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Comments on Draft Safety Evaluation for BAW-10252(P), Revision 0, "Analysis of Containment Response to Postulated Pipe Ruptures Using Gothic"

Ref. 1: Letter, Robert A. Gramm (NRC) to Ronnie L. Gardner (Framatome ANP), "Draft Safety Evaluation for Topical Report BAW-10252(P), Revision 0, 'Analysis of Containment Response to Postulated Pipe Ruptures Using GOTHIC' (TAC No. MC3783)," July 8, 2005.

The NRC issued a draft safety evaluation on BAW-10252(P) and requested that Framatome ANP review for any factual errors or clarity concerns. Framatome ANP has reviewed the draft SER provided in Reference 1. The SER contains one clarification that we recommend correcting. A marked up copy of the page in the draft SER containing the clarification is provided in Attachment A. Attachment B provides a summary table of the clarification.

Framatome appreciates this opportunity to offer clarifying comments.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
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cc: M. C. Honcharik
Project 728

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BAW-10252(P), REVISION 0, "ANALYSIS OF CONTAINMENT RESPONSE TO POSTULATED PIPE RUPTURES USING GOTHIC"

FRAMATOME ANP

PROJECT NO. 728

1.0 INTRODUCTION

By letter dated July 13, 2004, Framatome ANP (Framatome) submitted Topical Report (TR) BAW-10252(P), Revision 0, "*Analysis of Containment Response to Postulated Pipe Ruptures* Using GOTHIC (Agencywide Documents Access and Management System (ADAMS) Accession Number ML041980468)." Framatome requested Nuclear Regulatory Commission's (NRC's) review and approval of the TR for the purpose of referencing it in licensing actions. By letter dated March 7, 2005, Framatome provided supplemental material in support of its July 13, 2004 letter, "Response to Request for Additional Information Regarding BAW-10252(P), Revision 0, 'Analysis of Containment Response to Postulated Pipe Ruptures Using GOTHIC' (ADAMS Accession Number ML050680191)."

The TR describes the GOTHIC[1] computer program models and features to be used to perform licensing analyses of the pressure and temperature response of a large, dry, pressurized-water reactor (PWR) containment to a spectrum of high energy line breaks using the Electric Power Research Institute (EPRI) sponsored GOTHIC computer program developed by Numerical Applications, Inc. (NAI). The topical report also describes the methodology to be used by Framatome to obtain the mass and energy releases for use with GOTHIC. The methods used to establish the initial containment conditions at the start of an accident and the methodology for treatment of the containment's engineered safety systems for heat removal from the containment are also described.

This safety evaluation addresses the Framatome proposed use of GOTHIC for licensing analyses to: (1) evaluate the peak pressure and temperature response of a large, dry, PWR containment atmosphere to large pipe breaks in high energy piping systems, and (2) to evaluate the long-term containment response following a design-basis loss-of-coolant accident (LOCA).

[1] George, Thomas L., et al, "GOTHIC Containment Analysis Package," developed for EPRI, Numerical Applications, Inc (Generation of Thermal-Hydraulic Information for Containments).

2.0 REGULATORY BASIS

The General Design Criteria[2] (GDC) establish minimum requirements for the principal design criteria for water-cooled nuclear power plants. The NRC staff considered the following applicable functions and requirements for this review.

(a) The containment structure must be capable of withstanding, without loss of function, the pressure and temperature conditions resulting from postulated loss-of-coolant, and steam line or feedwater line break accidents. The containment structure must also maintain functional integrity during the long term following a postulated accident. It must remain a low leakage barrier against the post-accident release of fission products for as long as postulated accident conditions require. The NRC staff evaluation included the consideration of the following GDC:

> GDC 16, *Containment design*. "Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require."
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> GDC 38, *Containment heat removal*. "A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels. Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure."
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> GDC 50, *Containment design basis*. "The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters."

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[2] Appendix A to Title 10 of the *Code of Federal Regulations* Part 50 (10 CFR Part 50) - General Design Criteria for Nuclear Power Plants.

(b) The primary containment materials and the equipment inside the primary containment that must function after an accident for safety or monitoring purposes should be capable of withstanding the anticipated post-accident environment, including the effects of pressure, temperature, humidity, spray, and radiation. Equipment outside the primary containment that takes suction from within the primary containment and that must function after an accident for safety or monitoring purposes, should also be capable of withstanding the anticipated post-accident environment. The NRC staff considered the following GDC for containment materials and equipment inside and outside the primary containment that must function in the anticipated post-accident environment.

> GDC 4, *Environmental and dynamic effects design bases.* "Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents; including loss-of-coolant accidents (LOCAs). These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping."

The staff used the guidance in Standard Review Plan (SRP), "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," NUREG-0800, Section 6.2.1, "Containment Functional Design," Section 6.2.1.1.A, "PWR Dry Containments, Including Subatmospheric Containments," Section 6.2.1.3, "Mass and Energy Release Analysis for Postulated Loss-of-Coolant Accidents," Section 6.2.1.4, "Mass and Energy Release Analysis for Postulated Secondary System Pipe Ruptures," and Section 6.2.2, "Containment Heat Removal Systems," for this review.

