FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT (TR) WCAP-16608-P, REVISION 0

"WESTINGHOUSE CONTAINMENT ANALYSIS METHODOLOGY"

INCLUDING APPENDIX A "GENERATION OF THERMAL HYDRAULIC INFORMATION FOR

CONTAINMENTS (GOTHIC) GENERIC BOILING WATER REACTOR (BWR) MARK I MODEL,"

AND APPENDIX B "BWR MASS AND ENERGY RELEASE INPUT

CALCULATION METHODOLOGY"

WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE)

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated August 15, 2006 (Reference 1), Westinghouse submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval TR WCAP-16608-P, Revision 0, "Westinghouse Containment Analysis Methodology". Included in the submittal are Appendix A to this TR, "Generation of Thermal Hydraulic Information for Containments (GOTHIC) Generic Boiling Water Reactor (BWR) Mark I Model," and Appendix B, "BWR Mass and Energy Release Input Calculation Methodology."

The NRC staff accepted this TR along with Appendices A and B for review by letter to Westinghouse dated January 4, 2007 (Reference 2). The NRC staff transmitted a Request for Additional Information (RAI) to Westinghouse by letter dated August 20, 2007 (Reference 3). Westinghouse responded in a letter dated December 18, 2007 (Reference 4).
On March 3, 2008, the NRC staff also requested Westinghouse to perform a GOTHIC sensitivity study as part of this review. Westinghouse provided the results of this sensitivity study in a letter dated April 11, 2008 (Reference 5). A Westinghouse letter dated July 16, 2008, resolved several issues raised during the review (Reference 6).

The TR describes Westinghouse methods for performing design-basis analyses with the GOTHIC computer code and a proposed new methodology for generating loss-of-coolant accident (LOCA) mass and energy input data for the containment response.

This safety evaluation (SE) contains Westinghouse proprietary information. The proprietary information is enclosed in brackets **[ ]**.

The introduction to TR WCAP-16608-P states that once approved, Westinghouse intends to use the TR methods for the following applications:

1. Pressurized water reactor (PWR) and BWR containment design analysis for peak pressure,
2. PWR and BWR containment design analysis for peak temperature,
3. PWR and BWR containment design analysis for peak containment liner temperature,
4. PWR and BWR minimum emergency core cooling system (ECCS) containment, backpressure analysis,
5. PWR containment analysis for peak sump temperature,
6. BWR containment analysis for peak suppression pool temperature,
7. PWR and BWR containment analysis for thermal-hydraulic input to ECCS pump available net positive suction head (NPSH) analysis,
8. BWR containment analysis for thermal hydraulic input to hydrodynamic loads analysis, and
9. PWR and BWR containment analysis for thermal hydraulic input to equipment qualification analysis.

Based on the information provided by Westinghouse in the August 15, 2006, submittal, this SE will address items 1, 2, 3, 4, 6, 7, 8 and 9 for BWR Mark I containments only. In response to RAI #2 dated December 18, 2007, Westinghouse agreed with this scope of review (Reference 4).

Item 8 deals with methods to predict thermal hydraulic conditions needed to determine the containment blowdown loads (i.e., drywell and wetwell pressures and temperatures). The suppression pool phenomena of pool swell and fallback, condensation oscillations, and chugging were not discussed in TR WCAP-16608-P and their modeling is not part of the NRC review and approval of this TR. In addition, TR WCAP-16608-P did not address subcompartment analysis and it is not considered further.

Standard Review Plan (SRP) Section 6.2.1.1.A (SRP Acceptance Criterion 2) discusses long-term containment calculations to demonstrate that the containment accident pressure following a LOCA has decreased by at least 50 percent within 24 hours. Table 2-1 of TR WCAP-16608-P states that Westinghouse **[ ]**

Westinghouse proposes to use the GOTHIC computer code to perform the containment analyses. GOTHIC is described in the GOTHIC manual as a state-of-the-art general purpose thermal hydraulics software package for the analysis of nuclear power plant containments and other confinement buildings. GOTHIC can model the containment response to a full spectrum of high energy line breaks. GOTHIC solves the conservation equations for mass, energy, and momentum for multi-component, multi-phase flow. Its principal element is the control volume which models a space within a building or subsystem that is occupied by fluid. GOTHIC noding allows a volume to be treated as a lumped parameter or as a one-, two-, or three-dimensional space. GOTHIC also contains models for equipment such as pumps, fans, heat exchangers, valves, and nozzles. The Westinghouse Mark I model uses lumped parameter modeling for all **[ ]** models in TR WCAP-16608-P.

Westinghouse states that although the containment models and methods described in TR WCAP-16608-P were developed using GOTHIC 7.2a, Westinghouse intends to use the future versions of GOTHIC for plant-specific containment analyses as they become available. Westinghouse clarified this position in its December 18, 2007, response to NRC staff RAI (Reference 4). This is discussed later in this SE.

GOTHIC 7.2a documentation consists of three volumes: the GOTHIC Technical Manual (Reference 7), the GOTHIC User Manual (Reference 8) and the GOTHIC Qualification Report (Reference 9). GOTHIC calculations have been compared with solutions to analytical problems and to experimental data relevant to containment modeling. In most cases, the comparisons are in agreement. Where the results deviate, the Qualification Report points this out and attempts to assign a reason.

The GOTHIC User Manual states that GOTHIC is intended to be a best-estimate containment analysis package. Thus, when conservative calculations are called for, as in licensing applications, the GOTHIC calculations are biased by using conservative input. The primary emphasis of the NRC staff review has been assessing the Westinghouse input assumptions.

2.0 REGULATORY EVALUATION

Westinghouse proposes to use GOTHIC for a wide variety of containment safety analyses as discussed in Section 1.0 of this SE. In addition, GOTHIC would be used, either alone or with other analytical methods, to demonstrate compliance with several regulations. These include the General Design Criteria (GDC) of Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50 and Appendix K to 10 CFR Part 50.

GDC 4, “Environmental and dynamic effects design bases,” requires that structures, systems, and components shall be designed to accommodate environmental conditions from various postulated events including LOCAs. GDC 4 also requires that these structures, systems, and components be designed to withstand dynamic effects including those from discharging fluids. Westinghouse intends to use GOTHIC to predict containment conditions for hydrodynamic loads analyses of BWR structures, systems, and components. GOTHIC will not be used to predict such phenomena as pool swell and fallback, condensation oscillation, and chugging.

GDC 16, “Containment design,” requires the containment design to be essentially leak tight and that the containment design conditions important to safety are not exceeded for as long as the postulated accident conditions require. Westinghouse proposes to use GOTHIC to, in part, provide this assurance.

GDC 38, “Containment heat removal,” requires that a system to remove heat from the containment must be provided. The safety function of the system shall rapidly reduce, consistent with the functioning of other systems, the containment pressure and temperature following any LOCA and it should maintain the pressure and temperature at acceptable levels. Westinghouse proposes to use GOTHIC, in part, to demonstrate compliance with GDC 38.

GDC 50, “Containment design basis,” requires the containment structure, penetrations, and heat removal system to accommodate a LOCA without exceeding the design leakage rate. Westinghouse proposes to use GOTHIC, in part, to demonstrate this.

10 CFR Appendix K, I.D.2, “containment pressure,” requires that the containment pressure used for evaluating the cooling effectiveness during reflood and spray cooling following a LOCA shall be calculated conservatively (i.e., minimized) for this purpose. Westinghouse intends to use GOTHIC for these calculations.

Westinghouse has referred to the American National Standards Institute (ANSI)/American Nuclear Society (ANS) 56.4-1983 (Reference 10) which provides guidance for containment transient analysis. Although this standard has not been endorsed by the NRC, its guidance is generally consistent with the NRC staff positions on this type of analysis. Table 2-1 of TR WCAP-16608-P, "ANSI/ANS 56.4-1983, Requirements for Containment Analysis," summarizes how Westinghouse proposes to comply with the guidance of this standard.

