Westinghouse Non-Proprietary Class 3

WCAP-8355-A
Revision 1

September 2017

LONG TERM ICE CONDENSER CONTAINMENT CODE-LOTIC CODE

Westinghouse

WCAP-8355-A
Revision 1

LONG TERM ICE CONDENSER CONTAINMENT CODE-LOTIC CODE

Arthur C. Craig*
Containment & Radiological Analysis

September 2017

Reviewer: Christopher P. Logan*
Containment & Radiological Analysis

Approved: Kent W. Bonadio*, Manager
Containment & Radiological Analysis

*Electronically approved records are authenticated in the electronic document management system.

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066, USA

August 31, 2017

Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

SUBJECT: RESULTS OF THE U.S. NUCLEAR REGULATORY COMMISSION REVIEW OF WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE) CHANGES IN WESTINGHOUSE WCAP-8354-P-A (PROPRIETARY) AND WCAP-8355-A (NON-PROPRIETARY), "LONG TERM ICE CONDENSER CONTAINMENT CODE - LOTIC CODE" (CAC NO. MF9354)

Dear Mr. Gresham:

By letter dated February 1, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17034A376), Westinghouse submitted information to the U.S. Nuclear Regulatory Commission (NRC) indicating that during an ongoing code maintenance of the LOTIC1 code used for the loss-of-coolant accident (LOCA) containment response for ice condenser containments, a discrepancy was discovered between the methodology described in topical reports (TRs) WCAP-8354-P-A and WCAP-8355-A and its implementation in the source code. The information included revised page number 5.2-6 of the above TRs. In this letter, Westinghouse also stated that it is not necessary to update the source code for resolving this issue because it would not result in an improved transient behavior or influence on the limiting time of the event nor increase in nuclear safety. The NRC staff reviewed the information in the Westinghouse letter and revised page 5.2-6 of the TR and requested additional information from Westinghouse.

By letter dated June 6, 2017 (ADAMS Accession No. ML17130A736), the NRC staff issued its request for additional information (RAI) questions asking Westinghouse to (1) perform a sensitivity analysis for the most bounding ice-condenser plant in the U.S. and (2) provide a quantitative impact of this change on the entire LOCA containment pressure response, including the peak pressure.

By letter dated July 5, 2017 (ADAMS Accession No. ML17195A259), "Westinghouse Submittal of RAI Response Regarding WCAP-8354-P-A (Proprietary) and WCAP-8355-A, (Non-Proprietary), 'Long Term Ice Condenser Containment Code - Lotic Code,'" Westinghouse responded to the NRC staff RAI questions by providing quantitative results of a sensitivity study performed by creating a temporary version of the LOTIC1 code consistent with its description in the TR. Using biased input data, Westinghouse analyzed the containment response for the sensitivity case based on the temporary version of LOTIC1 code and the base case based on the current version of the LOTIC1 code. Figures 1 through 4 in the Westinghouse RAI response letter referenced above shows practically insignificant difference between the graphs of containment pressure response, upper and lower containment compartment temperature responses, and the active sump water temperature response for the base case and the sensitivity case. Westinghouse stated that the peak pressure for the base case as 11.2053 psig and the sensitivity case as 11.1966 psig; a difference of 0.0087 psi.

Based on comparing the results of the sensitivity case with the base case, the NRC staff agrees with Westinghouse that an update of the LOTIC1 code for resolving the discrepancy between the source code and the methodology described in the TR would not result in an improved transient behavior or influence on the limiting time of the event nor it affects the nuclear safety. The NRC staff also agrees with the proposed changes in page number 5.2-6 of WCAP-8354-P-A and WCAP-8355-A, and requests that Westinghouse submit the updated versions of these TRs.

If you have any questions, please contact Ekaterina Lenning at 301-415-3151.

Sincerely,

/Serita Sanders Acting for RA/

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

SUBJECT: RESULTS OF THE U.S. NUCLEAR REGULATORY COMMISSION REVIEW OF WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE) CHANGES IN WESTINGHOUSE WCAP-8354-P-A (PROPRIETARY) AND WCAP-8355-A (NON-PROPRIETARY), "LONG TERM ICE CONDENSER CONTAINMENT CODE - LOTIC CODE" (CAC NO. MF9354)
DATED: AUGUST 31, 2017

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ADAMS Accession No.: ML17213A579; ***via e-mail** **NRR-106**

OFFICE	NRR/DPR/PLPB	NRR/DPR/PLPB*	NRR/DSS/SRXB*	NRR/DPR/PLPB
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DATE	8/1/17	8/29/17	8/31/17	8/31/17

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

JAN. 2[illegible] 1976

Mr. C. Eicheldinger, Manager
Nuclear Safety Department
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, Pennsylvania 15230

Dear Mr. Eicheldinger:

The Nuclear Regulatory Commission staff has completed its review of Westinghouse Electric Corporation reports WCAP-8354 (Proprietary) and WCAP-8355 (Non-Proprietary) entitled, "Long Term Ice Condenser Containment Code - LOTIC Code." A summary of our evaluation is enclosed.

Report WCAP-8354 satisfies the criteria of our "Nuclear Regulatory Commission Topical Report Program", presented in the April 15, 1975 edition of our Topical Report Review Status Book, and thus is considered a topical report. We consider WCAP-8355 an acceptable non-proprietary version of WCAP-8354. When either of these reports is used as a reference, both the proprietary report and its non-proprietary version must be referenced.

As a result of our review, we have concluded that the Westinghouse LOTIC-1 computer code is acceptable for use in the long-term analysis of the maximum pressure and temperature response of ice condenser containments to a loss-of-coolant accident. We have further concluded that the LOTIC-2 computer code is acceptable for use in the analysis of (1) the minimum pressure response of ice condenser containments for the purpose of evaluating the ECCS performance and (2) the maximum reverse differential pressures which could occur across the structures between the containment upper and lower compartments during a loss-of-coolant accident. Therefore, WCAP-8354 may be referenced in license applications as an accepted topical report when used to support these conclusions. However, we have concluded that the LOTIC computer codes are not acceptable for the analysis of the maximum temperature response of the ice condenser containment lower compartment to postulated secondary system pipe breaks.

We do not intend to repeat our review of WCAP-8354 and WCAP-8355 when they appear as references in a particular license application except to assure that the material presented in these reports is applicable to the specific plant involved.

In accordance with established procedures, we request that within three months of receiving this letter, you issue revised versions of WCAP-8354 and WCAP-8355 to include this acceptance letter and any changes to the reports as a result of our review.

If you have any questions about our evaluation of WCAP-8354 and WCAP-8355, please contact us.

Sincerely,

D B Vassallo

D. B. Vassallo, Chief
Light Water Reactors
Project Branch No. 5
Division of Project Management

Enclosure:
Topical Report
Evaluation

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ENCLOSURE

TOPICAL REPORT EVALUATION

Report Numbers & Titles: (Proprietary) WCAP-8354 Long-Term Ice Condenser Containment Code - LOTIC Code - July 1974;
(Non-Proprietary) WCAP-8355 - Long Term Ice Condenser Containment Code - LOTIC Code - July 1974
(Proprietary) WCAP-8354 - Supplement 1 Long Term Ice Condenser Code - LOTIC Code - June, 1975
(Non-Proprietary) WCAP-8355 - Supplement 1 Long Term Ice Condenser Code - LOTIC Code - June, 1975

Originating Organization: Westinghouse Electric Corporation

Reviewed By: Containment Systems Branch, Office of Nuclear Reactor Regulation

SUMMARY OF TOPICAL REPORTS

Report WCAP-8354 provides documentation of the Westinghouse Electric Corporation's LOTIC-1 code which is used for the long-term analysis of the pressure and temperature response of ice condenser containments to postulated loss-of-coolant accidents (LOCA's). This code has been previously described in detail in the Safety Analysis Reports for D. C. Cook Units 1 & 2; Floating Nuclear Plant; Sequoyah Units 1 & 2; and McGuire Units 1 & 2.