The staff has performed similar reviews for the use of GOTHIC 7.0 for Fort Calhoun[3] and for the use of GOTHIC 7.0 for Kewaunee.[4] The current version of GOTHIC is version 7.2. The Framatome submittal is based on version 7.1. The differences between GOTHIC 7.0, 7.1 and 7.2, with respect to the analyses of the containment response to design-basis accidents (DBAs) as discussed in this safety evaluation report, are not significant. The later versions of GOTHIC correct unrelated coding errors and include user features to enable the user to apply models consistent with NRC limitations as, for example, identified during the Kewaunee review.

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[3] ADAMS Accession No. ML033100290, letter from A. B. Wang, USNRC, to R. T. Ridenoure, Omaha Public Power District, "Fort Calhoun Station, Unit No. 1 - Issuance of Amendment (TAC No. MB7495)," dated November 5, 2003.

[4] ADAMS Accession No. ML012490176, letter from J. G. Lamb, USNRC, to M. Reddemann, Nuclear Management Company, LLC, "Kewaunee Nuclear Power Plant - Review for Kewaunee Reload Safety Evaluation Methods Topical Report WPSRSEM-NP Revision 3 (TAC No. MB0306)" dated September 10, 2001.

3.0 TECHNICAL EVALUATION

GOTHIC, is maintained under a 10 CFR Part 50, Appendix B, quality assurance program, is widely used in the U.S. and worldwide, and has been extensively verified and validated by NAI, as documented in the GOTHIC Qualification Manual.[5] Closed-form analytical solutions, separate effects consideration, and full scale tests are used to verify and validate the code.

Most of the qualification work reported in the qualification manual involved NAI's comparisons of GOTHIC predictions to experimental data. Experimental data were available from a variety of facilities which included containments with small scale to large scale volumes. Small facility experiments generally focused on a few selected issues, also referred to as separate effects studies. Large scale tests, some performed at reactor sites, provided additional information for code qualification.

The small scale containment model facilities included the Battelle-Frankfurt containment model, the Light Water Reactor Aerosol Containment Experiments, and the Containment Systems Test Facility – part of the Hanford Engineering Development Laboratory experiments, each with a containment volume less than 1,000 m^3. The intermediate size containment facilities included International Standard Problem 35, with a containment volume of about 1,500 m^3. The Marviken, Carolinas Virginia Tube Reactor, and Heissdampfreaktor (HDR) represented large scale containments with volumes of 4,100, 6,400, and 11,300 m^3, respectively.

Therefore, there is reasonable assurance that GOTHIC can be used to reliably represent the features of a large, dry, PWR containment; and the features in the PWR reactor coolant system (RCS), to address the long-term containment response.

The following GOTHIC modeling methodologies, as they apply to the evaluation of the containment pressure and temperature responses to DBAs, were evaluated by the staff using the guidance provided in the SRP.

3.1 Lumped-Parameter Modeling Approximation

The lumped-parameter modeling approximation has been found to be an acceptable approach for the analysis of the containment atmospheric response to a postulated high energy fluid pipe break with a large break area because of the large break jet momentum. The steam and noncondensable components of the containment atmosphere can be considered to be homogeneously mixed and in thermal equilibrium with each other. Thermal and noncondensable gas stratification within a volume need not be considered. This approach has been used in other computer programs used to perform containment analyses, such as

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[5] GOTHIC Containment Analysis Package Qualification Report, latest version 7 2, September 2004, NAI 8907-09 Rev 8

CONTEMPT[6] and CONTAIN[7]. GOTHIC comparisons to a large set of experiments using this modeling approach have shown good agreement between the GOTHIC calculation and the experimental data, with the lumped-parameter model generally overestimating (conservative) the peak pressure and peak temperature responses. The existence of water droplets, in the releases exiting from the break (see Section 3.2 of this evaluation) or from the containment sprays (see Section 3.5 of this evaluation), into the containment atmosphere may be included if the treatment of their thermodynamic and mechanical behavior is justified.

Framatome's proposal to use a simple single, lumped-parameter volume is an acceptable approach for modeling a large, dry containment design for the evaluation of the pressure and temperature responses to DBAs, both the large-break LOCA and the main steam line break (MSLB) accident.

3.2 Break Flow

The partitioning of the mass and energy releases into containment, from the break or from spillage from the emergency core cooling system (ECCS), can influence the containment pressure and temperature response. A "temperature flash" or "pressure flash" process can be assumed to maximize the temperature or the pressure response. In the "temperature flash" process the water-steam mixture from the break mixes instantaneously with the entire containment vapor region and instantaneously reaches thermal equilibrium, resulting in a conservative containment atmospheric temperature and pressure calculation. In the "pressure flash" process the water-steam mixture from the break comes into thermal equilibrium at the total containment pressure prior to mixing with the entire containment vapor region and the mixture remains in this state long enough for the water to drop out of the atmosphere, resulting in a conservative containment sump temperature calculation. These models were developed to conservatively address uncertainness in the break flow characteristics by bounding the effects of water-steam mixture on the containment response.