3.0 TECHNICAL EVALUATION

3.1 Scope of Review

TR WCAP-16608-P discusses both PWR and BWR analyses. However, Appendices A and B of TR WCAP-16608-P discuss, in detail, the modeling of the BWR Mark I containment. This review is limited to the proposed Westinghouse modeling of the BWR Mark I containment. In particular, the following aspects of Mark I containment analysis were reviewed and are discussed in this SE:

- BWR Mark I containment design analysis for peak pressure,
- BWR Mark I containment design analysis for peak temperature,
- BWR Mark I containment design analysis for peak liner temperature,
- BWR Mark I minimum ECCS containment backpressure analysis,
- BWR Mark I containment analysis for peak suppression pool temperature,
- BWR Mark I containment analysis for thermal-hydraulic input to ECCS pump available NPSH analysis,
- BWR Mark I containment analysis for thermal hydraulic input to hydrodynamic loads analysis, and
- BWR Mark I containment analysis for thermal hydraulic input to equipment qualification analysis.

Westinghouse stated that it does not intend to use the GOTHIC BWR Mark I containment model documented in TR WCAP-16608-P for subcompartment analysis.

SRP Section 6.2.1.1.A (SRP Acceptance Criterion 2) states that to satisfy the requirements of GDC 38, the containment pressure should be reduced to less than 50 percent of the peak calculated pressure for the design-basis LOCA within 24 hours after the postulated accident. Table 2-1 of TR WCAP-16608-P stated that Westinghouse **[**

] Table 1 provides a summary of the events covered by TR WCAP-16608-P and some of the significant assumptions and analysis methods used.

TABLE 1: SUMMARY OF TR WCAP-16608-P BWR MARK I CONTAINMENT POSTULATED ACCIDENTS

BWR Accident Parameter	Event Interval Analyzed (sec)	Short-term Mass and Energy Release Computer Code	Long –term Mass and Energy Release Computer Code	Decay heat Model and Uncertainty	Assumed Single Active Failure	Passive Heat Sinks Included	Drywell and Wetwell Spray credited
Double-ended recirculation suction line break (RSLB) peak pressure	[						
Hydrodynamic loads criteria-Double-ended RSLB							
Hydrodynamic loads criteria – Intermediate (IBA) LOCA							
Hydrodynamic loads criteria – Small LOCAs (SBA)							
RSLB Minimum ECCS Back-pressure (Compliance with 10 CFR 50.46)							
Minimum Available NPSH							
RSLB long term pressure and temperature							
Main steam line break (MSLB) peak pressure							
MSLB long term pressure and temperature							

TABLE 1 (continued): SUMMARY OF TR WCAP-16608-P BWR MARK I CONTAINMENT POSTULATED ACCIDENTS

BWR Accident Parameter	Event Interval Analyzed (sec)	Short-term Mass and Energy Release Computer Code	Long –term Mass and Energy Release Computer Code	Decay heat Model and Uncertainty	Assumed Single Active Failure	Passive Heat Sinks Included	Drywell and Wetwell Spray credited
Anticipated Transient without Scram (ATWS)							
Peak drywell temperature – Small LOCA (SBA)							]

3.2 Mark I Containment

A BWR Mark I containment consists of: (1) a drywell which encloses the reactor vessel, the reactor coolant system (RCS) and other branch connections to the RCS, (2) a toroid-shaped pressure suppression chamber (or wetwell) partially filled with a large volume of water (the suppression pool) which is the primary source of water for the ECCS low head pumps, (3) a vent system connecting the drywell atmosphere to the suppression pool, (4) containment isolation valves, (5) containment cooling systems, and (6) other equipment.

The Mark I ECCS typically consists of low pressure coolant injection (LPCI) pumps (which are also the residual heat removal (RHR) pumps) and low pressure core spray pumps which take suction from the suppression pool. In some BWRs, a toroid-shaped ECCS ring header circumscribing the suppression chamber is the primary source of water for the ECCS low head pumps.

A high pressure coolant injection pump provides injection flow when the vessel is at high pressure. An Automatic Depressurization System (ADS) depressurizes the reactor coolant system so as to allow injection with the low head ECCS.

3.3 The GOTHIC Code

GOTHIC is a general purpose software package for the calculation of nuclear power plant containment thermal hydraulic conditions. It is developed for the Electric Power Research Institute (EPRI) by Numerical Applications, Incorporated (NAI). GOTHIC is validated by comparison with a wide range of experimental data, both single effects data and data from integral experimental facilities. This validation is documented in the GOTHIC Qualification Report.

TR WCAP-16608-P proposes to use GOTHIC 7.2a. TR WCAP-16608-P states that although the containment models and methods described in TR WCAP-16608-P were developed using Version 7.2a, Westinghouse intends to use future versions of GOTHIC for plant-specific analyses as they become available. Westinghouse clarified this position in Reference 4.

Westinghouse stated, in Reference 4, that the use of newer GOTHIC versions is subject to the Westinghouse Quality Management System (QMS) which has been reviewed and approved by the NRC staff. In addition, Westinghouse states that:

> When updating GOTHIC versions, Westinghouse will use the 10 CFR 50.59 approach to changing “elements of a methodology” as defined in NEI 96-07, Revision 1, "Guidelines for 10 CFR 50.59 Evaluations," and endorsed by USNRC Regulatory Guide 1.187, “Guidance for Implementation of 10 CFR 50.59, Changes, Tests, and Experiments.” Prior to application of the new GOTHIC code version, the calculated results from an existing containment evaluation model (the benchmark) would be compared with the results from the same containment model using the new GOTHIC code version to identify differences caused by the change in code version. The new GOTHIC code version would be acceptable for the containment design basis analysis application if the calculated results are “essentially the same as, or more conservative than, either the previous revision of the same methodology or another methodology previously accepted by the NRC staff through issuance of an SER.” If either of these acceptance conditions is met, Westinghouse will document the results of the evaluation in accordance with the applicable procedure and the documentation would be retained for NRC staff review. If neither of these conditions is met, then NRC staff review and approval would be required prior to using the new GOTHIC coded version for a containment design analysis.

The NRC staff finds the Westinghouse approach to using a new version of GOTHIC to be acceptable.

GOTHIC is developed and maintained under NAI’s quality assurance (QA) program in compliance with 10 CFR Part 50, Appendix B. In Reference 4, Westinghouse states that its use of the GOTHIC code will comply with 10 CFR Part 50, Appendix B, and 10 CFR Part 21. In addition, Westinghouse states that:

> …computer software used in engineering applications is governed by procedures and processes established in accordance with the Westinghouse Quality Management Systems (QMS). These procedures are in compliance with, and address the requirements of, 10 CFR Part 50 Appendix B and 10 CFR Part 21. According to the Westinghouse procedures, GOTHIC 7.2a is external software obtained from a qualified vendor. Westinghouse software QA (quality assurance) procedures control the installation, configuration, control, notification, and resolution of errors for software obtained from qualified software vendors.

The EPRI periodically reports problems discovered with GOTHIC. Westinghouse states that Westinghouse uses QA procedures to address software error reports. Upon receiving a GOTHIC error notification, the Westinghouse “code-responsible” engineer forwards a copy to code users. Both the “code-responsible” engineer and other users determine whether previous analysis results are affected by the errors. If it is determined that an error could affect a licensing calculation, Westinghouse will notify the affected customer and a plan of action is developed.

The NRC staff finds the Westinghouse use of GOTHIC for BWR Mark I containment calculations acceptable with respect to QA since the licensing calculations are monitored by an NRC approved QA program.

10 CFR Appendix K, I.D.2, requires that the containment pressure used in calculations required by 10 CFR 50.46 should be a minimum value. In response to RAI question 1(b), Westinghouse stated that it is planning to submit a supplement to WCAP-16608-P to address this calculation. A July 16, 2008, letter revised this response. The methods described in TR WCAP-16608-P will now be used for this calculation and were evaluated as part of this review. Since these methods are used to demonstrate compliance with 10 CFR 50.46, they are part of the ECCS evaluation model.

Many of the GOTHIC models are relevant to the applications of GOTHIC such as discussed in TR WCAP-16608-P. These are discussed in this section.

Heat Transfer

GOTHIC offers several heat transfer options. The GOTHIC User Manual recommends the Direct Option for containment analysis and TR WCAP-16608-P uses this option to model heat transfer between the vapor and the dry portion of the torus wall and between the liquid and the wet portion of the torus wall. A SPLIT variable determines the fraction of the torus wall that is dry and the portion that is wet. The Direct Option is also used for modeling heat transfer between the containment atmosphere and the drywell shell. The SPLIT variable is used to account for any liquid in the drywell.