Supplement 1 to WCAP-8354 documents the Westinghouse Electric Corporation's LOTIC-2 code. The LOTIC-2 code is used to calculate the minimum pressure response of ice condenser containments for use in the evaluation of ECCS performance. The LOTIC-2 code is also used to calculate the maximum possible reverse (upper compartment to lower compartment) differential pressure which could occur across the structures separating the containment compartments during a loss-of-coolant accident.

The primary containment of an ice condenser, pressure suppression containment is of conventional design; i.e., a vertical cylinder with a hemispherical dome and a flat base. The primary containment design pressure for various ice condenser plants is between 12 and 15 psig. The containment volume (about 1,250,000 ft^3) is divided into three major subvolumes, including a lower compartment enclosing the reactor system, an intermediate volume housing an ice bed in which steam is condensed during a LOCA, and an upper compartment to accomodate air displaced from the other two compartments during the LOCA.

The intermediate, or ice condenser compartment, is an enclosed annular compartment encompassing most of the perimeter of the containment structure. Borated flake ice is stored in cylindrical perforated metal baskets within the ice condenser compartment. The ice in the baskets is provided to condense steam in the event of a LOCA. During plant operation the ice bed is maintained at about 10°F by a redundant refrigeration system. Refrigeration ducts and insulation on the ice condenser walls serve to minimize heat transfer into the ice bed. In the unlikely event of a complete loss of the refrigeration system, the ice condenser insulation is sufficient to prevent significant ice melting for a minimum period of seven days during which time the plant could be safety shut down.

Inlet and outlet doors are provided at the bottom and top of the ice condenser compartment. In the event of a LOCA, the rising pressure in the lower compartment pushes open the inlet doors located at the bottom of the ice condenser. Air, entrained water, and steam then flow from the lower compartment into the ice condenser. The displaced air in the ice condenser forces open the outlet doors at the top of the ice condenser and flows into the upper compartment.

Steam condensation by the ice limits the containment pressure rise during reactor blowdown and maintains the containment pressure at acceptably low levels following blowdown until the time that meltout of the ice bed occurs.

Ice meltout would occur approximately one-half hour after the design basis LOCA. Following ice meltout, the containment pressure increase due to the continued release of decay energy steam is limited by containment sprays in the upper containment volume. Continued containment spray results in the containment pressure being returned to atmospheric pressure.

The containment response to the reactor coolant system initial blowdown (short-term analysis) is determined using the Transient Mass Distribution (TMD) code, rather than the LOTIC code which is used for the long-term analysis of the containment response to the reactor coolant system blowdown.

Following initial reactor coolant system blowdown, the LOTIC-1 code is used to determine the maximum containment pressure and temperature as a function of time. For the LOTIC-1 code, the containment is divided into separate volumes to model the containment lower and upper compartments, dead-ended compartments and the ice condenser compartment. The ice condenser compartment is subdivided into six circumferential sections each with two vertical sections to analyze the effects of flow maldistribution and early ice meltout in localized sections of the ice condenser. The containment sump is modeled as two volumes (active and inactive sumps) such that sump flooding and temperature history are determined. Performance of the air return fan(s) is also simulated to provide for the transfer of air from the containment upper compartment to the lower compartment. Containment internal heat sinks, containment sprays and residual and containment spray heat exchangers are modeled in the LOTIC code. The code also considers the addition of accumulator gas (nitrogen) to the containment as well as the reduction in free volume due to the addition of the refueling water storage tank water to the containment through the ECCS and containment spray systems.

The LOTIC-1 code uses a control volume technique to model the physical geometry of the system. Fundamental mass and energy equations are applied to the appropriate control volumes and solved by numerical methods. The initial containment conditions for each compartment are specified before blowdown. Ice melt is calculated for the blowdown period based on the mass and energy released to the containment. A basic assumption made in the LOTIC-1 code is that the total pressure in all compartments is uniform. This assumption is justified by the fact that after the initial blowdown of the reactor coolant system, the mass and energy release rates into the containment are low and very slowly changing. The resulting flow rates between compartments will also be relatively low since the flow paths between compartments are large. These flow rates are unable to maintain significant pressure differentials between the containment compartments. On this basis the LOTIC-1 code does not incorporate a flow model capable of determining differential pressures and induced flow rates between compartments.

In an ice condenser plant, if the steam condensation rate in the lower compartment exceeds the steam release rate, the lower compartment will depressurize at a greater rate than the ice condenser and upper compartments. This would result in a reverse differential pressure between the upper compartment and the lower compartment which, coupled with the action of lower inlet door flow proportioning springs, will close the ice condenser lower inlet doors (i.e., the ice condenser doors will act as large check valves). The differential pressure between the upper and lower compartments will also force the flow of air from the upper compartment back to the lower compartment through the air return fan ducts. The fans are equipped with a time delay circuit which will prevent their operation during the first ten minutes following an accident but a very small differential pressure across the fan dampers will open them to provide a flow path from the upper compartment to the lower compartment.

The potential for the steam condensation rate to exceed the release rate into the lower compartment exists during the "refill" period when the steam release rates from the reactor coolant system are very low. During the refill period accurac of the prediction of lower compartment pressure does not appear to be important because the ECCS evaluation model assumes adiabatic heating of the core during this period. However, the reduction of the lower compartment pressure which could be experienced during the refill period will establish the backpressure available to the reactor coolant system at the start of "reflooding" of the core. The lower compartment pressure will begin to increase when the steam release rate into the lower compartment exceeds the lower compartment steam condensation rate and will continue to rise until the upper and lower compartment pressures are equalized and the ice condenser lower inlet doors reopen.

The LOTIC-2 code is a modified version of the original LOTIC code (LOTIC-1). The LOTIC-2 code uses the conservation of momentum equations to calculate flow rates and pressure differentials between the containment compartments. The LOTIC-2 code includes the capability to model the cooling effect of water from the ice condenser draining to the lower compartment, and conden-

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sation on the containment sump pool surface. The LOTIC-2 code also includes the capability to model the check valve action of the ice condenser lower inlet doors when the upper compartment pressure exceeds the lower compartment pressure.

SUMMARY OF STAFF EVALUATION

The LOTIC-1 code was reviewed in conjunction with and as a part of the D. C. Cook Nuclear Plant FSAR review. We concluded in the D. C. Cook Safety Evaluation Report that the LOTIC-1 code conservatively calculates the maximum containment pressure and temperature responses to a loss-of-coolant accident. For the purpose of maximum long-term containment response the omission of a differential pressure dependant flow model is justified. Also, neglecting the cooling effects of ice condenser drain water and condensation on the sump pool surface in the lower compartment is conservative. The calculation of mass and energy release data for loss-of-coolant accidents does not consider a refill period, but the accident is assumed to progress directly from the end of reactor coolant system blowdown to the start of core reflooding. Therefore, the simplifying assumptions used in the LOTIC-1 code are conservative for the analysis of the maximum containment pressure response for ice condenser plants.