In GOTHIC, with separate conservation equations for liquid, vapor, and drops, the break flow steam and drops are assumed to be in thermal equilibrium at the source pressure, with the drop characterization based on experimental data. A user specified break drop size (diameter) is used to model the break liquid in the containment atmosphere. The default break drop diameter is assumed to be 100-microns (0.00394 inches), based on guidance provided by the program developer, NAI (Section 21.5, "Boundary Conditions," of the GOTHIC User Manual).

During a DBA LOCA, the water entering the containment from the RCS is at a temperature above the saturation temperature at the containment pressure. The water flashes to steam when it enters the containment, fracturing the water jet into fine droplets. Experimental test

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[6] Hargroves, D.W., L.J. Metcalfe, "CONTEMPT-LT/028 - A Computer Program for Predicting Containment Pressure-Temperature Response to a Loss-of-Coolant Accident," NUREG/CR-0155, March 1979; CONTEMPT4 MOD4 NUREG/CR-3716, BNL-NUREG-51754 (1984) and MOD5 NUREG/CR-4001, BNL-NUREG-51824 (1984).

[7] Murata, K.K. et al., "Code Manual for CONTAIN 2.0: A Computer Code for Nuclear Reactor Containment Analysis," NUREG/CR-6533, USNRC, December 1997.

data[8] have shown that when superheated water flashes to steam the mean drop diameter is less than 100-microns. The GOTHIC qualification analyses, presented in the GOTHIC code documentation qualification report, were performed using a single-drop diameter of 100-microns. These qualification analyses showed that GOTHIC calculations with the 100-micron assumption agreed with, and typically bounded, the measured pressure and temperature response from blowdown tests and measured pressure drops from orifice pressure drop tests. A 100-micron drop has a terminal velocity (rainout velocity) of between one and 2 ft/sec. This terminal velocity is realistic and allows for the break drops to be in the containment atmosphere for a realistic time period.

Based on the above considerations, the NRC staff finds the GOTHIC default break drop size (diameter) acceptable for licensing calculations. This break drop size was also previously accepted by the staff as part of the Kewaunee review (ADAMS Accession No. ML012490176). The staff also finds the break model used in GOTHIC, in combination with the conservatively calculated mass and energy release rates, acceptable for licensing calculations. Although the calculated pressure is expected to be less when compared to the "temperature flash" model, which bounds the effect of the liquid in the break flow, the calculated containment pressure will still be conservative, because of the conservatism used to generate the mass and energy flow rates.

3.3 Heat Transfer Correlations

The Tagami[9] correlation for direct condensation heat transfer incorporated in GOTHIC model is considered to be appropriate for use during the blowdown portion of a LOCA analysis, consistent with the guidance in SRP 6.2.1.1.A. The Tagami correlation requires the specification of the time to the first peak pressure (known as the blowdown phase peak) and the accumulated energy into containment during this time phase. The staff finds the use of the Tagami correlation acceptable for GOTHIC licensing analyses. Additionally, the use of the Tagami correlation in GOTHIC was previously accepted by the staff as part of the Kewaunee review.

The Uchida[10] correlation for direct steam condensation after the LOCA blowdown period is considered to be appropriate for use after the blowdown portion of a LOCA analysis, consistent with the guidance in SRP 6.2.1.1.A The use of the Uchida correlation for direct steam condensation for the MSLB is also considered to be appropriate for use, consistent with the guidance in SRP 6.2.1.1.A. The use of the Uchida model in GOTHIC was also previously reviewed and accepted by the staff as part of the Kewaunee review and the Fort Calhoun review (ADAMS Accession No. ML033100290).

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[8] R. Brown and J. L York, "Sprays Formed by Flashing Liquid Jets," *AICHE Journal*. Vol 8, #2, May 1962, University of Michigan, Ann Arbor, Michigan.

[9] Tagami, T., *Interim Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June 1965 (No. 1)*, unpublished work, 1965

[10] H Uchida, A. Oyama, and Y. Toga, "Evaluation of Post-Incident Cooling Systems of Light-Water Power Reactors," *Proc. Third International Conference on the Peaceful Uses of Atomic Energy*, Volume 13, Session 3 9, United Nations, Geneva (1964).

In combination with the use of the Uchida correlation for MSLB cases, Framatome proposes to use the 8 percent revaporization fraction currently accepted by the staff in NUREG-0588.[11] In response to a staff request for additional information, Framatome clarified that the 8 percent revaporation would only be used in combination with the Uchida model. For other correlations, the GOTHIC built-in revaporization model would be used. The staff finds the Framatome proposal to account for revaporization, which is only important for MSLB cases with significant containment superheat, acceptable based on the previous staff position in NUREG-0588 and on the NRC staff's conclusions in its Kewaunee review (ADAMS Accession No. ML012490176).

GOTHIC, starting with version 7.0, incorporates a mist diffusion layer model (MDLM) for direct condensation and the modeling of heat transfer. This is described in the GOTHIC 7.0 Technical Manual.[12] The manual states that the mist diffusion layer model calculates the condensation rate and the sensible heat transfer rate using the heat and mass transfer analogy.