One of the GOTHIC condensation heat transfer model options is the diffusion layer model (DLM). GOTHIC offers several versions of the DLM. The version used in TR WCAP-16608-P complies with NRC staff guidance on acceptable GOTHIC heat transfer coefficient modeling for licensing calculations (Reference 11). However, a different version of the DLM is used in the GOTHIC Qualification Manual that provides comparisons of GOTHIC predictions with experimental data. The NRC staff requested that Westinghouse compare calculations of the sample problems presented in TR WCAP-16608-P using both the DLM previously approved by the NRC staff and the version used in the GOTHIC Qualification Manual (DLM-FM). Westinghouse provided a comparison of the two DLMs for two cases: (1) the recirculation suction line break peak pressure, and (2) the ECCS minimum backpressure (Reference 5). The comparison showed no significant difference between the two models. Therefore, with respect to heat transfer, the GOTHIC Qualification Manual results and conclusions are applicable to GOTHIC as used in TR WCAP-16608-P.

The GOTHIC User Manual recommends the Film Option for subdivided volumes and in cases where boiling occurs. TR WCAP-16608-P uses the Film Option **[**

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Surface to surface radiation heat transfer is not modeled for any of the BWR Mark I containment applications. The radiation heat transfer option between the vapor space and the thermal conductor surface is used. However, Westinghouse points out that because the temperatures of surfaces and vapor are close to each other for the BWR accident analysis considered in TR WCAP-16608-P, this is not a significant mode of heat transfer.

The characteristic length used in the heat transfer correlations is the cell hydraulic diameter. This is the GOTHIC default value and is acceptable. Studies done for an application of GOTHIC to a PWR found that raising or lowering the hydraulic diameter by as much as 40 percent did not impact the peak containment pressure or temperature (Reference 12).

The heat transfer modeling proposed by TR WCAP-16608-P is consistent with the recommendations of the GOTHIC User Manual and with previous NRC staff guidance on calculating condensation heat transfer coefficients using GOTHIC. The GOTHIC heat transfer modeling has been successfully benchmarked against a variety of experimental data. Therefore, the NRC staff finds that the heat transfer modeling of TR WCAP-16608-P for the BWR Mark I containment is acceptable.

Revaporization Fraction

The postulated small steam line break accident is capable of producing superheated conditions in a Mark I BWR containment.

In a scenario in which the containment atmosphere is superheated, a fraction of the condensate which forms on containment structures, the revaporization fraction, vaporizes from the surfaces. This fraction of condensate which is vaporized tends to reduce the vapor temperature to saturation. GOTHIC models this process as part of the condensation heat transfer models as the revaporization default option. This method was used for all of the validation cases in the GOTHIC Qualification Report. The revaporization fraction is obtained from the condensation heat transfer model (DLM with no mist). However, a user specified revaporization fraction can be specified. The NRC specifies a revaporization fraction of eight percent (Reference 13). When this option is selected in GOTHIC, the normal interfacial heat and associated mass transfer between the vapor and the liquid due to superheated vapor is set to zero.

Westinghouse proposes to use the GOTHIC default option for the revaporization fraction. Westinghouse points out that the revaporization fraction is not a constant but varies (decreases) as the steam becomes less superheated. Westinghouse references a previous study that showed that the peak pressure and temperature resulting from a MSLB in a PWR showed close agreement with those obtained using the eight percent revaporization fraction (Reference 14).

The NRC staff, therefore, finds the use of the GOTHIC default option for the revaporization fraction to be acceptable for BWR Mark I containment analysis.

Fog and Mist Modeling

Westinghouse states that the mist model will be used in containment calculations. The mist model creates mist in the containment vapor space when the atmosphere becomes supersaturated. The maximum mist density is set to default (1 gram/meter^3). Excess mist creates drops. The drop diameter is set to 200 microns. As a sensitivity study, Westinghouse turned off the mist model and found that:

> Neither the peak drywell pressure (calculated for the RSLB (recirculation suction line break) LOCA event) nor the peak drywell temperature (calculated for the SBA (small break accident) event) was significantly affected by turning off the mist model.

Westinghouse uses the GOTHIC default value of mist model drop size which is 200 microns. Westinghouse further states that:

> The 200 micron drop size is based on numerical experiments conducted by NAI, as stated in Section 8.8.9 of the GOTHIC technical manual. Mist drop diameter sensitivity cases were made using the RSLB peak pressure case. There was no change in calculated peak pressure when the mist drop diameter was increased or decreased by an order of magnitude. Therefore, the BWR conditions are not sensitive to the default assumption of a 200 micron mist droplet size.

Since the mist model models a physical phenomenon, and the calculation results are insensitive to the droplet size chosen, the NRC staff finds the use of the mist model acceptable.

Jet and Drop Breakup Model

The GOTHIC jet and drop breakup model is not used in the BWR Mark I containment model.
[ ]

Drop-Liquid Phase Conversion

GOTHIC models the creation and destruction of drops by several mechanisms including entrainment from films and pools, agglomeration, formation and release of drops from horizontal surfaces (dripping), gravitational settling (dropping through a stagnant atmosphere), and deposition.

For the short-term (peak pressure) calculations, **[ ]** This is conservative and, therefore, is acceptable.

Structural Heat Sinks

Structural heat sinks are represented by GOTHIC thermal conductors. These are described in GOTHIC Technical Manual Section 7. GOTHIC allows flexibility in modeling the thermal conductors.

TR WCAP-16608-P describes the conservatism included in the thermal conductor modeling.

> **[ ]**

Since the kind of heat sinks modeled and the number varies from case to case, the NRC staff approval of thermal conductor modeling will be done on a case-by-case basis.

Containment Spray

BWR Mark I containments typically have both drywell and wetwell spray systems. The RHR pumps supply water to the spray spargers. The spray is manually initiated. For the LOCA it is typically assumed that the operator initiates spray at 10 minutes after accident initiation. The time would be plant specific.

An important characteristic of the containment spray is the spray drop size. GOTHIC models spray drops with a single value of the diameter. The drop diameter used is the Sauter mean diameter or a conservative value. The NRC staff will review the use of plant specific information in containment spray modeling on a case-by-case specific basis.

Heat Exchangers

In a Mark I containment, the suppression pool is cooled by the RHR heat exchanger. This heat exchanger also cools the drywell and wetwell spray and the low head safety injection flow. The heat exchanger can be modeled by providing flows, heat transfer areas and material properties and dimensions. The heat exchanger can also be modeled by providing a value of UA (an overall heat transfer conductance for a given heat exchanger geometry).
TR WCAP-16608-P states that:

> The heat exchanger models used in the residual heat removal, recirculation spray, component cooling water and service water system models are benchmarked against available design data, operational data, and/or previous analysis to confirm that the systems are modeled appropriately and conservatively for the specific analysis being performed.

The NRC staff will review the heat exchanger models described above and used in the analysis, as appropriate, on a case-by-case basis.

Fan Coolers

BWR Mark I containment fan coolers are typically not safety related and do not perform a safety function during a postulated accident. However, in some postulated accident cases the fan coolers may continue to operate and they, therefore, may be modeled in the safety analysis where this is conservative.

TR WCAP-16608-P states that fan coolers may be modeled with a GOTHIC “cooler” model or as a coupled model of the containment fan and cooling coil unit using a heat exchanger model.

The NRC staff will review the fan cooler models described above and used in the analysis, as appropriate, on a case-by-case basis.

BWR Vent Modeling

Mass and energy released into the drywell of a Mark I containment by a postulated pipe break (or safety valve discharge in some older Mark I containment designs) is transferred to the suppression pool through a vent system consisting of vents, a vent header, and downcomers. This system is described in any Final Safety Analysis Report for an operating BWR with a Mark I containment.

The correct modeling of this vent system is important in determining the short-term pressures and pressurization rate in the drywell and wetwell.