We reviewed the LOTIC-1 code as a proposed analytical tool for the calculation of the minimum containment pressure response of ice condenser plants for use in the ECCS performance evaluation. In the staff "Status Report for the Westinghouse Electric Corporation ECCS Performance Evaluation Model," published October 15, 1974, and amended November 13, 1974, we concluded that the LOTIC-1 code could not be used for the calculation of minimum containment pressure for ice condenser plants for the following reasons:

1. The simplifying assumption of uniform pressure throughout the containment in the LOTIC-1 code results in the inability to calculate flow rates and differential pressures between major compartments within the containment.
2. The LOTIC-1 code omits the cooling effects of two potentially significant heat sinks in the containment lower compartment (i.e., the pool surface of the containment sump and water spilling to the containment lower compartment from the ice condenser drains).
3. The LOTIC-1 code does not permit modeling of the check-valve type action of the ice condenser lower inlet doors.

We have reviewed the LOTIC-2 code described in Supplement 1 to WCAP-8354 and find that the code incorporates the necessary equations and assumptions to include the effects of differential pressure induced flow between compartments, check valve action of the ice condenser lower inlet doors and additional sources of energy removal in the containment lower compartment.

Based on our review of the LOTIC-1 and LOTIC-2 codes we have found that the method of calculating heat transfer in the containment lower compartment is not conservative for the evaluation of lower compartment temperatures in the event of a secondary system pipe rupture. For accidents that release a quantity of superheated steam to the containment (i.e., steam line breaks) the containment lower compartment may become superheated. Heat removal from the containment atmosphere will cause condensation on heat removal surfaces and the condensate will fall to the containment floor. The LOTIC codes assume that heat is removed uniformly from the containment atmosphere and no liquid is removed until the containment atmosphere is saturated. This approach may result in the calculation of lower compartment temperatures that are not conservative for containment and/or equipment design. Therefore, we believe that for the analysis of postulated secondary system pipe breaks, the LOTIC-1 code should be modified to include the effect of local condensation on lower compartment heat sinks.

STAFF POSITION

We have concluded that:

1. The LOTIC-1 code is acceptable for the long-term analysis of the maximum pressure and temperature response of ice condenser containments to a loss-of-coolant accident
2. The LOTIC-2 code is acceptable for the analysis of
   a) the minimum pressure response of ice condenser containments for the purpose of evaluating the ECCS performance and
   b) the maximum reverse differential pressures which could occur across the structures between the containment upper and lower compartments during a loss-of-coolant accident.
3. The LOTIC codes are not acceptable for the analysis of the maximum temperature response of the ice condenser containment lower compartment to postulated secondary system pipe breaks.

We find WCAP-8355 to be an acceptable non-proprietary version of WCAP-8354.

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ABSTRACT

An analytical model is presented for the calculation of ice melt and long-term pressure transients in the ice condenser reactor containment after a loss-of-coolant accident. The method applies conservation equations to control volumes used to simulate spatial variation. The control volumes represent the functionally distinct compartments of the ice condenser containment.

Uniform pressure and saturated steam conditions has been assumed throughout the containment in order to reduce the computing time for a given problem. Several required quantities are assumtpions based on conclusions derived from Ice Condenser Test Facility test results.

The code is flexible enough to analyze the effectiveness of the engineered safeguard systems, including internal and external sprays and a sump water recirculation cooling system. Temperature gradients in, and heat absorption by, the containment structure are also considered.

CONCLUSION

The computer code developed for the long-term temperature and pressure calculation in the ice condenser containment can perform these calculations effectively. This is achieved by simplifications in the thermodynamic, flow and heat transfer models, and incorporating of the test results of the Ice Condenser Test Facility where appropriate. The code also models Containment Spray System and a Safety Injection System to the Reactor Core. The heat-absorbing capacity of the structural walls may also be considered in the problem. Several options exist as energy input sources to the containment. With the given input options, and the input data to be supplied, the containment integrity design analysis and the Emergency Core Cooling System back pressure analysis of the ice condenser containment can be performed.

1.0 INTRODUCTION

Early in the ice condenser development program it was recognized that there was a need for computer modeling of ice condenser containment performance. It was realized that the model would have to have capabilities comparable to those of the "dry" containment, COCO, model. These capabilities would permit the model to be used to solve problems of containment design and optimize the containment safeguards systems.

To more fully understand the development of the analytical model, a brief description of the arrangement of ice condenser reactor containment is presented. The general arrangement of a containment for a four-loop reactor coolant system is shown in Figures 1-1, 1-2 and 1-3.

The containment is divided into three compartments: the reactor coolant system or lower compartment, the upper compartment, and the ice condenser compartment. Figures 1-1, 1-2 and 1-3 show the boundaries of these three compartments, as well as the boundaries of dead-ended compartments within the containment whose air volumes are not displaced by steam into the upper compartment. The lower compartment completely encloses the reactor coolant system equipment. The upper compartment contains the refueling canal, refueling equipment, and the polar crane used during refueling and maintenance operations. The upper and lower compartments are separated by the operating deck, which provides a low-leakage barrier between these two compartments. The ice condenser compartment, which contains the borated ice provided to quench the loss-of-coolant accident energy, is a completely enclosed and refrigerated annular compartment located radially between the reactor coolant system compartment and outer wall of the containment, and in elevation, generally above the operating deck. The dead-ended volumes are adjacent to the lower compartment and include the auxiliary pipe tunnel, the fan accumulator compartments, and the instrument room.

The operation of the ice condenser reactor containment can be divided into two distinct periods:

a. The initial reactor coolant blowdown, which for the largest pipe break assumed can occur in approximately 15 seconds.

b. The post-blowdown period, which is of interest for two to three hours after the blowdown.

For the ECCS back pressure analysis the input is selected to be conservatively low based upon test results.

The LOTIC code (Long-Term Ice Condenser Code) has capability to properly describe the post-blowdown period in the ice condenser containment. Not only are the upper, lower, and ice condenser volumes described, but also the ice condenser is divided into six circumferential sections, each with two vertical divisions. In this way maldistribution and sectional burnout effects can be studied as well as the changing volume distribution during the depletion of the ice bed. Another significant feature of the code is the two sump configuration (active and stagnant sumps) such that the sump floodup and temperature history of the containment is accurately modeled. The code also describes the performance of the air recirculation fan in returning upper compartment air to the lower compartment. Coupling of residual and component cooling heat exchangers is provided tc give an accurate indication of performance for these heat exchangers. The spray heat exchanger performance is also accurately modeled in the transients. The basic equations used are the standard transient mass and energy balances and the equations of state used in any containment transient, but appropriately coupled to the multi-volume ice condenser containment. The code also considers accumulator gas added to the containment and the displacement of free volume by the refueling water storage tank volume.

The LOTIC Code uses the control volume technique to represent the physical geometry of the system. Fundamental mass and energy equations are applied to the appropriate control volumes and solved by suitable numerical procedures. The initial conditions of the containment by compartment is specified before blowdown. Ice melt is calculated for the blowdown period based on the mass and energy released to the containment. After the RCS blowdown, the basic LOTIC Code assumption is made that the total pressure in all compartments is uniform. This assumption is justified by the fact that after the initial blowdown of the RCS the remaining mass and energy released from this system into the containment are small and very slowly changing. The resulting flow rates between compartments will also be relatively small. These small flow rates are unable to maintain significant pressure differentials between the containment compartments.

Waltz Mill tests have been performed to demonstrate the long term performance capability of the ice condenser. Specifically, these tests verified the ability of the ice condenser to reduce the containment pressure within a few minutes following the blowdown and, in addition, tests have shown excellent condenser performance for tests simulating the long term addition of residual heat.

