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# Application of Conservatively Calculated Containment Backpressure to BWR ECCS Evaluation Model Analyses

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# ACRONYMS

| | |
|---|---|
| 10CFR50 | Code of Federal Regulations Title 10 Part 50 |
| ANS | American Nuclear Society |
| AOR | Analysis of Record |
| BWR | Boiling Water Reactor |
| DBA | Design Basis Analysis |
| DLM | Diffusion Layer Model |
| DW | Drywell |
| ECCS | Emergency Core Cooling System |
| EPRI | Electronic Power Research Institute |
| EPU | Extended Power Uprate |
| GE | General Electric |
| GOTHIC | Generation of Thermal-Hydraulic Information for Containments |
| HDR | Heissdampfreaktor |
| HEDL | Hanford Engineering Development Laboratory |
| HPCI | High Pressure Coolant Injection |
| HWL | High Water Level |
| IBA | Intermediate Break Accident |
| LACE | LWR Aerosol Containment Experiments |
| LOCA | Loss of Coolant Accident |
| LOOP | Loss of Offsite Power |
| LPCI | Low Pressure Coolant Injection |
| LPCS | Low Pressure Core Spray |
| LWL | Low Water Level |
| LWR | Light Water Reactor |
| M&E | Mass & Energy |
| MAPLHGR | Maximum Average Planar Linear Heat Generation Rate |
| NAI | Numerical Applications Incorporated |
| NPSH | Net Positive Suction Head |
| NPSHa | Net Positive Suction Head Available |
| NRC | Nuclear Regulatory Commission |
| PCT | Peak Cladding Temperature |
| RSLB | Recirculation Suction Leg Break |
| SER | Safety Evaluation Report |
| U.S. | United States |

# 1 INTRODUCTION AND BACKGROUND

The purpose of this report is to provide the basis for applying a non-atmospheric, but conservative, containment backpressure in the Westinghouse BWR Emergency Core Cooling System (ECCS) Evaluation Model application to the Quad Cities and Dresden units.

The Westinghouse BWR ECCS Evaluation Model was originally approved by the Nuclear Regulatory Commission (NRC) in 1987 and is described in RPB-90-93-P-A and RPB-90-94-P-A (Reference 1). This methodology was first revised in 1996 to extend its application to SVEA-96 fuel, which is described in CENPD-283-P-A and CENPD-293-P-A (Reference 2). Another revision was made to the methodology in 2003, primarily to improve the fuel rod cladding rupture model, which is described in WCAP-15682-P-A (Reference 3). A subsequent revision was made in 2004 to extend its application to SVEA-96 Optima 2 fuel, which is described in WCAP-16078-P-A (Reference 4).

The methodology is an *Appendix K* methodology (as opposed to being a *best-estimate* methodology). Consistent with 10CFR50 Appendix K, it employs conservative assumptions to ensure that the peak cladding temperature (PCT) calculated by the methodology bounds the probable values for LOCA events. Among these imposed conservative assumptions are:

- 1.02 times the licensed power
- ANS 1971 decay heat plus 20%
- Metal-water reaction using Baker-Just equation
- Moody break flow
- Consideration of most limiting single failure
- Conservative containment pressure (atmospheric pressure)
- Zero heat transfer from the uncovered fuel until rated core spray flow is established
- Prescribed spray and reflood heat transfer coefficients

In addition to these Appendix K conservatisms, Loss of Offsite Power (LOOP) concurrent with LOCA is assumed, consistent with Appendix A criterion 35. All of these conservative assumptions result in hundreds of degrees Fahrenheit peak cladding temperature increase in the calculated results, relative to a calculation performed with realistic models and assumptions. The intent of the Appendix K requirements is to ensure safe operation by imposing conservatism to bound all uncertainties. Although some of these conservatisms are mandated by the Appendix K regulations, others were assumed solely to simplify the analysis. However, to remain under the regulatory limit, under certain conditions, plant operation and core design may be overly penalized by an overly conservative LOCA analysis. To remedy this unintended adverse outcome a conservatively calculated non-atmospheric containment pressure, consistent with Requirement D.2 of Appendix K to 10CFR50, is considered herein.