As part of the review of TR WCAP-16608-P, the NRC staff performed independent calculations for comparison with those in TR WCAP-16608-P (Reference 15). The NRC staff used the NRC containment computer code CONTAIN 2.0 (Reference 16) and performed the calculations consistent with the CONTAIN BWR User Guide (Reference 17). In order to resolve differences between the NRC staff and TR WCAP-16608-P calculations, Westinghouse proposed several changes to vent modeling from those in the original TR in Reference 4.

While using typical values of vent system flow loss coefficients, the Westinghouse Mark I GOTHIC model predicted relatively low values of drywell pressure. Westinghouse determined that this was due to **[**

] To avoid this, Westinghouse determined that **[**
] as was done originally.

Westinghouse also proposed other changes to the vent system modeling. These included modeling the vent system flow as compressible. This resulted in a small increase in the pressure drop through the vent system. **[**

] (Reference 18).

These proposed changes produce a more conservative but also a more realistic calculation of the short-term drywell and wetwell pressures and are, therefore, acceptable.

Even with these changes, Westinghouse calculates peak pressures less than those calculated by CONTAIN 2.0 **[** **]**. Westinghouse included passive heat sinks in its calculations while the NRC staff did not. This would account for approximately **[** **]** in the peak pressure. This difference is acceptable based on evidence that CONTAIN 2.0 is conservative compared with other BWR licensing calculations (Reference 17).

<u>Interfacial Area</u>

GOTHIC models heat and mass transfer between the liquid and vapor phases. The interfacial area between the phases can be used to control how the heat and mass transfer occur. An infinite interfacial area simulates thermal equilibrium between the liquid and vapor while an interfacial area of zero simulates thermal non-equilibrium. TR WCAP-16608-P proposed assuming **[**

] This is based on sensitivity studies performed by Westinghouse (Reference 6). TR WCAP-16608P will be revised accordingly.

These calculations show that the **[**

] The NRC staff agrees.

[

] Therefore, using the [ ] interface area model is

acceptable for [
] pressure calculations.

Break Flow Flashing

Break flow leaves the high pressure reactor vessel and enters the containment atmosphere which is initially at a much lower pressure. A fraction of the break flow flashes to steam. The remainder of the liquid break flow is assumed to consist of [ ] drops. [

]

ANSI/ANS 56.4-1983 (Reference 10) guidelines state that flashing should be assumed at the transient atmosphere steam partial pressure. GOTHIC calculates the flashing based on the atmosphere total pressure. Flashing at the steam partial pressure results in a higher fraction of steam and, therefore, is conservative for peak pressure and temperature calculations. For the same reason, this is not conservative for cases in which the pressure is to be minimized (minimum ECCS backpressure). However, Westinghouse stated in Reference 4 that:

> The liquid break flow is released as small ([ ]) drops during blowdown. The surface area to mass ratio for these drops is very large. As a result, after flashing to the atmospheric total pressure, the drops quickly evaporate to the saturation temperature at the steam partial pressure. This is the same as recommended in the ANSI/ANS 56.4-1983 guideline.

Therefore, the difference between the two assumptions, flashing at total pressure and flashing at the steam partial pressure disappears in a short time. The NRC staff finds this explanation acceptable since it is based on physical behavior of the break flow.

The peak suppression pool temperature, which produces the limiting condition for ECCS pump available NPSH, occurs much later in time than the peak drywell pressure. Therefore, the break flow flashing model is not important in determining minimum available NPSH. The flashing model may have a nonconservative effect on the minimum containment pressure for LOCA calculations. However, since the model is reflecting the physical process and the minimum pressure calculation has other conservative aspects; it is also acceptable for this application.

3.4 Mass and Energy Calculations

The discharge of high energy fluid from the postulated pipe break causes the containment pressure and temperature to increase.

Section 5 of TR WCAP-16608-P discusses the calculation of the mass and energy release into the containment. Appendix B describes the Westinghouse calculation of mass and energy release for the BWR Mark I containment.

TR WCAP-16608-P references SRP Section 6.2.1.3 (Reference 19) as documenting acceptable practice for calculating LOCA mass and energy release. The NRC staff concurs. Table B-1 of Appendix B of TR WCAP-16608-P summarizes compliance with the guidance of this section of the SRP.

TR WCAP-16608-P also refers to ANSI/ANS 56.4-1983 for further guidance in calculating mass and energy release. The NRC has not endorsed this standard; however, this standard, in general, provides conservative guidance in calculating mass and energy release. Table B-2 of Appendix B of TR WCAP-16608-P summarizes compliance with the guidance of this standard. SRP Section 6.2.1.3 refers to 10 CFR Part 50, Appendix K, Paragraph I.A for the sources of energy which should be considered in these calculations. TR WCAP-16608-P uses this guidance.

SRP Section 6.2.1.3 and ANSI/ANS 56.4-1983 specify that analyses for containment integrity shall include a spectrum of accident sequences, break locations, break sizes, and power levels that ensure that the maximum or minimum pressure and the temperature are identified. Westinghouse states that this will be accomplished by **[ ]**

Westinghouse justified the use of **[ ]**

However, Westinghouse states that **[ ]**

This approach is acceptable based on NRC staff experience with previous reviews by other vendors and Westinghouse's statement that **[ ]**

Section 5.2 of TR WCAP-16608-P states that:

> Mass and energy releases from the reactor coolant system during the blowdown, refill, reflood phases of the accident will be provided to the containment model using an NRC approved evaluation model. These methods include:
>
> 1. Mass and energy release data that are calculated by Westinghouse using previously approved models and methods.
>
> 2. Mass and energy release data that are calculated by Westinghouse using an approved ECCS evaluation model with input parameters appropriately and conservatively biased for the specific containment analysis, as described in TR WCAP-16608-P Section 5 and Appendix B.

3. Mass and energy release data that are provided by the customer that are either calculated by the customer or another vendor using their approved models and methods.

The first and third options involve methods previously approved by the NRC. The second option is the subject of this evaluation.

The second option is the use of the previously approved Westinghouse BWR ECCS evaluation model. The Westinghouse ECCS code GOBLIN (Reference 20) is such a code. TR WCAP-16608-P proposes that the mass and energy release calculation using GOBLIN continue until a conservative release rate is established to transition the calculation to a GOTHIC calculated mass and energy release.

Section B.2 of Appendix B to TR WCAP-16608-P discusses input biasing of the GOBLIN ECCS evaluation model for calculating the mass and energy release associated with the peak containment pressure, peak containment temperature, and hydrodynamic loads. Eight conservative assumptions are discussed later in this SE. The NRC staff finds these assumptions acceptable. Section B.3 of Appendix B to TR WCAP-16608-P discusses input biasing of the GOBLIN ECCS evaluation model for calculating the minimum ECCS backpressure, peak suppression pool temperature and ECCS pump available NPSH. Section B.3 lists two conservative assumptions. Additional conservative assumptions were included in a Westinghouse RAI response (Reference 4). The conservative assumptions for biasing the GOBLIN model for minimum containment pressure are also acceptable.

Westinghouse also intends to analyze the containment response to the ATWS event. The BISON computer code (Reference 21) will calculate the mass and energy release for this calculation. (See discussion of the ATWS event below in this SE.)

3.4.1 Single Failure

The analyses described in TR WCAP-16608-P should include consideration of the single failure criterion in accordance with 10 CFR Part 50 Appendix A. In TR WCAP-16608-P as well as in response to an NRC staff RAI question, Westinghouse has confirmed this will be done. For example, Section 3.2.1 of TR WCAP-16608-P states that:

> A spectrum of system failures is considered to establish the worst single failure for the DBA (design basis accident) case.

In response to a NRC staff RAI question Westinghouse confirmed that for minimum available NPSH calculations the worst single failure will be determined on a case by case basis (Reference 4).

3.4.2 Break Flow

GOTHIC nozzle components, **[** **],** are used to model the release of liquid droplets. In the GOTHIC BWR Mark I containment model, the liquid break flow is assumed to be released **[**

]

The BWR mass and energy release model for peak containment pressure [

] This is conservative and acceptable.