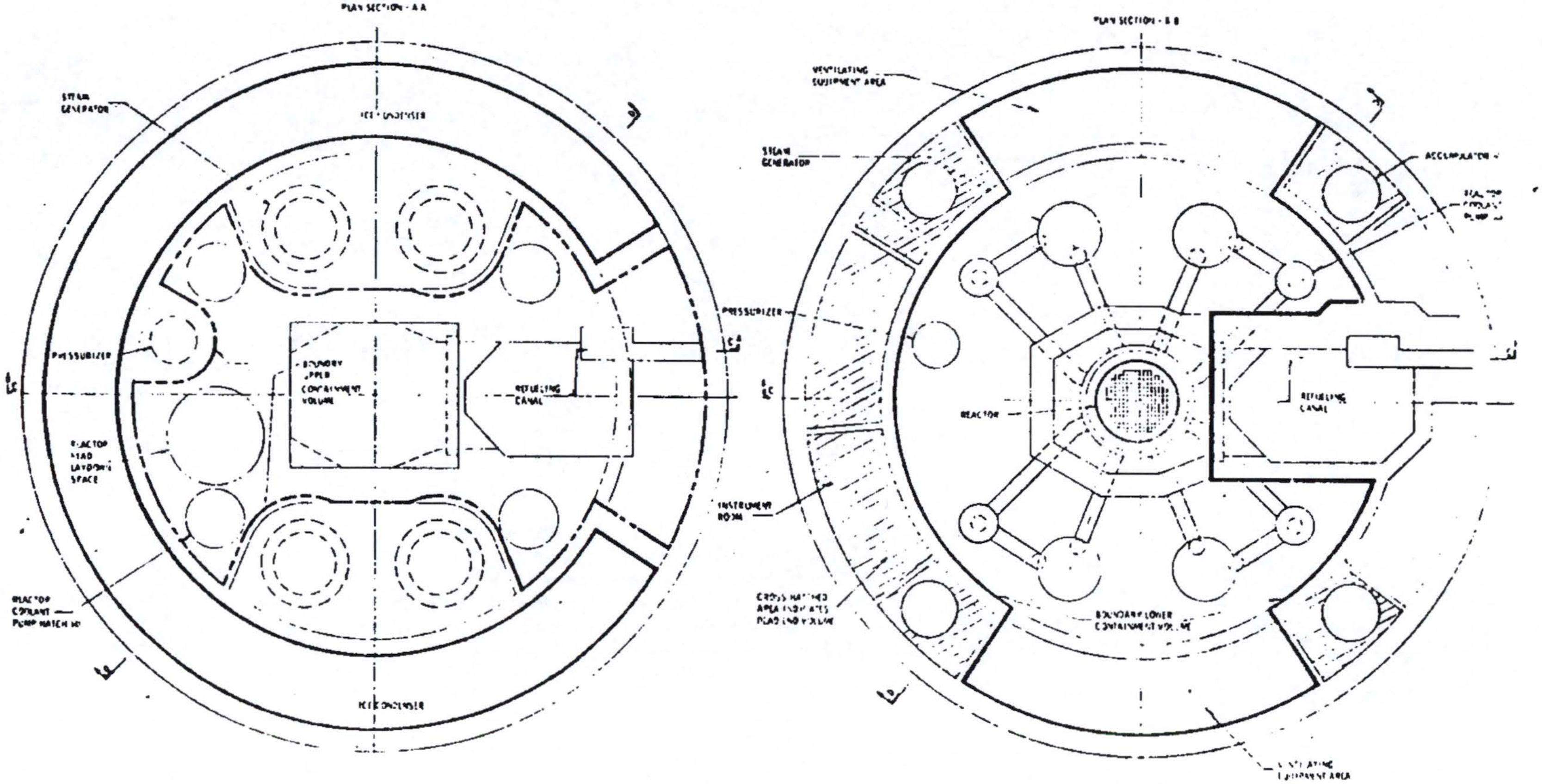

FIGURE 1-1 ICE CONDENSER CONTAINMENT VOLUME BOUNDARIES

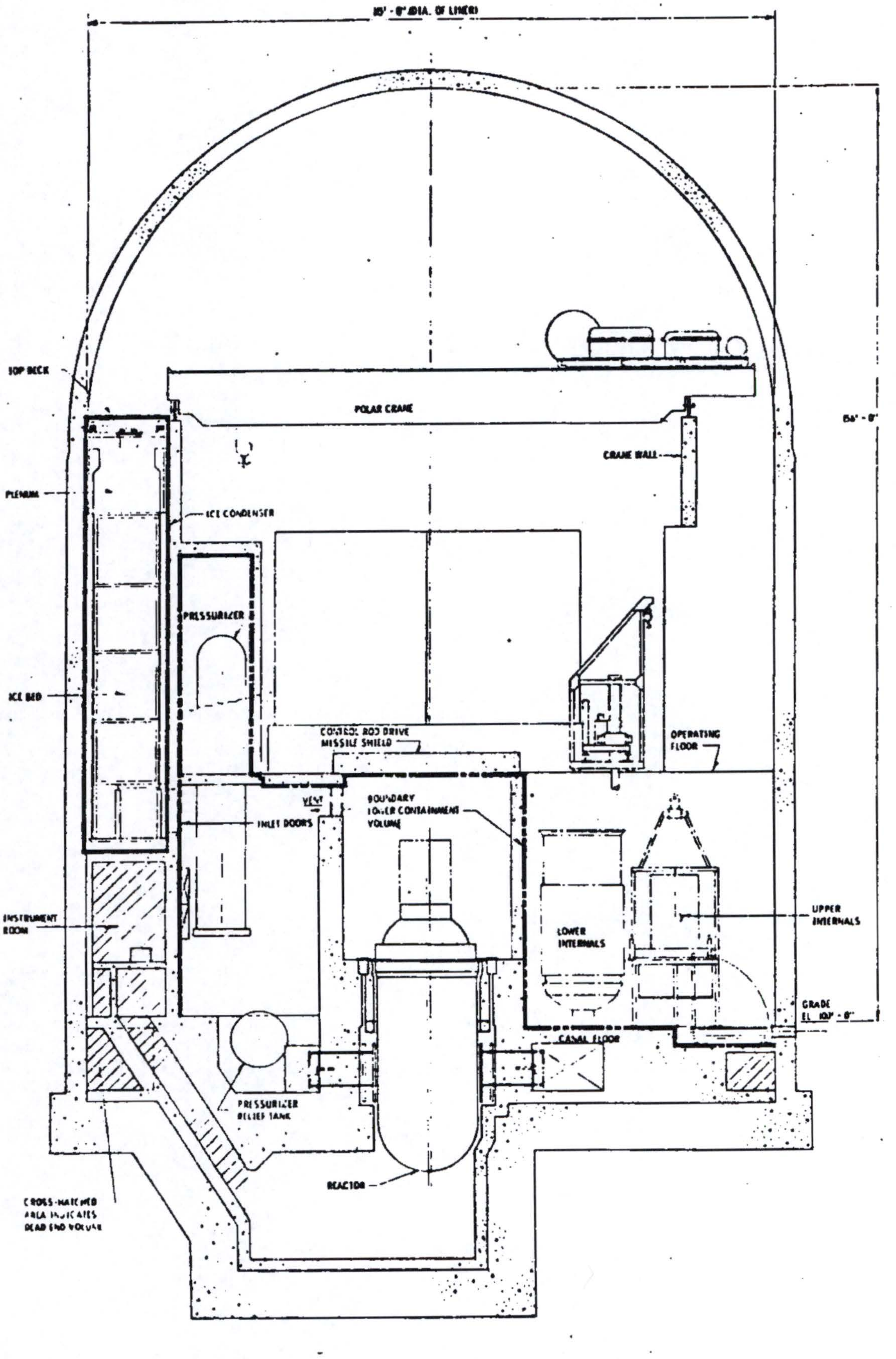

FIGURE 1-2 SECTIONAL ELEVATION
ICE CONDENSER CONTAINMENT
VOLUME BOUNDARIES

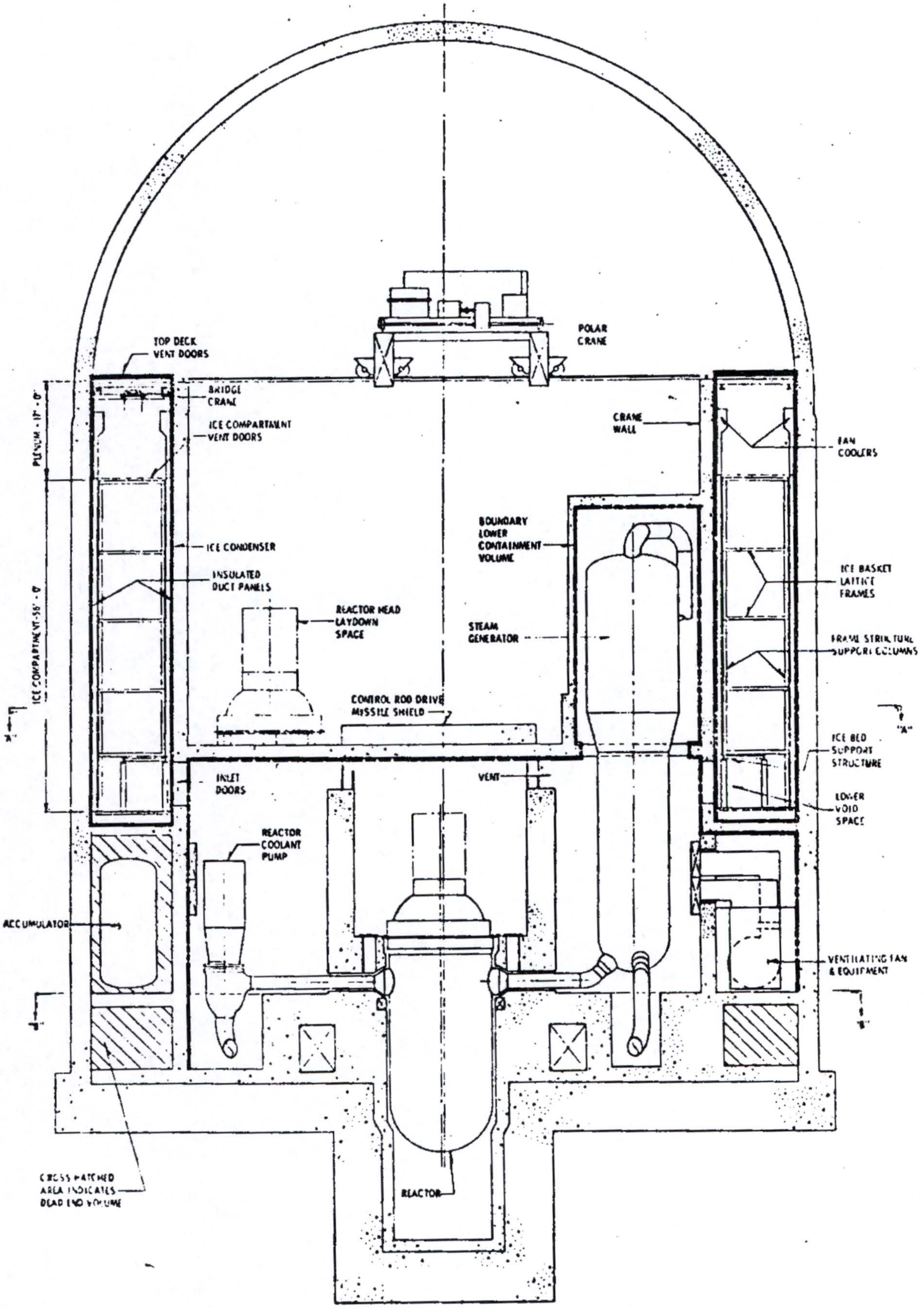

FIGURE 1-3 SECTIONAL ELEVATION
ICE CONDENSER CONTAINMENT
VOLUME BOUNDARIES

2.0 GENERAL DESCRIPTION OF THE LOTIC COMPUTER CODE

2.1 METHOD OF SOLUTION

The model of the containment consists of five distinct control volumes, the upper compartment, the lower compartment, the portion of the ice bed from which the ice has melted, the portion of the ice bed containing unmelted ice, and the dead ended compartments. The ice condenser control volume with unmelted and melted ice is further subdivided into six subcompartments to allow for maldistribution of break flow to the ice bed.

The thermodynamic conditions in these compartments are obtained as a function of time by the use of fundamental equations solved through numerical techniques. These equations are solved for three distinct phases of problem time. Each phase corresponds to a distinct physical characteristic of the problem. Each of these phases has a unique set of simplifying assumptions based on test results from the ice condenser test facility. These phases are the blowdown period, the depressurization period, and the long term period are discussed in Section 5.0.

2.2 ASSUMPTIONS

The most significant simplification of the problem is the assumption that the total pressure in the containment is uniform. This assumption is justified by the fact that after the initial blowdown of the reactor coolant system the remaining mass and energy release rates from this system into the containment are small enough and very slowly changing, thus differential pressures are small and the containment pressure is essentially uniform in all compartments. The resulting flow rates between the control volumes will also be relatively small. These small flow rates then are unable to maintain significant pressure differences between the compartments.

