in these areas, considering conservative hold up, will be addressed in the Appendix A plan outline.

In addition to the plan, the individual RAI points are addressed below:

1. Sensitivity on the distribution of containment leakage through a limited number of penetrations in select rooms, additional leakage paths for electrical penetrations, and penetration leakage location will be performed on a nominal GOTHIC calculation to quantify the conservatism in the containment penetration leakage considered in the licensing basis GOTHIC analysis. The licensing basis GOTHIC analysis is presented in NEDE-33279P Revision 2, ESBWR Containment Fission Product Removal Evaluation Model " provided via GEH letter MFN 06-205, Supplement 3 dated July 9, 2008.

2. The initial pressures were based on elevation. Higher elevations had lower pressures while lower elevations had higher pressures. The pressures are consistent with the methodology in the ASHRAE Fundamentals Handbook 2005 Chapter 6 Equation 3. The GOTHIC code adjusts pressures to account for the gravitational head at a volume's elevation during the calculation as presented in the GOTHIC Technical Manual.

3. High K values were used to block flow to the CLAVS area in the licensing basis GOTHIC analysis because allowing flow to this area would cause more hold up in comparison to a direct release to the environment. Additional hold up in this area is not credited in the dose analysis. The nominal GOTHIC calculation will be executed using realistic (lower) K values for doors that connect Contaminated Area Ventilation Subsystem (CONAVS) to other buildings and areas that do not communicate directly with the environment. The external pressure between CONAVS and CLAVS will initially be at atmospheric pressure for the nominal calculation and the code will determine the pressure and the flows between the areas. A sensitivity analysis on the pressure boundary conditions will be performed to quantify the conservatism in the licensing basis GOTHIC analysis. The K values of 1.2 and 2.77 in the licensing basis analysis were not included to restrict flow but to represent a door that allowed for a large amount of leakage, and the K values are significantly smaller than realistic spec door values. The nominal GOTHIC calculation will be executed using realistic (higher) K values for interior CONAVS doors and doors that connect CONAVS directly to the environment.

4. The nominal GOTHIC calculation will include additional locations of containment leakage in the model in comparison to the licensing basis GOTHIC calculation. Appendix J Type B and C tested penetrations are limited to 60% of the overall containment leakage (0.6 L_a) according to Generic Technical Specification (GTS) 5.5.9. This Type B and C test leakage will be distributed in the nominal GOTHIC calculation as follows; 0.05 L_a structural penetrations (air locks), the limit for an air lock specified in GTS 5.5.9 will be distributed through all the structural penetrations, 0.1925 L_a (35% of (0.6 L_a –0.05)) to electrical penetrations, 0.3575 L_a (65% of (0.6 L_a – 0.05)) to mechanical penetrations.

The remaining 40% of overall containment leakage (0.4 L_a) will be distributed as follows: 0.24 L_a (60% of 0.4 L_a) to instrumentation penetrations identified as part of the containment leakage Type A testing, and 0.16 L_a (40% of 0.4 L_a) to unknown leakage through "sleeves", containment liner and other unknown leakage. The unknown leakage will be distributed proportionally to the surface area of the containment that is in contact with a CONAVS room.

In order to account for wind loading during a Loss-of-coolant-Accident, positive and negative ¼ inch wg will be applied to all exfiltration or infiltration points that communicate with the environment in the GOTHIC calculation. For CONAVS areas of the Reactor Building that communicate with areas other than the environment, atmospheric pressure will be assumed initially. A sensitivity analysis on the pressure boundary conditions will be performed to quantify the conservatism in the licensing basis GOTHIC analysis.

5. The nominal GOTHIC analysis will be performed using realistic door gaps/losses. A sensitivity analysis will be performed on the door gaps/losses, and visual surveillance requirements for door gaps will be established as necessary based on the results of the analysis.

6. Rooms that were conservatively assumed to be sealed off in the licensing basis GOTHIC calculation will have realistic door gaps/losses, and multiple Reactor Building infiltration/exfiltration points will be applied in the nominal GOTHIC calculation.

7. The GOTHIC qualification report contains validation models similar to the current application. A comparison between the validation models and the current application is provided in Appendix B.

DCD Impact:

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

Appendix A

GEH Plan to Address GOTHIC Analysis Uncertainty

Action to Address Overall Uncertainty:

Reduce the mixing volume assumed in RADTRAD from approximately 70% to 50% of the CONAVS volume. The containment leakage rate has been reduced from 0.4% to 0.35% weight per day in order to maintain the current offsite dose values. This adds conservatism to the amount of hold up credited in the RADTRAD analysis. The reduction in the mixing volume is proportionally the same as a reduction in the primary containment leak rate, and minimizes the net change in the calculated control room and offsite dose. The conservatism gained by reducing the credited mixing volume will be quantified.