3.4.3 Mass and Energy Release for the Peak Containment Pressure

The double-ended guillotine break of a recirculation suction line is typically the break which results in the peak containment pressure for a BWR Mark I containment. TR WCAP-16608-P refers to this case as the DBA case. TR WCAP-16608-P proposes to bias the GOBLIN mass and energy release calculation in a conservative way for containment DBA calculations. These calculations predict the containment peak pressure. The conservative assumptions listed in Section B.2 are the following:

1. [ ]
2. [ ]
3. [ ]
4. [ ]
5. [ ]
6. [ ]
7. [ ]
8. [ ]

The NRC staff finds these assumptions conservative and acceptable.

3.4.4 Mass and Energy Release for Minimum Backpressure for ECCS Calculations and Available NPSH Calculations

TR WCAP-16608-P describes the Westinghouse input biasing for minimum ECCS backpressure and minimum available NPSH calculations in Section B.3.

This biasing includes:

- **[**

  ]
- **[**

  ]

Westinghouse proposed two additional conservative assumptions in response to an NRC staff RAI question (Reference 4). These are:

- **[**
- **]** This is a revision of the Westinghouse position in response to RAI Question 31 in the December 18, 2007, Westinghouse letter.

[

]

After the reactor vessel has refilled, the cooler ECCS water spills from the broken recirculation pump suction line causing steam in the drywell to condense. Westinghouse models this process by assuming **[**

] The NRC staff agrees that this is conservative.

If containment conditions exceed those for containment spray actuation, the operator is assumed to align one of the LPCI pumps through the RHR heat exchanger to initiate drywell and wetwell spray. The operator is typically assumed to initiate spray at 600 seconds. The use of spray reduces the drywell and wetwell pressures which is conservative for the minimum available NPSH calculations.

In addition to these conservative assumptions, the containment analysis initial conditions are biased conservatively to yield a lower bound containment pressure as discussed below in this SE.

The NRC staff considers the mass and energy release calculations for minimum ECCS backpressure and minimum available NPSH to be sufficiently conservative and, therefore, acceptable.

3.4.5 Transition from GOBLIN to GOTHIC

[

] Section A.2.10 of TR WCAP-16608-P describes how this is done. (The GOBLIN recirculation suction line break and the main steam line break calculations are typically run for approximately **[**
] prior to the transition to GOTHIC.)

[

]

This is conservative for the peak pressure and temperature analyses, but non-conservative for the minimum ECCS backpressure and minimum NPSHa analyses. Westinghouse justifies this by **[**

] The NRC staff agrees, based on **[**

]

Therefore, the NRC staff finds the TR WCAP-16608-P method of transition from GOBLIN to GOTHIC to be acceptable.

3.4.6 Mass and Energy Release for the ATWS

Section A.4.8 of TR WCAP-16608-P discusses the modeling of the containment response to an ATWS event. The mass and energy release was calculated using the BISON computer code (Reference 21). However, TR WCAP-16608-P also states that "the GOTHC vessel model could have been used to calculate the mass and energy release through the safety relief valves with an appropriate transient core heat rate input from BISON or another approved BWR transient analysis code." The NRC staff will, therefore, assess the acceptability of the ATWS mass and energy release calculation on a case-by-case basis if a code different from BISON is used. BISON has been found acceptable for modeling the ATWS event (Reference 21).

The approval of BISON was accompanied by four limitations and restrictions documented in the October 16, 1995, NRC staff SE included in the approved BISON TR. These remain in effect when BISON is used for ATWS containment mass and energy release calculations.

[

] This is acceptable because at this time the core power consists of residual and decay heat.

3.5 Containment Analysis

TR WCAP-16608-P includes analyses to determine the following limiting conditions. (The section number in this SE input is also given.):

- 3.5.1 BWR Mark I containment design analysis for peak pressure,
- 3.5.2 BWR Mark I containment design analysis for peak liner temperature,
- 3.5.3 BWR Mark I minimum ECCS, containment backpressure analysis,
- 3.5.4 BWR Mark I containment analysis for peak suppression pool temperature and BWR Mark I containment analysis for thermal-hydraulic input to ECCS pump available NPSH analysis,
- 3.5.5 BWR Mark I containment analysis for thermal hydraulic input to hydrodynamic loads analysis, and
- 3.5.6 BWR Mark I containment analysis for thermal hydraulic input to equipment qualification analysis and containment design analysis for peak temperature.

In addition, there are certain non-design basis events, called special events, which must be considered. These are the ATWS event, the Appendix R Fire event and the Station Blackout event.

No single postulated event determines every limiting condition. For example, the event which yields the highest drywell pressure is not the event which yields the highest drywell temperature. Therefore, a variety of events are analyzed.

TR WCAP-16608-P modeled each of these events and benchmarked the results against an existing calculation performed with different analysis methods. In some cases not all the input values for the benchmark case were available to Westinghouse and values were inferred or recalculated by Westinghouse.

Table A.2.9-1 provided in response to RAI Question 18 (Reference 4) provides the initial conditions assumed for the analysis of the conditions listed above. It is reproduced, as follows:

Table A.2.9-1 Containment Model Input and Initial Conditions Biasing					
	Peak Drywell Pressure	ECCS Minimum Backpressure	Peak Suppression Pool Temp	Minimum Available NPSH	Peak Drywell Temp
DW Free Volume	[				
WW Free Volume					
Heat Sink Area					
Heat Transfer Correlation Multiplier					
Drywell Pressure					
Drywell Temp					
Drywell Humidity					
Wetwell Pressure					
Wetwell Temp					
Suppression Pool Temp					
Wetwell Water Volume					]

The NRC staff has reviewed this table and agrees that the assumptions made for the various cases are conservative.

3.5.1 BWR Mark I peak pressure analysis

Peak drywell pressure for a BWR Mark I containment is the result of a double-ended guillotine break of a recirculation suction line. Discharge of subcooled water followed by a two phase mixture of steam and water from the postulated break causes the drywell pressure to increase and the level of water in the downcomer to be depressed until the water initially in the downcomers is ejected into the suppression pool. A mixture of nitrogen (the containment atmosphere is inerted by using nitrogen gas), steam, and water is then forced through the downcomers into the suppression pool. The water is added to the suppression pool, the steam is condensed by the suppression pool, and the nitrogen from the drywell is added to the suppression chamber increasing the suppression chamber pressure and the pressure at the downcomer exit. The drywell pressure is determined by the downcomer exit pressure.

The short-term drywell temperature is calculated along with the peak drywell pressure. The peak drywell temperature is a result of the SBA discussed below.

Important assumptions in this calculation include the initial conditions, the flow of the nitrogen, steam and water through the downcomers, and the modeling of the vent flow path including the vents, ring header, and downcomers.

The biasing of the initial conditions is listed in Table A.2.9-1. The NRC staff concurs with the TR WCAP-16608-P biasing of initial conditions for calculating peak containment pressure since in each case the biasing will tend to increase the containment pressure.

At the request of the NRC staff, Westinghouse investigated a discrepancy in the modeling of the vent system. Values in tables in TR WCAP-16608-P and independent NRC staff calculations showed differences in assumed values of loss coefficients and calculated peak pressures, respectively, that could not be explained. Westinghouse revised the calculation method, correcting a deficiency and adding several conservative assumptions. This was discussed prior in this SE.

The calculation of the peak containment pressure as a result of a MSLB is also discussed in WCAP-16088-P. The peak containment pressure calculation for the MSLB considers only the first 10 minutes of the event. No operator action is assumed during this time. A modified GOBLIN ECCS model was used to calculate the mass and energy release. A loss of offsite power is assumed to occur. A worst single failure is assumed (typically failure of one train of emergency power). The same assumptions are made for the bias of the initial conditions for the main steam line break as are made for the recirculation suction line break. These are listed in Table A.2.9-1.

The location of the MSLB will be determined by the licensing basis for the plant being analyzed. The case calculated in TR WCAP-16608-P assumed the break is located between the flow restrictor and the MSIV.

The NRC staff finds the Westinghouse approach to calculating BWR Mark I peak pressure to be acceptable.