In the control volumes, which are always assumed to be saturated, steam and air are assumed to be uniformly mixed and at the control volume temperature. When the circulation fan is in operation, the fan flow and the reactor coolant system boiloff are mixed before entering the lower compartment. The air is considered a perfect gas, and the thermodynamic properties of steam are taken from the ASME steam table.

The condensation of steam is assumed to take place in a condensing node located, for the purpose of calculation, between the two control volumes in the ice storage compartment. The exit temperature of the air leaving this node is set equal to a specified value which is equal to the temperature of the ice filled control volume of the ice storage compartment. Lower compartment exit temperature is used if the ice bed section is melted.

3.0 TEMPERATURE RESPONSE IN UPPER AND LOWER COMPARTMENTS

Fundamental Equations

A change in the mass or energy flow rates into or out of a control volume affects the temperature of the medium in the control volume. The equation for the response of this temperature shall be derived, using the mass and energy balances for the control volume.

The mass balance differentiated with respect to time is:

$$\frac{d}{dt} M = m_{in} - m_{out} \tag{1}$$

The energy balance differentiated with respect to time is:

$$P \frac{d}{dt} V + \frac{d}{dt} (uM) = (m_{in} h_{in} - m_{out} h_{out}) + q \tag{2}$$

Since the control volume has stationary boundaries, the first term equals zero.

In general, there exists a unique expression for the enthalpy of the medium as a function of its temperature. Considering this, the energy equation can then be written in the following way:

$$M \frac{du}{dT} \frac{d}{dt} T + u \frac{d}{dt} M = m_{in} h(T_{in}) - m_{out} h(T_{out}) + q \tag{3}$$

This form of the energy equation and some appropriate assumptions form the basis for the temperature response calculation in the control volumes.

Application

Substituting the mass balance into the energy equation and rearranging yields:

$$M \frac{du}{dT} \frac{d}{dt} T + m_{out} h(T_{out}) = m_{in} h(T_{in}) - u(m_{in} - m_{out}) + q \tag{4}$$

If the pressure in a system of control volumes is assumed to be uniform and the temperature transients in the control volumes are small, then the flow in the system may also be considered as uniform. This means that the flows entering and leaving teh control volume are equal.