Condensation of steam on a vertical cold surface results in a water film which flows down the surface to the containment floor. The presence of air, a noncondensable gas, results in the buildup of an air-rich boundary layer between the film and the bulk atmosphere. This boundary layer can significantly reduce the condensation rate since the steam must diffuse through this layer to condense on the water film. This air-rich boundary layer also reduces the sensible heat transfer (heat transfer not due to a phase change).

The MDLM calculates the condensation rate and sensible heat transfer rate using the heat and mass transfer analogy. The use of the heat and mass transfer analogy is consistent with the accepted engineering practice.[13] In addition, the mist diffusion layer model includes the formation of a mist or fog (small liquid droplets) near the cold wall. The presence of this mist has been noted by several experimenters and analysts. These include Mori and Hijikata.[14] They proposed heat transfer models to calculate the heat transfer coefficient for condensation on a vertical cold wall for a weight fraction range of one to 99 percent of a vapor in the presence of a noncondensable gas (e.g., air). Their model included the presence of droplets in the boundary layer. The model calculated a heat transfer value which asymptotically approaches free convection at the outer edge of the boundary layer and condensation at the liquid film flowing along the wall. Mori and Hijikata's paper also presented a photograph of a cylinder showing condensation occurring on its outer surface, and droplets occurring in the boundary layer. Brouwers and Chester and Brouwers[15] also proposed a condensation heat transfer model using film theory which accounted for the presence of droplets in the boundary

[11] NUREG-0588, Interim Staff Position on Environmental Qualification of Safety - Related Electrical Equipment, dated December 1979.

[12] GOTHIC Containment Analysis Package Technical Manual Version 7.0, NAI 8907-06 Revision 12, Numerical Applications Inc., July 2001.

[13] Bird, R. B., Stewart, W. E., and Lightfoot, E. N., *Transport Phenomena*, John Wiley and Sons, New York, 1960.

[14] Yasuo Mori and Kunjo Hijikata, "Free Convective Condensation Heat transfer With Noncondensable Gas on a Vertical Surface" *International Journal of Heat and Mass Transfer*, Vol 16, pp 2229-2240

[15] Brouwers, H. J. H. and Chesters, A. K., "Film Models for Transport Phenomena with Fog Formation: The Classical Film Model," *International Journal of Heat and Mass Transfer*," Vol. 35, pp. 1-11; Brouwers, H. J. H., "Film Models for Transport Phenomena with Fog Formation: The Fog Film Model," *International Journal of Heat and Mass Transfer*," Vol 35, pp. 13-28.

layer Steinmeyer[16] describes fog formation and its implications for industrial equipment. Thus, the presence of a mist in the boundary layer of a condensing fluid in presence of a noncondensable gas is a recognized phenomenon.

GOTHIC employs a "simplified" model which incorporates mist in the calculated heat and mass transfer. The model appears to be unique among those examined by the staff since it also includes the movement of the mist to the bulk atmosphere. In other models, the mist was assumed confined to the boundary layer. The movement of the mist to the bulk atmosphere from the boundary layer affects the pressure and temperature in the containment by the addition of liquid to the containment atmosphere. The GOTHIC model empirically determines the fraction of the mist which migrates to the wall. A portion of the remainder migrates to the bulk vapor. Migration of the mist to the bulk has no significant effect if the bulk atmosphere is saturated.

During a previous review of the "simplified" model incorporating mist, the staff concluded that the GOTHIC model would be acceptable for licensing analyses without the features of boundary layer mist formulation and film roughness enhancements (Kewaunee review, ADAMS Accession No. ML012490176).

The NRC's acceptable form of the MDLM is now referred to as the diffusion layer model (DLM), as incorporated starting with GOTHIC 7.1 Patch1 (QA) (the original MDLM without the boundary layer mist formulation and without the film roughness enhancements). The Framatome proposal to use the DLM model is consistent with the staff's previously approved use and is acceptable.

If the containment atmosphere becomes supersaturated, a mechanism or modeling assumption is needed to condense the excess steam and release the heat of condensation to the containment atmosphere. The GOTHIC "fog" model or the GOTHIC default "mist" model is used to address this situation. The default "mist" model accounts for a deficiency in the "fog" model. Framatome does not propose the use of the "fog" model, since the default "mist" model is recommended by NAI, the code developer. In response to a staff request for additional information, Framatome stated that it does not propose to apply the GOTHIC default "mist" model (or the "fog" model) for licensing calculations. Sensitivity studies performed by Framatome showed that the inclusion of the default "mist" model in both the LOCA and MSLB cases had a negligible impact on the peak containment pressure or peak containment temperature response. The Framatome proposal to turn off the "fog" model and not apply the default "mist" model for licensing analyses is acceptable for the peak pressure and peak temperature analyses. However, for the long-term containment response there is a potential for the containment atmosphere to develop into a supersaturated vapor. If this occurs, modeling features in GOTHIC without the default "mist" model may lead to non-conservative results. Under this condition, the use of the default "mist" model during the long-term cooling evaluation is acceptable to the staff. Because the default "mist" model in GOTHIC does not impact the peak containment pressure or peak containment temperature response, when the containment atmosphere is saturated or slightly superheated, and the default "mist" model is intended to

[16] Steinmeyer, D. E. "Fog Formation in Partial Condensers." *Chemical Engineering Progress*, Vol. 68, No. 71, July 1972.

address supersaturated conditions late in the accident, the staff finds the original Framatome proposal to apply the default "mist" model acceptable for all licensing analyses.