3.5.2 <u>BWR Mark I peak liner temperature analysis</u>

The initial conditions for the peak containment temperature are biased as shown in Table A.2.9-1. **[**

]

The heat transfer from the containment atmosphere to the containment liner is increased by multipliers on the heat transfer coefficients. Although the multipliers are not consistent with the heat transfer coefficients used (Reference 4), they produce a conservative liner temperature and are, therefore, acceptable. Westinghouse states that comparisons with test data (see Figure 5-41 in the GOTHIC Qualification Report) have shown the DLM correlation to be within approximately 20 percent of the measured value under both free and forced convection conditions. **[**

]. The NRC staff finds this acceptable.

3.5.3 <u>BWR Mark I minimum ECCS containment backpressure analysis</u>

The regulation of 10 CFR Part 50 Appendix K I.D.2 requires that the containment pressure used to evaluate cooling effectiveness during reflood and spray cooling shall not exceed a pressure calculated conservatively for this purpose. In this case a conservative calculation minimizes the calculated containment pressure.

The mass and energy input also must be biased to give a conservative value of minimum containment pressure. This is discussed prior in this SE.

Westinghouse proposes to use GOTHIC to calculate the containment pressure for application to the ECCS evaluation model. Westinghouse (correctly) points out that there is no regulatory guidance to determine the minimum ECCS backpressure for BWR containments. Westinghouse, therefore, applied the PWR guidance which is documented in the NRC SRP, Section 6.2.1.5 and Branch Technical Position CSB 6-1 (Reference 22). The initial conditions are biased as given in Table A.2.9-1 given previously. The NRC staff has evaluated the proposed biasing of Table A.2.9-1 and agrees that the biases will produce a minimum value of containment pressure.

Westinghouse confirmed that the effects of any non-safety-related equipment which would be in operation during an event for which minimum containment pressure is to be determined would be included if it makes the results more conservative (Reference 4). TR WCAP-16608-P also applies multipliers greater than 1.0 to the heat transfer from the containment atmosphere to the thermal conductors for the minimum containment pressure calculations. As discussed earlier, this is acceptable.

3.5.4 <u>Peak suppression pool temperature and minimum available NPSH analysis</u>

The two parameters, peak suppression pool temperature and minimum available NPSH, are related since the most conservative available NPSH conditions occur when the suppression pool temperature is maximized. The accident analyses of some BWR Mark I containments include crediting containment accident pressure in determining available NPSH. In this case, a minimum accident pressure is applied. A minimum containment accident pressure is also used to comply with the requirement of 10 CFR Part 50 Appendix K for a conservatively low pressure for the reflood and spray cooling portions of the design-basis LOCA analysis, as discussed above.

For available NPSH calculations the GOTHIC code calculates only the containment conditions: wetwell pressure, suppression pool water volume and suppression pool water temperature. The other necessary information, pump flow rates, flow losses and water elevation above the pump suction centerline will be obtained from other sources and the final calculation of available NPSH will be made outside the GOTHIC code and is outside the scope of TR WCAP-16608-P and this review. In particular, since GOTHIC does not account for the shape of the volume containing the water (e.g., the suppression pool), Westinghouse states that the water volume will be provided as input for the calculation of available NPSH (Reference 6).

BWR Mark I available NPSH calculations for the large-break LOCA event are typically divided into a short-term and a long-term period. The short term period is the first 10 minutes during which no operator action is credited. Due to the break, one train of low pressure coolant injection pumps injects into the broken recirculation line. These pumps are assumed to be operating at or near runout and the flow discharges through the break. At ten minutes, the operator takes action to switch a train of LPCI pumps to the RHR containment spray mode. This reduces the pressure in the drywell and wetwell which is conservative for NPSH calculations. Operation of the containment spray is assumed to continue until the end of the analysis. The analysis ends when “credit for containment accident pressure is no longer needed” (Reference 4).

As shown in Table A.2.9-1, reproduced in this SE, the same biases are used in determining both the minimum containment pressure for the design basis LOCA calculation and for the determination of available NPSH. The NRC staff reviewed these biases and finds them conservative and acceptable for both calculations since they tend to increase suppression pool temperature and reduce containment pressure.

Westinghouse studied the effect of thermal equilibrium between the suppression pool and the atmosphere above it. This was discussed prior in this SE. The conclusion is that the GOTHIC **[ ]** model for interfacial area is conservative and acceptable.

For the available NPSH calculation, containment leakage is included. TR WCAP-16608-P proposes to model containment leakage **[**

]. Many BWR technical specifications consider MSIV leakage separately. In this case, this leakage should also be included in the K/A^2 value.

3.5.5 <u>BWR Hydrodynamic Loads</u>

The acceptability of suppression pool dynamic loads for plants with Mark I containments is based on conformance with NRC acceptance criteria found in NUREG 0661 (Reference 23). These criteria derive from the basic requirements of GDC 4 regarding the dynamic effects associated with normal and accident conditions. NUREG-0661 and SRP Section 6.2.1.1.C (Reference 24) guidelines specify that the determination of dynamic loads should be based on appropriate analytical models and supported by applicable test data.

Based on the information provided by TR WCAP-16608-P, the scope of hydrodynamic loads analysis is limited to drywell and wetwell pressure and temperature calculations. Westinghouse has not attempted to demonstrate that GOTHIC may be used to predict pool swelling and fallback, condensation oscillation, or chugging. GOTHIC was also not demonstrated to predict local pool temperatures due to safety/relief valve discharge through quenchers into the suppression pool.

The intermediate break accident (IBA) is also analyzed, along with the large break, for hydrodynamic loads analysis. A liquid break of 0.1 ft^2 is assumed. The GOTHIC IBA model includes **[**

] The timing of operator actions and available equipment could be plant specific and will be reviewed on a plant specific basis. The input biasing is the same as for the large break case. The modeling of containment calculations for hydrodynamic loads in TR WCAP-16608-P is acceptable. The calculations are the same or similar to those for peak containment pressure.

3.5.6 <u>BWR Mark I containment analysis for thermal hydraulic input to equipment qualification analysis and containment design analysis for peak temperature</u>

The SBA is a small steam line break in the drywell. The small break results in superheated steam and, therefore, imposes the most severe temperature conditions on the drywell structures and on the safety equipment in the drywell. For larger steam line breaks, the superheat temperature is nearly the same as for small breaks, but the duration of the high temperature condition is less for the larger break since larger breaks depressurize faster.

The reactor is assumed to continue operation at full power until the suppression pool temperature reaches 120 °F. This is conservative since BWR technical specifications require a reactor trip at 110 °F and reactor vessel depressurization at 120 °F. The feedwater control system provides makeup for the lost inventory. The example analysis given in Section A.4.7 of TR WCAP-16608-P is a 0.05 ft^2 steam line break. The example models the reactor pressure vessel cooldown rate at the maximum technical specification allowed value of 100 °F/hour. Suppression pool cooling with the RHR system begins at 600 seconds. These assumptions are typical but an actual licensing calculation would depend on the plant specific scenario.

Westinghouse assumes **[**

]. The GOTHIC vessel model was used to calculate the mass and energy release for this event after the controlled cooldown begins. These assumptions are acceptable for this event since they lead to conservative results.

<u>ATWS</u>

The GOTHIC ATWS Mark I containment modeling is discussed in Section A.4.8 of TR WCAP-16608-P. The following are additional conservative modeling provisions specified for the ATWS event.

1. **[**

   ]

2. **[**

   ]

3. **[**

   ]

4. **[** **]**

5. **[**

   ]

The NRC staff finds the proposed modeling for the ATWS acceptable since acceptable computer analysis methods and conservative assumptions are used.

NPSH for Non-design Basis Events

Licensees for BWRs with Mark I containments must demonstrate that these containments can meet the regulatory requirements for certain events which are not included in the design basis. These events are sometimes referred to as special events. These are the Station Blackout, the ATWS, and the Appendix R Fire. Definitions of these events are provided in Sections 50.63, 50.62, and 50.48, respectively, of 10 CFR.

For each of these events adequate core cooling must be demonstrated by showing adequate available NPSH for those pumps used, including those taking suction from the suppression pool. Containment analyses of these events are part of the NPSH analyses.