The current methodology, as described in the aforementioned topical reports, uses atmospheric pressure boundary condition for containment. This conservative assumption is a simplification meeting the 10CFR50 Appendix K requirements. However, it is not a requirement of the Safety Evaluation Report (SER) and there are no restrictions placed on this aspect of the methodology. The only discussion in the SER pertaining to the containment pressure is the following wording, which is merely a confirmation of how the requirement is met (Reference 1):

> *"Containment Pressure – GOBLIN analyses will conservatively assume atmospheric pressure in the containment volume throughout the LOCA transient. This assumption adequately addresses the requirements for this feature of Appendix K."*

Regarding the containment pressure, 10CFR50 Appendix K states the following under the 'Required and Acceptable Features of Evaluation Models' Section, requirement D.2:

> *"The containment pressure used for evaluating cooling effectiveness during reflood and spray cooling shall not exceed a pressure calculated conservatively for this purpose. The calculation shall include the effects of operation of all installed pressure-reducing systems and processes."*

This report documents the application of non-atmospheric pressure boundary condition for containment as an input to ECCS evaluation calculations. The report has primarily two parts: (1) explanation of how the conservative containment backpressure is calculated and (2) discussion of the impact of the change in pressure boundary condition on the most limiting LOCA calculations.

Westinghouse plans to revise the LOCA calculations for Quad Cities 1 & 2 and Dresden 2 & 3 units to credit any gain in operational margin by application of a conservatively calculated containment backpressure.

The most limiting break from the break spectrum analysis of Quad Cities and Dresden (Reference 6) is the 100% double-ended guillotine recirculation suction line break (RSLB) with the failure of the Low Pressure Coolant Injection (LPCI) system injection valve in the selected loop to open. The case is characterized with the blowdown of coolant into the drywell (DW) causing a rapid depressurization of the reactor vessel. The high DW pressure signal trips the reactor and provides an ECCS actuation signal. Transition boiling and uncovery at the midplane of the core occurs typically within the first 20 seconds. The low reactor pressure signal clears the ECCS permissive, which allows the low pressure ECCS injection valves to open. BWR/3's are equipped with a loop select logic whose primary function is to divert the LPCI to the intact loop. With the single failure of the LPCI injection valve, the only available ECCS component benefiting heat removal is the Low Pressure Core Spray (LPCS) system. Per Appendix K requirements, until the rated core spray flow conditions are reached, no heat transfer from the rods to the coolant is considered (neglecting the steam cooling effect, a physical phenomena). Once the rated core spray flow conditions are reached in the core, conservatively low spray cooling heat transfer coefficients are assumed. During this period, rod heat-up continues until the core spray water can restore two-phase conditions at the peak power point in the hot assembly. When the two-phase conditions are restored, the cladding temperature drops. That is the recovery point in the transient.

The benefit of an increased containment backpressure (over the atmospheric backpressure) is the increase in the ECCS injected flow rate which results in a faster recovery of system inventory after the break, and therefore results in a benefit to the peak cladding temperature analysis.

# 2 CONSERVATIVE BACKPRESSURE CALCULATION

In order to obtain a conservatively low containment backpressure, certain biases both in the Mass & Energy (M&E) release calculation and in the containment response calculation are employed. This is an iterative process where the M&E release output data from the biased model for the limiting break / single failure combination are input to a containment model that has been biased to calculate a low containment pressure. The M&E release data used as input to the containment response calculation is obtained from a calculation using GOBLIN, the code approved for LOCA ECCS performance calculations. To ensure that the containment pressure is not over predicted, biases are applied to the GOBLIN input data for that calculation. The containment response is then calculated using GOTHIC with a model biased to produce low containment pressure.