Action to Address Uncertainty:

Perform a nominal GOTHIC calculation. Determine the predicted dose associated with the exfiltration value calculated in the nominal run. Perform sensitivity analysis outlined below to determine the affects on the predicted dose by varying parameters in GOTHIC. Quantify the individual conservatisms and uncertainties in the analysis using the predicted dose values calculated by the sensitivity runs. The nominal calculation will include realistic door gaps and multiple infiltration and exfiltration locations. The nominal calculation will also consider containment leakage through mechanical penetrations, electrical penetrations, and unknown leakage that can account for leakage through "sleeves" and the containment liner, as well as other leakage. Sensitivity studies are outlined in Table 6.2-165S01-1. The conservatism in the licensing basis GOTHIC analysis will be quantified based on the sensitivity analysis. GEH may propose containment leakage administrative limits on Reactor Building areas that will only allow a fraction of the total containment leakage into a particular area as part of GTS Section 5.5.9, "Containment Leakage Rate Testing Program," based on the outcome of sensitivity analysis.

Actions to Address Post Accident Dose with Respect to EQ and Operators in the Reactor Building:

- The dose rate in the Reactor Building CONAVS area considering significant hold up will be determined, and its impact will be included with the final RAI response.
- The dose rate in the Reactor Building CLAVS area considering leakage from the CONAVS area with significant hold up will be evaluated, and its impact will be included with the final RAI response.

Table 6.2-165S01-1 Planned GOTHIC Sensitivity Analysis

GOTHIC Sensitivity Analysis to Address Uncertainties	
Parameter - (Relative to nominal unless otherwise noted)	Potential Negative Impact (Offsite Dose / Dose in RB)
Subdivided Volumes - Additional Nodes	Dose in Reactor Building
Subdivided Volumes - Less Nodes	Offsite Dose
Door Gaps/Losses - Additional Leakage	Offsite Dose
Door Gaps/Losses - Less Leakage	Dose in Reactor Building
Nitrogen - Higher Temperature	Dose in Reactor Building
Nitrogen - Lower Temperature	Offsite Dose
Room Heat Up - Additional Heat Up	Offsite Dose
Room Heat Up - Less Heat Up	Dose in Reactor Building
Initial Room Temperature - Higher Temperature	Offsite Dose
Initial Room Temperature - Lower Temperature	Dose in Reactor Building
Internal Boundary Pressure Conditions	Offsite Dose
Penetration & Unidentified Leakage Variations / Locations	Offsite Dose
Exfiltration Points	Dose in Reactor Building
Run Licensing Basis GOTHIC Calculation further to determine equilibrium point and compare to extended RADTRAD calculation of hold up to determine if GOTHIC is always conservative during period of interest	Offsite Dose

Appendix B

GOTHIC Qualification and Validation for ESBWR Reactor Building Model

1. GOTHIC Overview

GOTHIC (Generation of Thermal-Hydraulic Information for Containments) is a general purpose thermal-hydraulics software package (Reference 1) for design, licensing, safety and operating analysis of nuclear power plant containments and other confinement buildings. [[

]] (See Note 1).

The complete GOTHIC software package includes the following three programs and associated documentation:

[[

]] (See Note 1).

For further modeling details of GOTHIC_S program, please refer to the GOTHIC Technical Manual (Reference 1).

2. Current Application

In the current application, GOTHIC (version 7.2a (QA), Reference 1) has been used to provide a best-estimate analysis of containment leakage dilution in the ESBWR Reactor Building (RB) and the RB release rate. The details are in Reference 2 and a summary is provided in Reference 3.

Several sub-volumes of the ESBWR RB are modeled in GOTHIC. They include the CONAVS and CLAVS areas, and stairwells, as shown in Figure 2.1 (adapted from Reference 2). The CONAVS ventilation area envelopes all the containment penetrations except those in the steam tunnel. In some cases, the CLAVS areas are barriers between the CONAVS and the environment. The stairwells act as a transport path from the CONAVS to the environment. All the interior doors connecting the different rooms in the building as well as the doors that connect to other buildings or to the environment are modeled. Additionally, the HVAC ductwork connecting the appropriate volumes is also modeled in GOTHIC.

Each RB room is assigned a specific geometry determined by its volume, height, and elevation. More specific geometric characteristics are assigned to the rooms important to transport based on the room size, location and significance of flow obstructions.

These selected rooms within the CONAVS areas are subdivided in the GOTHIC model. Further details are given in Reference 2.