The containment analyses for available NPSH will be done using GOTHIC. Westinghouse provided a list of biases and assumptions for these events used in determining the available NPSH of the ECCS pumps (Reference 4). This list also includes conservative assumptions included in the NPSH containment analyses for design basis events (such as a stuck open relief valve). For the special events, more realistic assumptions may be used. These assumptions may contain a degree of conservatism but they are not bounding to the extent of design basis analyses. For example, the single failure criterion is not applied to the special events. Westinghouse elaborated on this in a July 16, 2008, letter. Because of their importance, these assumptions are repeated here.

[

]

In addition to the listed assumptions which reduce the heat transfer rate of the RHR heat exchanger, other assumptions dealing with tube plugging and fouling are conservatively determined. These assumptions are plant specific and will be reviewed by the NRC staff for plant specific applications.

The use of GOTHIC for determining the available NPSH of ECCS pumps, with the above assumptions is acceptable.

4.0 LIMITATIONS AND CONDITIONS

The NRC staff did not perform a detailed review of the GOTHIC code itself. The scope of the review included the application of those models of particular interest to the proposed scope and the input assumptions and modeling of the BWR Mark I containment. These aspects are acceptable with the following comments.

Some BWR safety analyses are not in the scope of this review. These include aspects of the BWR hydrodynamic loads such as pool swell, vent thrust, condensation oscillation, chugging, and local pool temperature increase resulting from safety relief valve discharge through quenchers to the suppression pool. Subcompartment analyses are also not within the scope of this review.

Some aspects of the safety calculations will be reviewed on a plant specific basis. These are generally equipment models such as those for pumps, heat exchangers (e.g., tube plugging and fouling), containment spray and fan coolers. Thermal conductor modeling will also be reviewed on plant specific basis. The biases for the thermal conductors described in TR WCAP-16608-P for the events for which the containment pressure is maximized and minimized are acceptable. Other plant specific aspects include the timing and extent of operator actions, the break location and worst single failure assumptions.

The methods for calculating the mass and energy release are acceptable. The use of GOBLIN, the Westinghouse ECCS code, is acceptable for containment mass and energy release for both the maximum and minimum pressure calculations as described in TR WCAP-16608-P. The transition from GOBLIN to GOTHIC is acceptable as described in TR WCAP-16608-P for both the peak pressure and minimum pressure calculations. The acceptability of GOBLIN for minimum pressure calculations depends on the inclusion of the conservative assumptions given in TR WCAP-16608-P and the responses to NRC staff RAI Questions.

The NRC staff will assess the acceptability of the ATWS mass and energy release calculation on a case by case basis since TR WCAP-16608-P states that "either BISON or GOTHIC with an appropriate transient core heat up rate input from BISON or another approved BWR transient analysis code" could be used to calculate the mass and energy release through the safety and relief valves. The approval of BISON was accompanied by four limitations and restrictions documented in the October 16, 1995, NRC staff SE included in the approved BISON TR. These remain in effect when BISON is used for ATWS containment mass and energy release calculations.

The use of GOTHIC, as described in TR WCAP-16608-P and the letters to the NRC supplementing TR WCAP-16608-P, is acceptable for:

(1) the large recirculation suction line break, both the peak pressure and long term analyses,

(2) the intermediate and small breaks (IBA and SBA),

(3) the main steam line break,

(4) the minimum containment backpressure calculations as part of demonstrating compliance with 10 CFR 50.46,

(5) the containment response to the ATWS event, and

(6) the containment conditions used in calculating available NPSH for the special events, as described in the Westinghouse reply to a NRC staff request for additional information. These include: ATWS, Station Blackout and the Appendix R Fire.

ANSI/ANS 56.4-1983 specifies that analyses should be carried out for a sufficient time to demonstrate that the maximum pressure and temperature have been determined. The NRC staff also expects that if containment accident pressure is included in determining the available NPSH of the RHR and core spray pumps that the pressure calculations are carried out until the time when containment accident pressure is no longer needed.

5.0 CONCLUSION

TR WCAP-16608-P proposes using the GOTHIC containment thermal-hydraulic analysis computer code for containment safety analyses. WCAP-16608-P Appendices A and B, included in this review, describe proposed methods for performing the safety analyses for BWR Mark I containments and this review is limited to Mark I containment safety analyses.

With limitations and conditions listed in Section 4.0, TR WCAP-16608-P may be referenced for BWR Mark I containment safety analyses.

6.0 REFERENCES

1. Westinghouse Electric Company, letter to the U.S. Nuclear Regulatory Commission (NRC), “Submittal of TR WCAP-16608-P, ‘Westinghouse Containment Analysis Methodology.’" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML062430594).

2. S. L. Rosenberg, U.S. NRC, letter to J. A. Gresham (Westinghouse), “Acceptance for Review of Westinghouse TR WCAP-16608-P ‘Westinghouse Containment Methodology’ (TAC No. MD2953),” January 4, 2007 (ADAMS Accession No. ML063530632).

3. J. H. Thompson, U.S. NRC, letter to J. A. Gresham (Westinghouse), “Request for Additional Information RE: Westinghouse Electric Company TR WCAP-16608-P, Revision 0, ‘Westinghouse Containment Analysis Methodology’ (TAC NO. MD2953),” August 20, 2007 (ADAMS Accession No. ML072180174).

4. J. A. Gresham, Westinghouse Electric Company, letter to the U.S. NRC, “Response to NRC’s Request for Additional Information by the Office of Nuclear Reactor Regulation for TR WCAP-16608, ‘Westinghouse Containment Analysis Methodology,’ (TAC No. MD2953) (Proprietary/Non-Proprietary),” December 18, 2007, LTR-NRC-07-64 (ADAMS Accession No. ML081410490).

5. J. A. Gresham, Westinghouse Electric Company, letter to the U.S. NRC “Response to NRC's Request for Sensitivity Studies Regarding Appendix A of TR WCAP-16608-P, ‘Westinghouse Containment Analysis Methodology’ (TAC No. MD2953) (Non-proprietary),” April 11, 2008, LTR-NRC-08-19, (ADAMS Accession No. ML081190093).

6. J. A. Gresham, Westinghouse Electric Company, letter to U.S. NRC, “Response to NRC Questions on WCAP-16608-P, ‘Westinghouse Containment Analysis Methodology,’ (TAC No. MD2953) (Proprietary/Non-Proprietary),” July 16, 2008, LTR-NRC-08-35 (ADAMS Accession No. ML082030132).

7. GOTHIC Containment Analysis Package Technical Manual, Version 7.2a, NAI 8907-06 Rev 16, Numerical Applications, Inc., January 2006.

8. GOTHIC Containment Analysis Package User Manual, Version 7.2a, NAI 8907-02 Rev 17, Numerical Applications, Inc., January 2006.

9. GOTHIC Containment Analysis Package Qualification Report, Version 7.2a, NAI 8907-09 Rev 9, Numerical Applications, Inc., January 2006.

10. ANSI/ANS-56.4-1983, "Pressure and Temperature Transient Analysis for Light Water Reactor Containments," American Nuclear Society.

11. A. C. McMurtray, U.S. Nuclear Regulatory Commission, letter to Thomas Coutu, Nuclear Management Company, LLC, "Kewaunee Nuclear Power Plant – Issuance of Amendment (TAC No. 6408)," September 29, 2003 (ADAMS Accession No. ML032681050).

12. D. J. Banister, Omaha Public Power District (OPPD), letter to the U.S. NRC, "Fort Calhoun Station (FCS) Unit No. I License Amendment Request, 'Containment Pressure Analysis using the GOTHIC Computer Code,'" January 27, 2003 (ADAMS Accession No. ML030360205).

13. A. J. Szukiewicz, Task Manager, Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment, Resolution of Generic technical Activity A-24, USNRC, NUREG-0588, revision 1, July 1981.

14. T. Coutu, Kewaunee Nuclear Power Plant, letter to the U.S. NRC, "Response to Request for Additional Information Related to Nuclear Management Company (NMC) Request for the Use of GOTHIC 7 for the Kewaunee Nuclear Power Plant Containment Design Basis Accident Analyses," July 24, 2003 (ADAMS Accession No. ML032170646).

15. R. Lewis, Acting Deputy Director, Division of risk Assessment and Special Projects, Office of Nuclear Regulatory Research, Memorandum to Jared S. Wermiel, Deputy Director, Division of Safety Systems, Office of Nuclear Reactor Regulation, "Technical Assistance Related to Auditing BWR Mark I Short-Term Analysis for Review of TR WCAP-16608-P Entitled Westinghouse Containment Analysis Methodology," June 13, 2007 (ADAMS Accession No. ML071630373).