The Westinghouse methodology for calculating containment response (Reference 5), including minimum containment pressure for BWR ECCS calculations, is currently under review by the U.S. NRC. Until the methodology is approved, the application of the containment analysis code (GOTHIC) requires plant-specific benchmarking and a description of the biases that will be applied.

The containment minimum ECCS backpressure is calculated using the GOTHIC (Generation of Thermal-Hydraulic Information for Containments) code, version 7.2a. The benchmark cases for Quad Cities and Dresden model validation are also carried out using the same version. The GOTHIC code is becoming the industry standard for performing containment analyses, as well as analyses for auxiliary buildings outside containment. The code has been developed by Numerical Applications Incorporated (NAI) with funding by the Electric Power Research Institute (EPRI). The GOTHIC code consists of a pre-processor for input generation; a solver, which performs the calculations; and a post-processor, which produces output data tables and plots. The GOTHIC Technical Manual (Reference 7) provides a description of the governing equations, constitutive models, and solution methods in the solver. The GOTHIC Qualification Report (Reference 8) provides a comparison of the solver results with both analytical solutions and experimental data. The GOTHIC User Manual (Reference 9) provides information to help the user develop models for various applications.

## 2.1 GOTHIC CODE VALIDATION

The GOTHIC code has undergone extensive review and validation against an array of tests (Reference 8). The code has been validated against a number of Battelle-Frankfurt tests performed to study steam blowdowns and hydrogen releases. A number of Hanford Engineering Development Laboratory (HEDL) tests were modeled to simulate steam-hydrogen jets. The LACE (LWR Aerosol Containment Experiments) tests were modeled to validate rapid depressurization events with aerosols. Several of the Heissdampfreaktor (HDR) full scale containment tests were modeled to study steam and water blowdowns and hydrogen releases in a full-scale multi-compartment containment geometry.

GOTHIC transient results have been compared with results from other containment design analysis codes (COCO, CONTEMPT, CONTRANS, CONTAIN and COPATTA). The Westinghouse benchmark comparisons with COCO, CONTEMPT and CONTRANS results are presented in References 10 through 12. Differences between the GOTHIC results and the results from other codes are attributed to the ability of GOTHIC to better model droplet phase interface heat and mass transfer.

The containment analysis models and methods described in this report are not intended to be restricted to a specific GOTHIC code version. The code is being continuously maintained and updated by EPRI and NAI to include new features and/or correct problems. Therefore, although the containment models and methods described in this report were developed using GOTHIC version 7.2a, Westinghouse intends to use future versions of GOTHIC for plant specific containment analyses as they become available.

## 2.2 GOTHIC BWR MARK-I CONTAINMENT MODEL DESCRIPTION

The GOTHIC BWR Mark-I containment model was developed for Dresden and Quad Cities plants. The containment input data necessary to develop the GOTHIC model was obtained from the applicable plant specific data supporting the EPU analysis for the Dresden and Quad Cities plants. The model contains [ ]$^{a,c}$ control volumes as follows:

[

]$^{a,c}$

The control volume inputs, such as free volume, elevation, height, hydraulic diameter, etc., are determined from the most appropriate plant data. [

]$^{a,c}$

There are [ ]$^{a,c}$ flow paths in the model connecting the control volumes and the boundary conditions, as necessary to represent the Mark-I configuration. [ ]$^{a,c}$

The heat sinks in the drywell and the wetwell are represented by [ ]$^{a,c}$ thermal conductors in the model. The containment thermal conductor input data was taken from the EPU analysis for the Dresden and Quad Cities plants. [

]$^{a,c}$

[

]$^{a,c}$

The ECCS components are modeled and made available in the base deck. They are invoked depending on their availability for the given event with particular single failure assumption. The engineered features are also modeled representing the plant configuration. The containment spray is modeled [

]$^{a,c}$

The break mass and energy release data and ECCS flow rates are calculated externally with a plant specific GOBLIN model. [