GOTHIC also includes the Gido-Koestel heat transfer correlation[17] for steam condensation. Framatome did not propose the use of this correlation for licensing analysis, consistent with the staff's evaluation of this correlation during the Kewaunee review.

GOTHIC provides a variety of heat transfer correlations for applications. Natural and forced convection heat transfer correlations are used to account for heat transfer to the containment passive heat structures (walls, floors, and in-containment structures and equipment). The characteristic length of a structure is used to determine if the conditions are laminar or turbulent for natural convection to obtain the heat transfer coefficient. It is also used to obtain the forced convection heat transfer coefficient. In GOTHIC, the characteristic length is the containment hydraulic diameter. Typically, the characteristic length is related to the specific structure, for example the length of the wall. The use of the containment hydraulic diameter is conservative since the heat transfer coefficients are either not dependent on the value or decrease with increasing characteristic length – the containment hydraulic diameter is larger than the typical structure's characteristic length. The use of natural and forced convection heat transfer, to supplement the direct condensation heat transfer, is consistent with American National Standards Institute (ANSI)/ANS-56.4-1983[18] and is acceptable to the staff for licensing analyses. The Framatome proposal to use only natural convection heat transfer, to supplement the direct condensation heat transfer, and to use the containment hydraulic diameter for the characteristic length, are acceptable to the staff because the approach is consistent with the guidance provided in SRP 6.2.1 and 6.2.1.1.A for a conservative containment atmospheric pressure and temperature analysis.

Consistent with ANSI/ANS-56.4-1983, GOTHIC also included containment atmosphere (vapor) to containment heat structure radiation heat transfer. The GOTHIC model is based on consideration of a grey gas with grey surrounding walls[19] for the purpose of radiation heat transfer. For LOCA analyses, and for MSLB analyses that do not rely on a break size to ensure a pure steam blowdown, the containment atmosphere is not superheated and the effects of radiation heat transfer will have a negligible impact on the containment pressure calculation. The containment atmosphere will be superheated for MSLB analyses only with the selection of the break size to ensure a pure steam blowdown. In this case the impact on the containment pressure will be small, on the order of one psi lower. The Framatome proposal to neglect radiation heat transfer is acceptable to the staff because the approach is consistent with the guidance provided in SRP 6 2.1 and 6.2.1.1.A for a conservative containment atmospheric pressure and temperature analysis.

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[17] Gido, R. G., and Koestel, A., "Containment Condensing Heat Transfer," Second International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Santa Barbara, California, January 1983

[18] ANSI/ANS-56.4-1983, "American National Standard Pressure and Temperature Transient Analysis for Light Water Reactor Containments," prepared by the American Nuclear Society.

[19] McAdams, W. H., *Heat Transmission*, Third Edition, McGraw-Hill, 1954

3.4 Generalized Equipment Models

GOTHIC includes an extensive set of models (components) for operating equipment for heat transfer both in the containment and in the RCS. The analysis of the long-term containment responses requires consideration of features of the RCS (for example, emergency core cooling systems (ECCSs) and residual heat removal systems).

3.4.1 Pumps and Fans

The model simulates a centrifugal pump or fan. The differences between pumps and fans lie in the unique characteristics of rated conditions and performance curves. These components can affect the flow in any junction except when the junction is connected to a flow boundary condition. There are three basic pump models in GOTHIC: (a) the pump performance is defined by user-defined or built-in homologous curve, (b) the pump performance is defined by a user-defined head versus volumetric flow curve, and (c) the flow is specified.

3.4.2 Valves and Doors

The valve and door components are used to model flow path characteristics that may change during the course of a transient.

3.4.3 Heat Exchangers and Fan Coolers

There are two types of heat exchanger models available: (a) a water-to-water heat exchanger, and (b) a fan cooler. The water heat exchanger is distinct from a fan cooler, but both models are based on similar heat exchanger principles. The distinction involves only the heat transfer fluids. For a water heat exchanger the fluid on both the primary and secondary sides is assumed to be water. In GOTHIC, water heat exchangers are commonly used to model cooling of sump water before it is pumped into the containment spray system or the reactor emergency core cooling system.

The fan cooler model allows heat transfer from the primary side steam/gas mixture to the secondary side coolant water, for example the service water system or the component cooling water system. Steam can be condensed to the extent allowed by the heat transfer or to the extent allowed by the amount of steam in the flow which enters the cooler.

3.4.4 Spray Nozzles

The spray nozzle component is used to model containment sprays, ice condenser drain flows into the lower containment, and vessel spray systems. The nozzle model converts liquid flow through a flow path from the continuous liquid phase to the droplet phase. The fraction of the liquid that is converted into droplets and the drop diameter can be specified as functions of time. Liquid is converted to drops only if the flow is directed into the nozzle discharge volume.