16. A Code Manual for CONTAIN 2.0: A Computer Code for Nuclear Reactor Containment Analysis, K. K. Murata, et al., Sandia National Laboratories, NUREG/CR 6533, December 1997.

17. K. K. Murata, et al., "CONTAIN Code Qualification Report/User Guide for Auditing Design Basis BWR Calculations," Office of Nuclear Regulatory Research, SMSAB-03-02, March 2003 (ADAMS Accession No. ML030700335).

18. The General Electric Pressure Suppression Containment Analytical Model, NEDO-10320 Supplement 1, Section 3.2, May 1971.

19. J. A. Gresham, Westinghouse Electric Company, letter to the U.S. NRC, "Response to NRC Questions on WCAP-16608-P, 'Westinghouse Containment Analysis Methodology,' (TAC No. MD2953) (Proprietary/Non-Proprietary)," July 16, 2008, LTR-NRC-08-35 (ADAMS Accession No. ML082030132).

20. Section 6.2.1.3, Mass and Energy release Analysis for Postulated Loss-of-Coolant Accidents, "Revision 1, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," US Nuclear Regulatory Commission, March 2007.

21. TR WCAP-16608-P Appendix B lists 7 references which constitute the GOBLIN computer code.

22. BISON – A One Dimensional Dynamic Analysis Code for Boiling water Reactors: Supplement 1 to Code Description and Qualification, Combustion Engineering, CENPD-292-PA, Revision 0, July 1996.

23. Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Section 6.2.1.5, “Minimum Containment Pressure Analysis for Emergency Core Cooling System Performance Capability Studies.” Branch Technical Position CSB 6-1 has been renumbered and revised to CSB 6-2, “Minimum Containment Pressure Model for PWR ECCS Performance Evaluation,” March 2007, since TR WCAP-16608-P was issued. However, with respect to TR WCAP-16608-P CSB 6-2 is equivalent to the earlier CSB 6-1.

24. Safety Evaluation Report Mark I Containment Long Term Program Resolution of Generic Technical Activity A-7, US NRC, NUREG 0661, July 1980.

25. Section 6.2.1.1.C, Pressure Suppression Type BWR Containments, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” US Nuclear Regulatory Commission, March 2007.

Attachment: Resolution of Comments

Principal Contributor: R Lobel

Date: January 27, 2009

RESOLUTION OF COMMENTS ON DRAFT SAFETY EVALUATION FOR

WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE)

TOPICAL REPORT (TR) WCAP-16608-P, REVISION 0

"WESTINGHOUSE CONTAINMENT ANALYSIS METHODOLOGY"

PROJECT NO. 700

By letter dated August 15, 2006, Westinghouse submitted to the U.S. Nuclear Regulatory Commission (NRC) Topical Report (TR) 16608-P, Revision 0, entitled "Westinghouse Containment Analysis Methodology," for review and approval. This Attachment provides the NRC staff's review and disposition of the comments made by Westinghouse in its November 17, 2008, letter. Editorial changes suggested by Westinghouse are noted in bold. Westinghouse proprietary information is noted within brackets **[ ]**.

1. Westinghouse Comment:
As suggested in the discussion on October 31, Westinghouse will respond to items identified as being needed on a case-by-case basis as specified in the safety evaluation (SE) by providing plant specific information as part of the license amendment request.

NRC Resolution for Comment 1 on the draft SE:

The NRC staff agrees with this comment. Certain items such as models for plant equipment (heat exchangers, pumps, fans, etc.) vary from plant to plant. GOTHIC also has the capability to model these components in more than one way. Therefore, it is necessary that the modeling of these components be specified in plant specific documents for NRC staff review.

2. Westinghouse Comment:
The following changes are suggested for the last sentence on page 10.

"The NRC staff will approve the use of plant specific information in containment spray modeling on a case-by-case specific basis."

NRC Resolution for Comment 2 on the draft SE:

The NRC staff agrees with this comment. The suggested change makes it clear that the information is specific to the plant being analyzed. The word approve will be replaced by the word review, which is more appropriate.

3. Westinghouse Comment:
The following changes are suggested for the last line in the section, Heat Exchangers, on page 11:

"The NRC staff will review ~~the~~ **which type of** heat exchanger model**s described above is used in the analysis,** as appropriate, on a cases-by-case basis."

NRC Resolution for Comment 3 on the draft SE:

The NRC staff disagrees with the proposed wording. The NRC staff may review not just the type of heat exchanger model but also the model itself. The NRC staff revised the SE to state:

"The NRC staff will review the heat exchanger models described above and used in the analysis, as appropriate, on a cases-by-case basis."

4. Westinghouse Comment:
The following changes are suggested for the last line in the section on Fan Coolers on page 11:

"The NRC staff will review ~~the~~ **which type of** fan cooler model**s described above is used in the analysis,** as appropriate, on a case-by-case basis."

NRC Resolution for Comment 4 on the draft SE:

The NRC staff disagrees with the proposed wording. The NRC staff may review not just the type of fan cooler model but also the model itself. The NRC staff revised the SE to state:

"The NRC staff will review the fan cooler models described above and used in the analysis, as appropriate, on a cases-by-case basis."

5. Westinghouse Comment:
It is suggested that the NRC consider removing the second paragraph from page 15, as that paragraph is repeated at the bottom of page 27 where the context better facilitates interpretation.

NRC Resolution for Comment 5 on the draft SE:

The NRC staff agrees.

6. Westinghouse Comment:
The following changes are suggested for the last paragraph on page 27:

"The NRC staff also expects that if the containment accident pressure is included in determining the available NPSH of the RHR and core spray pumps that ~~these~~ **the pressure** calculations are carried out until the time when the containment accident pressure is no longer needed."

NRC Resolution for Comment 6 on the draft SE:

The NRC staff agrees.

7. Westinghouse Comment:
The following changes are suggested for the sixth line in table A.2.9-1:

Heat Transfer Correlation multiplier	**[**				**]**

NRC Resolution for Comment 7 on the draft SE:

The NRC staff agrees with the proposed changes to the second and fourth columns (ECCS minimum backpressure and minimum available NPSH). As discussed in the NRC staff SE, the multipliers are not consistent with the heat transfer coefficients used but they produce conservative results. The **[ ]** multiplier, however, is more conservative than necessary since the uncertainty in the heat transfer correlations used is within **[ ]** percent. Therefore, the NRC staff agrees with these changes.

The last column contains the assumptions for the peak drywell temperature. The event which results in the peak drywell temperature is the small steam line break as discussed in Section 3.5.6 of the draft SE. The suggestion by Westinghouse would not be conservative for the peak drywell temperature and therefore this entry in the table should remain unchanged. Section 3.5.2 of the draft SER states that for liner temperature calculations, a multiplier on the heat transfer correlation of **[ ]** is used.

8. Westinghouse Comment:
Westinghouse requests that the following text on page 21 in section 3.5.2 be marked as proprietary, or otherwise eliminated from the text:

[

]

NRC Resolution for Comment 8 on the draft SE:

The NRC staff agrees that the text is proprietary; therefore, the text has been marked appropriately.

9. Westinghouse Comment:
Westinghouse requests that the following text on page 12 in lines 16-20 be marked proprietary, or otherwise eliminated from the text:

"Even with these changes, Westinghouse calculates peak pressures less than calculated by CONTAIN 2.0 **[ ]** Westinghouse included passive heat sinks in its calculations while the NRC staff did not. This would account for approximately **[ ]** in the peak pressure."

NRC Resolution for Comment 9 on the draft SE:

The NRC staff agrees that the text is proprietary; therefore, the text has been marked appropriately.

10. Westinghouse Comment:
Westinghouse requests that text containing the phrase **[ ]** drops on page 13 in Break Flow Flashing and anywhere else that information may be contained be marked proprietary or otherwise eliminated from the text:

NRC Resolution for Comment 10 on the draft SE:

The NRC staff agrees that the text is proprietary; therefore, the text has been marked appropriately.