]$^{a,c}$

## 2.3 GOTHIC BWR MARK-I CONTAINMENT MODEL QUALIFICATION

The GOTHIC BWR Mark-I containment model based on Quad Cities/Dresden was qualified using benchmark comparisons to plant-specific results from previously approved BWR containment models. Comparisons were made for a recirculation suction leg break (RSLB) transient (to compare the short-term containment blowdown response) and an intermediate break accident (IBA) transient (to compare the long-term containment response). These comparisons were used to calibrate the base model to ensure that proper model biases are applied in the case of minimum backpressure calculation. The results also demonstrate that the GOTHIC model is capable of calculating the important transient phenomena.

### 2.3.1 Recirculation Suction Leg Break Benchmark Comparison

The RSLB event typically results in the peak containment pressure and is the design basis accident (DBA) for many BWR containments. The RSLB event assumes a double ended guillotine break in the pump suction leg of one of the two recirculation lines. The reactor vessel blowdown occurs through the pump suction leg on the vessel side and through the jet pump nozzles reversing the flow in the pump discharge leg on the pump side of the break.

The benchmark for this comparison is a GE M3CPT analysis for Dresden (Reference 14, Figures 6.2-31 and 6.2-33). In the absence of available the benchmark mass and energy release input data, a simplified vessel model was added to the GOTHIC model to calculate the blowdown mass and energy release along with the containment response.

The GOTHIC RSLB peak pressure benchmark model used to generate the output for comparison with the benchmark case results is based on data from the Dresden and Quad Cities containments. A comparison of the key containment input values used in the RSLB peak pressure benchmark model versus the values biased for ECCS backpressure calculation is shown in Table 2.3-1. [

]$^{a,c}$

[

]$^{a,c}$

The short-term RSLB peak pressure benchmark comparison results are shown in Figures 2.3-1 through 2.3-4. The GOTHIC response is shown as a solid line and the benchmark data points are shown with Δ in the figures. The GOTHIC RSLB benchmark model [

]$^{a,c}$

**Table 2.3-1 Comparison of Key Containment Model Input Values**

| Value | RSLB Benchmark Model | | Min Backpressure Model |
|---|---|---|---|
| Drywell Volume | | | |
| Torus Volume | | | |
| Vent Line/Header/Downcomer Volume | | | |
| Downcomer Flow Area | | | |
| Downcomer Loss Coefficient | | | |
| Downcomer Inlet Inertia Length | | | |
| Downcomer Exit Inertia Length | | | |
| Initial Torus Water Volume | | | |
| Initial Drywell Pressure | | | |
| Initial Wetwell Pressure | | | |
| Initial Drywell Temperature | | | |
| Initial Wetwell Temperature | | | |

a,c

Note: (1) Lower values are conservative for the minimum backpressure case.

a,c

Figure 2.3-1 Short-Term RSLB Drywell Pressure Comparison

a,c

Figure 2.3-2 Short-Term RSLB Wetwell Pressure Comparison

a,c

Figure 2.3-3 Short-Term RSLB Drywell Vapor Temperature Comparison

a,c

Figure 2.3-4 Short-Term RSLB Wetwell Vapor Temperature Comparison

### 2.3.2 Intermediate Break Accident Benchmark Comparison

The intermediate break accident (IBA) represents a liquid line break that is below the threshold where the loop selection logic can detect the broken recirculation loop (0.15 $ft^2$) and produces a break flow rate that is higher than the injection capability from a single HPCI pump. Typically, the break size is 0.1 $ft^2$ and it is assumed to be located in the recirculation suction line. The benchmark for this case was a GE SHEX analysis (Reference 14, Figures 6.2-35 and 6.2-36).

The GOTHIC IBA benchmark comparison model is similar to the model which was used for the short-term RSLB benchmark comparison; it also employs a simplified vessel component to generate M&E releases. [

]$^{a,c}$ A comparison of the key containment model input parameters from the GOTHIC IBA benchmark model with the plant specific ECCS minimum containment backpressure is shown in Table 2.3-2.