3.4.5 Coolers and Heaters

Coolers and heaters are provided to simulate a heat source or sink, with or without a mass source or sink, when the total heat transfer is known. This component may be used to model furnaces (or a reactor core's decay heat), air conditioners, heaters, heat generating equipment or heated vessels. A cooler can also act as a condenser if a positive volumetric flow through the cooler is specified. A condensing cooler will condense as much steam out of the flow as possible, subject to the limits given by the heat removal rate and the available steam in the flow. Heat not used to condense steam is used to cool the steam/gas mixture in the volume. The condensate is deposited in the liquid film in the volume.

By specifying a positive flow rate through a heater, a boiler can be modeled. The boiling rate is limited by the rate of heat addition, the flow rate through the heater and the total available water in the volume. A boiler will boil as much water out of the flow as possible. Additional heat will be used to raise the liquid temperature in the volume. A heater or cooler operates on only one phase in a volume, but there may be as many heaters and coolers in a volume as needed to obtain a required performance, for example one cooler may operate on the vapor and a second cooler may operate on the liquid.

3.4.6 Volumetric Fans (Annular Fans, Deck Fans, etc.)

Volumetric fans are used to specify the volumetric flow of a steam/gas mixture and droplets through a flow path as a function of time or as a function of the pressure drop across the flow path. The fraction of the volumetric flow that is made up of droplets is determined by the relative drop volume fraction in the volume from which the flow is taken. The droplets and steam/gas mixture are assumed to have equal velocities through the fan. The velocity of the continuous liquid phase in the flow path is set to 0.0 (zero). If there is no vapor in the upstream volume, or if the upstream end of the junction is submerged, the flow through the fan is set to zero.

Heating or cooling of the flow through the fan can be specified as a function of time or as a function of the volumetric flow through the fan. This component may be used in place of a heater or cooler by locating the volumetric fan on a junction for which both ends are connected to the same volume. However, since phase change cannot occur in a junction, the volumetric fan is limited to sensible heating or cooling of the steam/gas mixture passing through the junction. A volumetric fan may also be used to model annular fans in dual containments.

Additional components available in GOTHIC, which were not considered during this review include (a) vacuum breakers, (b) hydrogen recombiners (forced and natural convection), (c) ignitors (spark device used to ignite hydrogen burns), and (d) pressure relief valves.

3.4.7 Generalized Equipment Models Summary

NAI used analytic problems for the qualification of GOTHIC, including quantitative and qualitative tests that evaluated the performance of individual models. By demonstrating good agreement with the analytic problems, NAI concluded that the basic building blocks of GOTHIC were validated.

GOTHIC, is maintained under a 10 CFR Part 50, Appendix B quality assurance program, is widely used in the U.S. and worldwide, and has been extensively verified and validated by NAI.

Therefore, there is reasonable assurance that the component models available in GOTHIC can be safely used to represent the features in a large, dry, PWR containment and to represent the features in the PWR RCS to address the long-term containment response.

3.5 Engineered Safety Systems

The two most common engineered safety systems used in large, dry containment designs for control of the post-accident containment atmosphere temperature and pressure are the containment sprays and containment fan coolers.

3.5.1 Containment Spray

The staff finds the modeling of the containment spray system acceptable for GOTHIC licensing calculations when used to produce a conservative containment calculation through the selection of the modeling parameters, for example the spray flow rate, spray drop size, and spray efficiency. The methodology used to model the effectiveness of the containment spray (active heat removal mechanisms) is consistent with the guidance in SRP 6.2.1.1.A and 6.2.2. The use of the GOTHIC containment spray models was also previously accepted by the staff as part of the Kewaunee review (ADAMS Accession No. ML012490176) and the Fort Calhoun review (ADAMS Accession No. ML033100290).

3.5.2 Containment Fan Coolers

The staff finds the modeling of the containment fan coolers acceptable for GOTHIC licensing calculations when used to produce a conservative containment calculation through the selection of the modeling parameters, for example the flow rate, the secondary side temperature, and the heat transfer rate. The methodology used to model the effectiveness of the containment fan coolers (active heat removal mechanisms) is consistent with the guidance in SRP 6.2.1.1.A and 6.2.2. The use of the fan cooler model was also previously accepted by the staff as part of the Fort Calhoun review (ADAMS Accession No. ML033100290).

3.6 Mass and Energy Releases

The peak pressure and temperature generally occur early in the accident (on the order of a few minutes), during the short-term period for both the LOCA and the MSLB. A full analysis, for the long-term, should be performed long enough to return the containment pressure and temperature to their original values prior to the initiation of the LOCA event. This duration, for a LOCA, may be up to two weeks. The distinction between the short-term and the long-term periods is made with reference to the time ~~at which the safety injection source is switched from the refueling water storage tank to the containment sump, the recirculation phase for long-term cooling.~~ The short-term analysis is concluded at this time and the long-term analysis continues afterwards for a specified period of time after the occurrence of the DBA.