At this point in the derivation of the transient equations for the system, the flow-rate calculations have deliberately been replaced by the abovementioned assumptions. This eliminates the need to solve the momentum equation and results in a considerable simplification of the process of solving the transient behavior of the system.

As the temperature in the control volume is uniform over the control volume, it follows that the temperature of the flow leaving the control volume and that of the control volume are equal.

If, as a final assumption, the enthalpy function of the medium can be written as [ ] Equation 4 (a,c) then becomes:

[ ] (5) (a,c)

Now define:

$$M \frac{du}{dT} = k_1,$$

$$b \; m_{out} = k_2 \text{ and}$$

right hand side of Equation 5 = RH.

Then Equation 5 can be written as:

[ ] (6) (a,c)

Upon inspection of the constants k_1, k_2 and RH, one finds that at a given instant these constants can be calculated. The problem is thus reduced to the solving of the first-order differential equation.

The solution of the homogeneous part, by setting RH = 0 and dividing by k_1 is:

[ ] (a,c)

For the particular solution try [ ] (a,c)

If t equals zero, which is the same as saying that the time-step size equals zero, the solution has to satisfy the condition at the given instant. This means that T has to be T_0 and so $C_1 + C_2 = T_0$. If t is an infinite time after the instant, a disturbance of the steady state has been introduced and the system has to be at a new steady state; or $\frac{d}{dt}$ in Equation 6 must equal zero; this means that T must equal $\frac{RH}{k_2}$.

For the assumed solution, [ ] (a,c)

The solution of the temperature response in the control volume after a disturbance has been introduced at a given instant is thus;

[ ] (7) (a,c)

For the Upper Compartment and Lower Compartment the temperature of the air, steam, and spray flowing out of the compartment is equal to the compartment temperature, and is unknown.

[ ] (a,c)

[ ] (8) (a,c)

The enthalpy-temperature relation for air is

$$h = 0.24T \qquad (9)$$

Since the mass in the compartment is assumed to be constant over the time interval of this calculation, it follows from Equation 1 that

$$m_{a,in} = m_{a,out} \tag{10}$$

$$m_{s,in} + m_{spray,in} = m_{s,out} + m_{spray,out} \tag{11}$$

The governing equations for the internal spray are:

From the mass-balance

$$m_{spray,out} = m_{spray,in} + m_c \tag{12}$$

From the energy balance

$$m_{spray,out}\ h_{spray,out} = m_{spray,in}\ h_{spray,in} + m_c\ h_s \tag{13}$$

From these two equations the spray flow leaving the control volume is then

$$m_{spray,out} = m_{spray,in} \frac{(h_s - h_{spray,in})}{(h_s - h_{spray,out})} \tag{14}$$

By assuming that the spray water leaves the control volume at the control volume temperature, it follows that $h_{spray,out} = h_w$ and Equation 14 can be solved directly.

Equations 14, 10 and 11 are solved to yield the values of the three flows leaving the compartments.

Since the temperatures, and thus the specific enthalpies, of the entering flows are known, and by an assumption the temperature and enthalpies of the outflowing air and steam are also known, the right-hand side of Equation 5 is known.

The right-hand side of Equation 5 can now be written as

[ ] (15) (a,c)

where q is the net heat addition rate at the given constant.

Eliminating from this equation the terms with the unknown temperature, T results in

[ ] (16) (a,c)

The coefficient of $\frac{d}{dt}$ T in Equation 5 is calculated to be

[ ] (17) (a,c)

The coefficient of T in the second term of Equation 5 is

[ ] (18) (a,c)

If the term 16 is called C, term 17 called A and term 18 called B, Equation 5 becomes then

[ ] (19) (a,c)

The solution of this equation is then given in Equation 7 and is

[ ] (20) (a,c)

This equation gives the temperature in the upper compartment at a time Δt sec after the instant t, and is now easy to solve.

A special case is represented when, in Equation 19, the coefficient B is zero, which means that the spray flow out of the upper compartment is zero. The solution of Equation 19 is then

$$[\qquad\qquad] \qquad (21)$$ (a,c)

The temperature in the ice-condenser compartment is evaluated according to the following conditions:

a. It may be specified by input values as long as all the ice-condenser sections contain ice.

b. If some sections are melted, these sections are at lower compartment temperature. The ice-containing sections still have the specified input values. The temperature of the ice-empty part of the ice condenser is then evaluated by averaging over the empty ice condenser section volumes.

c. If all sections are melted, the temperature in the ice-condenser compartment equals the lower compartment temperature.

The dead-ended volume temperature is calculated as outlined in Section 5.2.

Since the temperatures in all the compartments are now known, the system pressure can be calculated using the procedure outlined in Section 4.0.

4.0 SYSTEM PRESSURE

Fundamental Equation

As mentioned in Section 2.2, the total pressure in the ice condenser containment is assumed to be uniform throughout the control volumes at a given instant. For the five control volumes this means that the sum of the steam and air pressures is equal for these control volumes.

The total air mass in the system must remain constant during the whole period of the problem, and can be calculated from the initial pre blowdown conditions. If air is added or subtracted from the system with a given rate, the total air mass can also be calculated at a given instant.

The fundamental equation for the calculation is the state equation for the air:

$$p_a V_a = M_a R_a (T_a + 460) \tag{22}$$

Application

It is clear that the total air mass in the system must equal the sum of the air masses in each control volume. Rewriting Equation 22 and summing yields:

$$M_a = \sum_{i=1}^{5} M_{a,i} = \sum_{i=1}^{5} \frac{p_{a,i} V_i}{R_a (T_{a,i} + 460)} \tag{23}$$

As $p_{sys} = p_s + p_a$, one can write

$$M_a = \sum_{i=1}^{5} \frac{p_{sys} V_i}{R_a (T_{a,i} + 460)} - \sum_{i=1}^{5} \frac{p_{s,i} V_i}{R_a (T_{a,i} + 460)} \tag{24}$$

If the temperature in each compartment is known, either by calculation or from some assumption, the relation between the temperature and the steam pressure is known. It follows that p_{sys} in Equation 24 is the only unknown, and thus can be evaluated.

Equation 24 is written as

$$p_{sys} = \frac{M_a + \sum_{i=1}^{n} \frac{p_{s,i} \; V_i}{R_a \; (T_{a,i} + 460)}}{\sum_{i=1}^{n} \frac{V_i}{R_a \; (T_{a,i} + 460)}} \qquad (25)$$

This equation can be solved directly if the condition of the steam in each compartment is assumed to be saturated. The steam pressure $p_{s,i}$ in each compartment is then known directly from the compartment temperature. The summation is over the number of active volumes at a given problem time. As mentioned before some of the compartments cease to exist as the problem time progresses.

Given the system pressure, the temperature, the volume of each compartment, and assuming the saturated state of the steam, the mass distribution and the necessary thermodynamic quantities of steam and air can be easily calculated by using the steam tables and the state equations for air.

5.0 CONTAINMENT ANALYSIS PHASES

The code is constructed to calculate the ice condenser containment pressure over a long time period after a loss-of-coolant accident. The problem is solved in the following manner. The control volume technique is used to represent the physical geometry of the system, allowing specification of the volumes of the compartments in the containment, structural walls, and initial conditions. As mentioned in Section 2, the containment is divided into five distinct control volumes. To allow for flow maldistribution in the ice condenser control volume, six sections are considered in this control volume.

The fundamental equations of the previous section are applied to the appropriate control volumes, and solved by suitable numerical procedures. Since there are three distinct phases in the pressure transient of the containment, the analysis has been split into three more or less distinct periods. Each period has its own set of simplifying assumptions, mainly to speed up the numerical calculations and, if applicable they are based on the test results from the ice condenser test facility. These periods are:

1. the blowdown period of the reactor coolant system.
2. the depressurization and circulation fan start period, and
3. the long-term period.