The IBA benchmark comparison results are shown in Figures 2.3-5 through 2.3-8. The GOTHIC IBA model tends to [

]$^{a,c}$

**Table 2.3-2 Comparison of Key Containment Model Input Values**

| Value | IBA Benchmark Model | | Min Backpessure Model |
|---|---|---|---|
| Drywell Volume | | | |
| Torus Volume | | | |
| Vent Line/Header/Downcomer Volume | | | |
| Downcomer Flow Area | | | |
| Downcomer Loss Coefficient | | | |
| Downcomer Inlet Inertia Length | | | |
| Downcomer Exit Inertia Length | | | |
| Initial Torus Water Volume | | | |
| Initial Drywell Pressure | | | |
| Initial Wetwell Pressure | | | |
| Initial Drywell Temperature | | | |
| Initial Wetwell Temperature | | | |

a,c

**Note:**

1. This value has no impact in a slower pressurization such as IBA.

a,c

Figure 2.3-5 IBA Drywell Pressure Comparison

a,c

Figure 2.3-6 IBA Wetwell Pressure Comparison

a,c

Figure 2.3-7 IBA Drywell Vapor Temperature Comparison

a,c

Figure 2.3-8 IBA Wetwell Vapor Temperature Comparison

## 2.4 BIASING MASS AND ENERGY RELEASE MODEL FOR LOW PRESSURE

The mass and energy release from GOBLIN results are used in calculation of the minimum containment backpressure. The limiting PCT model is biased to ensure that the minimum containment pressure in case of DBA LOCA can be conservatively predicted.

The following modifications are made to the GOBLIN BWR ECCS evaluation model to calculate conservative break mass and energy release input data for the GOTHIC containment analyses for the minimum ECCS backpressure analyses: [

]$^{a,c}$

The Quad Cities and Dresden units are BWR/3's with Mark-I containments of similar design. However, the Dresden units differ from the Quad Cities units in that they have isolation condensers, which are large passive heat exchangers connected to the reactor vessel that would provide additional mass and energy to the containment following a break in one of the recirculation lines. Therefore, in ECCS backpressure mass and energy calculation, the Quad Cities specific model conservatively represents all four units.

## 2.5 BIASING CONTAINMENT MODEL FOR LOW PRESSURE

[

]$^{a,c}$

[

]$^{a,c}$

## 2.6 RESULTS

The break mass and energy output data from the biased M&E release calculation were input to the biased containment model. Figures 2.6-1 and 2.6-2 compare the drywell pressure and pool temperature from the biased results to a case where M&E releases were not biased. [

]$^{a,c}$

The large blowdown mass and energy release causes the drywell pressure to increase rapidly to [ ]$^{a,c}$. After the vent path clears, the drywell pressure decreases and remains at [

]$^{a,c}$. The injection of the cooler ECCS water into the reactor vessel condenses steam and reduces break flow to a point where it completely stops since a constant backpressure is assumed. The containment drywell pressure decreases and remains at approximately 31 psia until the break flow rate becomes positive again.

A comparison of the containment drywell pressure response from various RSLB peak pressure cases is shown in Figure 2.6-3; the pressure boundary condition for the ECCS evaluation model is the lower bounding curve. Biasing the input for the mass and energy release and containment models to calculate a minimum ECCS backpressure results in approximately a 10 psi lower calculated drywell pressure.

The calculated containment pressure is also compared to short-term and long-term containment pressure calculation for NPSH in Figure 2.6-4. These calculations are given in the Quad Cities FSAR (Reference 15, Figures 6.2-16b and 6.2-16c). The biases necessary for calculating a minimum containment pressure for ECCS evaluation purposes and minimum containment pressure for NPSH are similar. The results demonstrate that the calculated pressure response is fairly conservative.

a,c

Figure 2.6-1 RSLB Pressure

a,c

Figure 2.6-2 RSLB Vapor Temperature

a,c

Figure 2.6-3 Comparison of the Predicted Minimum and Maximum Containment Pressures

a,c

Figure 2.6-4 Comparison with Short Term and Long Term Containment Pressure for NPSH

# 3 LOCA CALCULATION WITH REVISED INPUT

This section discusses the revised LOCA analysis utilizing the conservatively calculated containment backpressure.