3.6.1 Short-term Mass and Energy Releases

The Framatome proposed methodology for the short-term mass and energy releases for use in GOTHIC will be based on previously accepted methods and will be consistent with the guidance provided in SRP Section 6.2.1.3 for LOCAs and Section 6.2.1.4 for secondary side releases.

- AS DELINEATED IN SECTION 5.1.2.3.2 -

OF CORE QUENCH. THE LOCA EVENT THEN PROCEEDS INTO THE LONG-TERM COOLING PHASE OF THE ANALYSIS (POST RE-FLOOD AND DECAY HEAT PHASES).

3.6.2 Long-term Mass and Energy Releases for LOCA

The model for the long-term containment pressure analysis should have sufficient details to generate the containment pressure and temperature response trend for the specified time period. The modeling details should primarily address two aspects: (1) the break mass and energy transfer rates from the RCS to the containment, and (2) the cooling mechanism for the containment sump. The containment sump is typically cooled by shutdown cooling heat exchangers during the recirculation phase to provide sufficient net positive suction head for the safety injection pumps, as well as sufficient cooling to remove the stored energy in the RCS metal (sensible heat) and the decay heat generated by the core.

The Framatome proposed methodology for the long-term mass and energy releases for the LOCA will also be based on previously accepted methods, or GOTHIC will be used to model the long-term releases, consistent with the guidance provided in SRP Section 6.2.1.3 for LOCAs releases.

GOTHIC can model heat removal to secondary heat exchanges which use service water or component cooling water for heat removal from the containment. This allows for the modeling of heat removal from the containment sump and from the RCS through the residual heat removal system. As discussed in Section 3.4 above, GOTHIC has the necessary features to model the RCS long-term mass and energy transfer rates.

This is accomplished in GOTHIC by modeling the RCS primary system as a lumped parameter volume to represent the reactor vessel and the primary system piping. Thermal conductors are added to this volume to conservatively represent the RCS metal sensible heat, including the steam generator tubes, the RCS pipe runs, the vessel internals, etc.

Thermal conductors may also be used to represent the fuel rods producing the decay heat. An alternative to this approach is to account for the mass of uranium and zircaloy and include the decay heat as a forcing function using a GOTHIC heater component. The decay heat generation table is generated to conservatively model the decay heat, based on one of the currently used standards, ANS-1971 or ANS-1979, or based on SRP 9.2.5, "Ultimate Heat Sink," Branch Technical Position ASB 9-2 "Residual Decay Energy for Light-water Reactors for Long-term Cooling."

GOTHIC includes the capability to model both the short-term and the long-term operation of engineered safety equipment including the equipment used during the sump recirculation phase, the emergency core cooling function of the ECCS, and the containment heat removal functions of the sprays, heat exchangers and fan coolers; for the evaluation of the containment response.

GOTHIC contains adequately justified component models to simulate the required features of the RCS and the containment for this purpose. Conservative input values are to be used to evaluate the heat removal capabilities of these systems consistent with the guidance provided in SRP 6.2.1, 6.2.1.1.A, and 6.2.2 for a conservative containment atmospheric pressure and temperature analysis.

The staff finds the proposed use of GOTHIC to generate the long-term mass and energy releases due to LOCA, and to evaluate the long-term containment atmosphere response to the LOCA, acceptable.

3.7 Initial and Boundary Conditions

3.7.1 Mass and Energy Release Rates

The Framatome methodology for the generation of the mass and energy release rates, as a result of a large break in a high energy line, for input into GOTHIC is consistent with the staff guidance provided in SRP 6.1.2 3 for LOCAs and SRP 6.1.2.4 for secondary side breaks and is, therefore, acceptable for use in licensing analyses. For the long-term LOCA containment response, the Framatome methodology for the use of GOTHIC to generate these data is also consistent with the staff guidance provided in SRP 6.1.2.3 for LOCAs and is, therefore, acceptable for use in licensing analyses.

3.7.2 Initial Containment Conditions

The initial containment atmospheric conditions are to be chosen consistent with the guidance in SRP 6.2.1 and 6.2.1.1.A. for a conservative containment atmospheric pressure and temperature analysis. The containment free volume and the characterization of the passive heat sinks inside the containment are also to be chosen, consistent with the guidance in SRP 6.2.1 and 6.2.1.1.A., for a conservative containment atmospheric pressure and temperature analysis.

3.7.2.1 Initial Containment Pressure

A higher initial primary containment pressure yields a higher calculated transient pressure. Thus, a high initial pressure is conservative for a primary containment design.

3.7.2.2 Initial Containment Temperature

For a given pressure, a lower temperature results in a greater mass of air. A greater air mass yields a higher peak pressure when the peak occurs soon after the accident in analyses of PWRs with an early peak pressure (that is, at the end of the initial reactor coolant blowdown). The larger amount of noncondensible gases reduces the heat transfer to the passive heat sinks (structures).

An opposite effect may arise from the use of models where the initial temperature of all the passive heat sinks is set equal to the initial primary containment atmosphere temperature. A high initial primary containment atmosphere temperature reduces the heat absorption capability of the heat sinks. For PWR analyses with limiting second peak pressure (that is, a peak pressure which occurs at or after the time the core is reflooded), this effect may dominate and cause the upper bound initial temperature to be more conservative.