5.1 BLOWDOWN PERIOD

This phase coincides with the blowdown of the reactor coolant system. The duration of this period is from the instant of a loss-of-coolant accident until the end of the blowdown, which is recognized by the code as the final entry in the first break-flow table given as an input.

The pressure and temperatures in the containment are held constant during this phase at appropriate input values determined from analyses and compression ratio calculations. For the ECCS back pressure analysis the input pressure is selected to be conservatively low based upon test results. Tests at the ice condenser Waltz Mill test facility have shown that this phase represents that period of time in which the lower compartment air and a portion of the ice condenser air are displaced and compressed into the upper compartment and the remainder of the ice condenser. (The initial pre-blowdown atmosphere in the dead ended compartment is retained at that time.) The code represents this phenomenon through the use of an input value for the fraction of the ice bed which retains air during this phase. This fraction, determined from test data, is also used to establish the volumes of the two ice condenser control volumes which are held constant during this phase.

The temperatures in the upper and lower compartments are calculated from the input pressure. The portions of the containment which are primarily air-filled, i.e., the dead ended compartment and a portion of the ice bed, are assumed to be at upper compartment temperature during this phase. Deck leakage considerations resulted in the upper compartment atmosphere to be considered saturated at this temperature.

To calculate the containment steam and air mass distribution over the blowdown period, the temperature in each control volume must be known.

In case the dead-ended volume is part of the upper compartment, all the initial containment air is in the upper compartment and part of the ice compartment. Because the temperature in the latter is equal to the yet-unknown temperature, the total volume at this temperature is thus known. The solution of this temperature is based on the equations of Section 4.0, in a slightly different form. As P_{sys} is known and the steam is saturated, one can iterate for T_a in Equation 24. Write Equation 24 as follows:

$$M_a = \frac{(p_{sys} - p_s)\ V}{R_a\ (T_a + 460)} \tag{26}$$

Estimate T_a. The steam pressure P_s follows from the steam tables for saturated steam. Enter these in Equation 26 and compare the air mass thus calculated to the actual air mass. The Newton Iteration Scheme will provide a next better estimate. If the error is less than 0.01°F, the iteration is completed.

When the dead-ended volume is part of the lower compartment, its initial air mass stays constant and during this period it is assumed to be at a temperature equal to the upper compartment temperature with the steam at saturated condition. Equation 26 is now used, without including the dead-ended volume to calculate the upper compartment temperature. The compressed volume of the dead-ended volume can now be found from Equation 26 by writing it as

$$V = \frac{M_a R_a (T_a + 460)}{p_{sys} - p_s} \tag{27}$$

In the lower compartment and that part of the ice bed not filled with air, the temperature is equal to the saturation temperature of steam at the system pressure. Knowing the temperature, the partial pressures of steam and air, the volume of each control volume, and the fact that the steam is assumed to be saturated, the masses of steam and air in each control volume can be easily calculated.

To calculate the ice inventory remaining after the RCS blowdown the net mass and energy entering the ice condenser is determined. From the blowdown rate of mass and energy, given as an input table, the following is subtracted:

1. Steam mass and energy condensed by the structural heat sinks in the lower compartment and ice condenser up to the time of the pressure reduction period.

2. Steam mass and energy remaining in the steam filled lower compartment following blowdown. This steam is swept into the ice bed in the pressure reduction period to melt additional ice at that time.

The net mass and energy entering the ice bed is assumed to be condensed completely with the calculation of ice mass melted, described in Section 6, made by using the inputed ice bed drain temperature for this period.

Melted ice, blowdown steam and blowdown water are drained to the sump at the specified drain temperature and steam condensed by the structures is drained to the sump at lower compartment saturated liquid temperature. The sump volume is subtracted from the total lower compartment volume to obtain the steam-gas volume.

Summarizing, it can be said that during the blowdown period the mass distribution is calculated in accordance with a given total system pressure that is constant over the period. The major calculations are the inventory calculations of the ice mass, and the sump mass and temperature.

5.2 DEPRESSURIZATION PERIOD

This phase of the analysis corresponds to the period of time between the end of blowdown and the establishment of a circulation flow between the control volumes. At the end of blowdown the lower compartment volume is filled with steam. As soon as recirculation fan flow is initiated the lower compartment begins to fill with an air-steam mixture, composed of the upper compartment air of the fan flow and RCS boiloff steam displacing the previous steam atmosphere of the lower compartment through the ice bed in a piston type manner. As this occurs the code calculates the conditions in the upper and lower compartment from the compartment conditions and the spray and flow characteristics. This phase of the analysis ends when the air/steam mixture fills both the lower compartment and the melted out oortion of the ice bed.

During this phase the input non-condensable nitrogen blowdown from the accumulator occurs, RCS steam boiloff is initiated, and the engineered safeguards come into operation. The engineered safeguards which are initiated in this phase are the recirculation fan, the safety injection system, and the spray system. The recirculation fan forces upper compartment air into the lower compartment atmosphere and has the capability to force circulate the stagnant dead ended atmosphere in a similar manner. During this phase the spray systems and safety injection system take water from the refueling water storage tank and pump it into the containment.

Because of the nature of the calculation, this period is divided in two subperiods; the first, from the start the depressurization period till the start of the recirculation fan and the second covering the remainder of the period. It should be noted that natural convection of air from the upper compartment to the lower compartment is inputed as a fan flow rate. The flow rate is increased when the engineered safeguards fan is placed in operation.

At the beginning of this phase the blowdown ice melt is computed using the blowdown energy. This result is used to compute the actual volume of the melted out portion of the ice condensers, which is used to change the ice condenser volumes from the compressed value associated with the air displacement in the blowdown phase to the actual value computed from the ice melt. The temperature of the ice condenser volume is also changed over a period of time from the blowdown value to an input value. The temperature in the ice-filled part of the ice compartment (during the blowdown period set equal to the Upper Compartment) is, at a decreasing rate, changed to the input value for this control volume (specified in the input description, Section 12, by TEX (4)). The volume of this control volume (volume *No. 4) is also brought at a specified rate from the input value to the actual value of the ice-filled part of the ice compartment. Coinciding with this, and based on the ice inventory, the melted part of the ice compartment volume (volume *No. 3) is calculated. The latter volume is based on the length of ice melted and the gross area of the ice compartment. Thus the total ice condenser volume increases as ice melts out. The temperature of this volume is set equal to the input value specified by TEX (3) and is based on test data.

The system pressure over this period is governed by the conditions in the upper compartment and the ice-filled part of the ice compartment. The calculation is based on the existing temperatures in these compartments. The temperature in the upper control volume of the ice compartment is calculated by dividing the difference of the existing temperature and the input value by a constant and subtracting it from the existing value. Depending on the constant, the temperature will approach the input value and is set equal to it when the difference is less than 0.5°F. The temperature in this control volume will now stay constant until all the ice is melted.

The volume of the upper ice compartment control volume is calculated based upon the remaining ice bed length. This volume is proportional to the remaining ice mass and will eventually become zero.

Now the calculations for the second part of this period are described. The start of the circulation fan causes the lower compartment to be filled with

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*(See figure 9-3)

upper compartment atmosphere at a specified flow rate, which is the fan flow rate. The model employed is that of a growing volume displacing the atmosphere present in an open cylinder. The model assumes no mixing of the growing volume and the atmosphere in the cylinder; this infers unequal temperatures for the two volumes and uniform pressure in the cylinder.

The governing equations for this process are the mass and energy balance for the growing volume.