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Figure 2.1 Simplified GOTHIC Nodalization of the ESBWR Reactor Building

All RB rooms and volumes are initially filled with air. The radionuclide transport gas from the containment leakage is modeled as several nitrogen sources as shown in Figure 2.1. This is because nitrogen, along with steam, is the most abundant fluid in the containment and it does not condense. GOTHIC differentiates the nitrogen that leaks from the containment from the nitrogen that is part of the mixture of gases that make up air in the RB by treating the RB air as a gas rather than a mixture of gases. Therefore, in the current application, GOTHIC treats the RB fluid as a mixture of **two non-condensing gases**, namely, nitrogen (that leaks from the containment) and air (that was present in the RB).

3. GOTHIC Validation Model

GOTHIC (version 7.2a (QA)) has been validated against a wide range of analytical, separate-effects, and small, intermediate and large-scale integral experiments. The details are presented in GOTHIC Qualification Report (Reference 4).

Of all the validation cases presented in Reference 4, Tests 6, 12 and 20 conducted in Battelle-Frankfurt Model Containment (BFMC) test facility are the most appropriate GOTHIC validation models for the current application. [[

]] (See Note 1).
Comparisons were made between the measured and predicted hydrogen concentrations in various rooms, and the agreement was quite good. The details are discussed below.

3.1 <u>Battelle-Frankfurt Test Facility</u>

The Battelle-Frankfurt Model Containment (BFMC) was constructed specifically to study the thermal-hydraulic response of a containment system during accident conditions and to use test data to assist development of related thermal-hydraulic codes. [[

]] (See Note 1)

The general configuration of BFMC is shown in Figure 3.1. [[

]] (See Note 1). The elevation view of the BFMC test facility is shown in Figure 3.2. Further details of this test facility can be found in Chapter 7 of Reference 4.

[[

]]
(See Note 1)

Figure 3.1 Cutaway View of Interior Rooms in BFMC Test Facility (Reference 4)

[[

]](See Note 1)

Figure 3.2 Elevation View of BFMC Test Facility (Reference 4)

3.2 BFMC Test 6

The BFMC test program was designed to study transport of hydrogen by **convection and diffusion** through an air-filled containment. BFMC Test 6 is one of several hydrogen distribution tests selected to assess the ability of GOTHIC to accurately predict **transport of noncondensing gases,** and as such appropriate for the current ESBWR RB application.

[[

]] (See Note 1)

[[

]](See Note 1)

Figure 3.3 Room Configurations for BFMC Test 6 (Reference 4)

[[

]]

A single-volume, subdivided using a two-dimensional rectangular grid, shown in Figure 3.4, was used in GOTHIC modeling of Test 6. A two-dimensional nodalization, instead of three-dimensional, is acceptable for Test 6 since the test was axisymmetric. [[

]] (See Note 1).

[[

]] (See Note 1)

Figure 3.4 GOTHIC Model for BFMC Test 6 (Reference 4)

Figures 3.5 and 3.6 compare GOTHIC predictions to measured hydrogen concentrations (through hydrogen partial pressure ratio) for BFMC Test 6. The continuous lines are GOTHIC predictions, whereas the discrete markers (x or ·) are the experimental data.

[[

]] (See Note 1).

Overall, GOTHIC prediction of hydrogen or non-condensing gas distribution in initially air-filled Rooms 1 and 2 at different temperatures is quite good for BFMC Test 6. This validates the diffusion models incorporated in GOTHIC. For further details, please refer to Chapter 11 of Reference 4.

[[

]] (See Note 1)

Figure 3.5 GOTHIC Comparisons of Hydrogen Concentrations through Pressure Ratios in Room R1 of BFMC Test 6 (Reference 4)

[[

]] (See Note 1)

Figure 3.6 GOTHIC Comparisons of Hydrogen Concentrations through Pressure Ratios in Room R2 of BFMC Test 6 (Reference 4)

3.3 BFMC Tests 12 and 20

In addition to the BFMC Test 6 discussed in Section 3.2 above, BFMC Tests 12 and 20 were also selected to assess the ability of GOTHIC to accurately predict transport of noncondensing gases in the initially air-filled containment. Figure 3.7 shows the room configurations used for these tests, which include all inter-connected rooms of the BFMC test facility. [[

]]

(See Note 1).

[[

]] (See Note 1)

Figure 3.7 Room Configurations for BFMC Tests 10 through 23 (Reference 4)

[[

]] Therefore, the models and the results of Tests 12 and 20 are discussed separately.

3.3.1 GOTHIC Model and Results for BFMC Test 12

[[

]] (See Note 1).

[[

]] (See Note 1)

Figure 3.8 GOTHIC Model for BFMC Test 12 (Reference 4)

Figures 3.9 through 3.12 compare GOTHIC predictions to measured hydrogen concentrations through hydrogen pressure ratio for BFMC Test 12. Each available hydrogen concentration data plot includes data for several sensors. In general, the GOTHIC predictions agree very well with the data. [[

]] The test validates the natural convection and diffusion models incorporated in GOTHIC. For further details, please refer to Chapter 12 of Reference 4.