3.7.2.3 Relative Humidity

For a given total pressure and primary containment temperature, a lower relative humidity (that is, a lower steam content) means a greater mass of air. Since the specific heat of steam is greater than the specific heat of air (by approximately a factor of two), the use of the lower bound value is conservative for the analyses of the peak containment pressure and temperature

3.7.2.4 Passive Heat Sinks

The passive heat sinks inside the primary containment consist of all concrete and metal surfaces, painted and unpainted, which are exposed to the primary containment atmosphere and which are approximately at the primary containment ambient temperature during normal plant operation. The surface area of the heat sinks has a range of possible values with an upper and lower bound. The lower bound is conservative for evaluating the primary containment design.

3.7.2.5 Containment Free Volume

The net free volume (gas space) of a containment can be determined from the total volume less the volumes of the interior structures and equipment. The range of possible values is determined by estimating the lower and upper bounds of net free volume. The lower bound is determined by combining the lower bounding estimate of the total volume and the upper bound estimate of the volume comprising interior structures and equipment. The upper bound is obtained by the opposite procedure. The lower bound value of the net free volume is to be used for the calculation to find the highest peak pressure, or temperature, for the primary containment.

3.7.3 Boundary Conditions

Design parameters which are used in the analyses to characterize system performance are:

- initiation times
- flow rates
- spray thermal effectiveness
- heat exchanger size and thermal conductance
- cooling water temperature

The values of these parameters, when used in the analyses, are to be in the conservative direction with respect to the pressures and temperatures being calculated and by amounts which account for such effects as:

- wear
- surface fouling
- spray droplet diameter
- uncertainties in frictional pressure losses

- uncertainties in valve actuation time
- frictional effects
- uncertainties in pump acceleration time

The Framatome methodology addresses these parameters by reference to ANSI/ANS-56.4-1983.

3.7.4 Single Active Failure Consideration

The Framatome methodology considers single active failures as required by Appendix A to 10 CFR Part 50 when analyzing safety system performance and the impact on the containment response to large pipe breaks in high energy piping systems.

3.7.5 Offsite Power Consideration

The Framatome methodology considers using only onsite power and only offsite power, as required by Appendix A to 10 CFR Part 50, when analyzing safety system performance and the impact on the containment response to large pipe breaks in high energy piping systems.

3.7.6 Initial and Boundary Conditions Summary

The Framatome methodology uses the guidance provided in SRP Sections 6.2.1, 6.2.1.1.A, 6.2.1.3, 6.2.1.4, and 6.2.2, and in ANSI/ANS-56.4-1983 to establish the initial and boundary conditions for the development of the containment initial conditions and the development of the heat transfer capabilities of the engineered containment sprays and the engineered containment coolers. In addition, the guidance is also used to develop the heat transfer capability of support systems, such as the containment sump coolers and RCS residual heat removal coolers. The use of the guidance provided in the SRPs and in the ANSI standard is acceptable to the staff for establishment of the initial and boundary conditions to be used in licensing analyses for containment performance evaluations.

4.0 CONCLUSIONS

The Framatome methodologies for the use of GOTHIC to perform licensing analyses of a large, dry, PWR containment to (1) evaluate the containment atmosphere's peak pressure and temperature response to large pipe breaks in high energy piping systems, and (2) evaluate the long-term containment response following a design-basis LOCA, are based on the guidance provided in SRP Sections 6.2.1, 6.2.1.1.A, 6.2.1.3, 6.2.1.4, and 6.2.2, and in ANSI/ANS-56.4-1983. The guidance ensures a conservative evaluation of the peak containment pressure and peak containment temperature following a DBA LOCA or MSLB for use in demonstrating compliance with GDC 4, 16, 38, and 50. Use of the guidance also ensures a conservative evaluation of the long-term engineered cooling systems used to reduce the containment pressure to acceptably low values for use in demonstrating compliance with GDC 38.

The NRC staff finds the described use of GOTHIC for the stated licensing analyses, as presented in Topical Report BAW-10252(P), "Analysis of Containment Response to Postulated Pipe Ruptures Using GOTHIC," and as modified by letter dated March 7, 2005, "Response to a

Request for Additional Information Regarding BAW-10252(P), Revision 0, 'Analysis of Containment Response to Postulated Pipe Ruptures Using GOTHIC'," acceptable for the proposed licensing applications.

Principal Contributor: E. Throm

Date: July 8, 2005

ATTACHMENT B

SUMMARY TABLE OF PROPOSED CHANGES

PAGE NO.	LINE(S) NO.	PROPOSED CHANGE AND REASON
12	30 – 33	Revised the sentence "The distinction between the short-term and the long-term periods is made with reference to the time at which the safety injection source is switched from the refueling water storage tank to the containment sump, the recirculation phase for long-term cooling." to "The distinction between the short-term and the long-term periods – as delineated in Section 5.1.2.3.2 - is made with reference to the time of core quench. The LOCA event then proceeds into the long-term cooling phase of the analysis (post re-flood and decay heat phases)." This suggested rewording is more consistent with the contents of the topical report.