## 3.1 ORIGINAL MODEL AND INPUT MODIFICATION

The original model is the same as the one used in current LOCA analysis for Quad Cities 1 & 2 and Dresden 2 & 3 units (Reference 6).

The limiting break is double-ended guillotine break of the recirculation line at the pump suction side. The single failure assumption is failure of the LPCI injection valve. In this case, only the ECCS flow from two low pressure core spray pumps is credited. As shown in Figure 3.2-2, the reactor vessel blowdown is over by [ ]$^{a,c}$ As shown in Figure 3.2-5, ECCS water from LPCS pumps begins to flow into the reactor vessel at [ ]$^{a,c}$ As shown in Figure 3.2-6, the total mass in the reactor coolant system begins to recover shortly afterward since the mass flow rate of the injected water exceeds the mass flow rate lost to the break.

## 3.2 COMPARISON OF RESULTS

Figures 3.2-1 through 3.2-7 compare the system response for a case assuming atmospheric containment backpressure (Case 1) to a case assuming a conservatively calculated backpressure (Case 2). Figure 3.2-1 compares the conservatively calculated drywell pressure boundary condition (see also Figure 2.6-3). [

]$^{a,c}$

a,c

Figure 3.2-1 Comparison of Drywell Pressure Boundary Conditions

a,c

Figure 3.2-2 Comparison of Steam Dome Pressure

a,c

Figure 3.2-3 Comparison of Steam Dome to Drywell Pressure Difference

a,c

Figure 3.2-4 Comparison of Break Flow Rate

a,c

Figure 3.2-5 Comparison of Core Spray Flow Rate Delivered

a,c

Figure 3.2-6 Comparison of Reactor Coolant System Total Mass

a,c

Figure 3.2-7 Comparison of Cladding Heatup Rate Targeting 2150°F PCT

[

]$^{a,c}$

## 3.3 REMARKS ON INTENDED APPLICATION

The Westinghouse methodology does not have separate codes applied to large and small breaks. Therefore, the entire break spectrum is primarily analyzed using GOBLIN, including the small breaks, large breaks, and intermediate break sizes. The break spectrum results from the Westinghouse LOCA analysis of SVEA-96 Optima2 fuel for Quad Cities 1&2 and Dresden 2&3 are summarized in Figure 3.3-1. [

]$^{a,c}$

[

]$^{a,c}$

a,c

Figure 3.3-1 Quad Cities/Dresden LOCA Analysis, Summary of Break Spectrum Results

[

]$^{a,c}$

[

]$^{a,c}$

# 4 SUMMARY AND CONCLUSIONS

A BWR Mark-I containment model based on Quad Cities 1&2 and Dresden 2&3 has been developed and benchmarked against applicable data using GOTHIC Version 7.2a. The comparisons from these benchmark cases demonstrate the validity of the input model, particularly in predicting the drywell pressure. Mass and energy releases used to calculate the ECCS minimum containment backpressure were generated by biasing the approved GOBLIN model to provide lower containment pressurization. The containment model is also biased to predict low containment pressure. The resultant containment pressure is then compared to short-term and long-term containment response for NPSH for Quad Cities as shown in the FSAR. [

]$^{a,c}$

Since 10CFR50 Appendix K states that a conservatively low containment backpressure must be used in ECCS evaluation calculations, and since this feature was not restricted in the original SER, Westinghouse plans to apply the containment pressure documented in this report to Exelon's Dresden and Quad Cities in the SVEA-96 Optima2 LOCA analysis.

The calculations presented in this report are performed and documented according to the applicable Westinghouse procedures and are available for audit, if requested.

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