[[

]] (See Note 1)

Figure 3.9 GOTHIC Comparisons of Hydrogen Concentrations in Room R1 of BFMC Test 12 (Reference 4)

[[

]] (See Note 1)

Figure 3.10 GOTHIC Comparisons of Hydrogen Concentrations in Room R2 of BFMC Test 12 (Reference 4)

[[

]] (See Note 1)

Figure 3.11 GOTHIC Comparisons of Hydrogen Concentrations in Rooms R5 and R6 of BFMC Test 12 (Reference 4)

[[

]] (See Note 1)

Figure 3.12 GOTHIC Comparisons of Hydrogen Concentrations in Rooms R7 and R8 of BFMC Test 12 (Reference 4)

3.3.2 GOTHIC Model and Results for BFMC Test 20

The GOTHIC model for Test 20 was developed from a copy of the model for Test 12. The control volumes are unchanged from Figure 3.8. The only physical difference for Test 20 is that the boundary condition, i.e., hydrogen/nitrogen gas source is connected to R6, which represents a non-symmetric geometrical configuration with respect to the gas source. [[

]]

[[

]] (See Note 1)

Figure 3.13 Computational Grid and Junctions of GOTHIC Model for BFMC Test 20 (Reference 4)

Figures 3.14 through 3.16 compare GOTHIC predictions to measured hydrogen concentration (through hydrogen pressure ratio) in various rooms for BFMC Test 20. Excluding results for R6, the room into which hydrogen is injected, the GOTHIC model does a reasonably good job of predicting the hydrogen concentrations in various rooms. This validates GOTHIC models for diffusion, convection, etc. for non-symmetric injection location. [[

]] For further details, please refer to Chapter 12 of Reference 4.

[[

]] (See Note 1)

Figure 3.14 GOTHIC Comparisons of Hydrogen Concentrations in Rooms R1 and R2 of BFMC Test 20 (Reference 4)

[[

]] (See Note 1)

Figure 3.15 GOTHIC Comparisons of Hydrogen Concentrations in Rooms R5 and R6 of BFMC Test 20 (Reference 4)

[[

]] (See Note 1)

Figure 3.16 GOTHIC Comparisons of Hydrogen Concentrations in Rooms R7 and R8 of BFMC Test 20 (Reference 4)

4. Conclusions

Comparison of GOTHIC predictions of non-condensing gas (hydrogen) dispersions with the test data (Tests 6, 12 and 20) for initially air-filled interconnected rooms of the BFMC test facility is quite impressive. These also validate GOTHIC models for diffusion, convection and transport delay for (a) isothermal and non-isothermal walls, (b) symmetric and non-symmetric gas (hydrogen) injection location and (c) short and long durations.

The current application of using GOTHIC to determine dilution of ESBWR containment leakage (modeled as nitrogen tracer gas) in the initially air-filled Reactor Building (RB) is similar, in many ways, to the GOTHIC validation models of BFMC Tests 6, 12 and 20, discussed in Section 3. Nodalization of ESBWR Reactor Building (Figure 2.1) and BFMC (particularly, Figures 3.8 and 3.13) utilizes several large control volumes (or rooms) connected by flow paths with various restrictions or openings. In both cases, the larger rooms are further divided into smaller or subdivided volumes with internal communication. In both cases, transport of the injected gas (nitrogen for ESBWR RB and hydrogen/nitrogen for BFMC) in the initially air-filled system is caused by a combination of diffusion and convection. BFMC tests covered non-symmetric gas injection, non-isothermal walls, long durations, all of which are typical of the ESBWR RB application. Therefore, based on the good agreement between the GOTHIC predictions and the BFMC test data shown in Section 3, we can expect GOTHIC to provide reasonable best-estimate results for containment leakage dilution in the ESBWR Reactor Building.

References:

1. "GOTHIC Containment Analysis Package – Technical Manual," Version 7.2a(QA), NAI 8907-06 Rev 16, EPRI, Palo Alto, CA, January 2006.

2. "Reactor Building Gothic Mixing Model Calculation Report," EA Document No. 092-134-F-M-06000, May 2008. Enclosure 2 of GEH Letter MFN 08-630 dated August 14, 2008, to USNRC.

3. Pratt, C. et al., "ESBWR Containment Fission Product Removal Evaluation Model," NEDE-33279P, Revision 2, Class III, July 2008.

4. "GOTHIC Containment Analysis Package – Qualification Report," Version 7.2a(QA), NAI 8907-09 Rev 9, EPRI, Palo Alto, CA, January 2006.