Mass balance:

$$\frac{d}{dt} M = \Sigma m \tag{28}$$

Energy balance:

$$\frac{d}{dt} (uM) + p \frac{d}{dt} V = \Sigma mh + q - W \tag{29}$$

Application

The growing volume has an atmosphere of water, steam, and air. The only flow leaving this volume will be the steam that is condensing. Since there will be no work done the last term of Equation 29 is zero.

The mass balance can now be written as:

$$\frac{d}{dt} M_a + \frac{d}{dt} M_w + \frac{d}{dt} M_s = m_a + m_s - m_c \tag{30}$$

The energy balance becomes:

$$\frac{d}{dt} (M_a u_a + M_w u_w + M_s u_s) + p \frac{d}{dt} V = m_a h_a + m_s h_s - m_c h_c - q \tag{31}$$

The unknowns are now the internal energy which is a unique function of the mass, temperature, and volume.

The energy balance is now directly integrated between two instants and the pressure is kept constant over the integration period and equal to the value at the lower boundary of the integral. This results in:

$$(M_a u_a + M_w u_w + M_s u_s)_2 - (M_a u_a + M_w u_w + M_s u_s)_1 + p\,V_2 - pV_1 =$$

$$m_a h_a\ \Delta t + m_s h_s\ \Delta t - m_c h_c\ \Delta t - q \qquad (32)$$

At instant 1 the temperature, volume, and pressure are known.

$$H_1 + \Sigma\ mh\ \Delta t = (M_a u_a + M_w u_w + M_s u_s) + p\ V_2 \qquad (33)$$

To solve Equation 33, an iterative procedure is necessary. The left-hand side represents the energy in the expanding volume at the instant for which the volume is to be calculated. The second term represents all the net energy additions over the time-step to the expanding volume and can be calculated at any given instant.

From the mass balance, the mass of air at the end of the itegration can be found from

$$M_{a,2} = M_{a,1} + m_a \Delta t \qquad (34)$$

where m_a is specified by the recirculation fan flow.

The iterative procedure is as follows:

1. Estimate a temperature for the end of the integration step.

2. Find from the water-steam properties tables for this temperature, the pressure, the specific enthalpy, and the specific volume of

the saturated steam in the expanding volume. Since the total pressure is held constant over the step, the specific enthalpy and specific volume of the formed water can also be found.

3. The air pressure is now equal to the total pressure minus the steam pressure and thus the specific volume and enthalpy of the air can be calculated.

4. Calculate the specific internal energies of the three constituents of the expanding volume.

5. Now the volume can be calculated from the known air mass and its calculated specific volume.

6. With this volume, calculate the masses of water and steam from their specific volume values.

7. The total internal energy can now be calculated from the masses and the specific values of the internal energy of air, water, and steam.

8. As a closing condition, the left-hand side of Equation 33 can now be calculated.

The error, being the difference between the known left-hand side and the calculation of Step 8, is now used in Newton's method to find a better estimate for Step 1.

The steps are then repeated until an error criteria, one percent of the left-hand side of value of Equation 33 is met.

If the iteration is successful, the water mass in the volume is calculated as follows: with a given spray flow rate and fall velocity, a certain amount of water will be present in the volume. If the calculated amount of water in the volume is larger than the spray water, it will leave the volume as condensed steam. In case of no spray, the water is allowed to stay in the expanding volume.

The known masses and specific enthalpies in the expanding volume enable determination of the total enthalpy for the volume.

For the calculation of the temperature in the upper compartment, the same method as in the first part of this period is employed, taking into account the recirculation fan flow rate out of this compartment.

If the expanding volume is smaller than the lower compartment volume and ice-empty part of the ice compartment, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.

If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.

During the second period, the ice inventory calculations are identical to those of the first period, as are the containment control volume mass distribution calculations. The latter calculation takes the diminishing steam-filled volume of the lower compartment into account.

The dead-ended volume of the lower compartment is treated as follows. In case it is a part of the upper compartment, no calculations are necessary.

When assigned to the lower compartment, and acting independently, the volume of the initial air in this compartment is calculated, assuming it is at the upper-compartment temperature with saturated steam in it. If a purge rate from the dead-ended volume is specified, the purging of the dead-ended volume starts with the start of the circulation fan, and the purge rate is added to the circulation fan flow. The decreasing dead-ended volume is thus calculated by Equation 27 with the same assumptions as mentioned above. The decrease of this volume is added to the lower compartment volume and the dead-ended volume becomes an integral part of the lower compartment.

The structural heat removal calculation, discussed in Section 7, is based upon a volume averaged temperature of the lower compartment for this period.

5.3 LONG TERM PERIOD

This phase of the analysis begins as soon as the circulation flow through the containment has been established and continues until the problem is terminated. The major occurrences of this phase are recirculation and ice meltout. Recirculation occurs when the refueling water storage tank has been drained. At this time the safety injection and spray systems begin drawing from the active sump instead of the refueling water storage tank (the two sump model is discussed in Section 9.4). The spray system flow continues to be routed through the spray heat exchanger during this period, with the safety injection and residual spray flows through the residual heat exchanger.

Meltout occurs when there is no longer enough ice in the ice bed to prevent steam from flowing directly from the lower compartment to the upper compartment. As long as there is ice in the ice compartment, the temperature in the melted out part of this compartment has a constant value, specified by an input number (TEX (3)). The same applies to the temperature in the ice-filled part of the ice compartment, the input value being TEX (4). Due to maldistribution which is inputed to the code the sub-compartments may melt in a sequenced manner rather than simultaneously. If the ice in a section of the ice bed is completely melted, the temperature in this section is equal to the lower compartment temperature. The temperature in the total ice-melted part of the ice bed is then the average by volume of the temperatures in the empty ice sections. If the length of the ice bed in a section is less than one foot, the exit temperature of this section will linearly increase to that of the lower compartment temperature. If the melting of ice is complete, control volume *No. 4 ceases to exist.

During the long term phase the fan flow from the upper compartment and the flow out of the lower compartment are assumed to be at the temperature of the compartment the flow is leaving. The temperature in the upper and lower compartments is calculated by the methods described in Section 2.

* (See Figure 9-3)

6.0 ICE CONDENSER HEAT REMOVAL

The fundamentals for the heat transfer calculations in the ice condenser part of the containment are the test data gathered from the ice condenser test facility. These test data as applied in the calculation of the ice inventory are the following:

During the initial blowdown of the primary coolant system the total blowdown mass and energy enter the ice condenser compartment. The resulting ice bed drain temperature, being the blowdown mass and melted ice, is established by test results and is input to the code.

For the long-term period, only boiloff steam enters the ice compartment. The temperature of air-saturated-steam mixture leaving the ice condenser is established by test results and is input to the code. This exit temperature allows some steam to enter the upper compartment. The ice bed drain temperature for this period is also input based upon test results. These data enable one now to calculate the inventory of ice at a given instant. The governing equations are: For the mixture flowing in the ice condenser -

Mass balance:

$$m_{s,in} + m_{a,in} = m_{s,out} + m_{a,out} + m_c \qquad (35)$$

Energy balance:

$$m_s h_{s,in} + m_a h_{a,in} = m_s h_{s,out} + m_a h_{a,out} + m_c h_c + q + q_{ice} \qquad (36)$$

Dalton's law for a multiconstituent mixture of gases, applied at the exit side of the ice compartment:

$$m_{s,out} = \frac{18}{29} m_{a,out} \frac{P_s}{P_a} \qquad (37)$$

For the ice bed:

Mass balance:

$$\frac{d}{dt}(M_{ice}) = m_m \tag{38}$$

Energry balance:

$$q_{ice} = m_m (h_m - h_{ice}) \tag{39}$$

For the resulting drainflow

Mass balance:

$$m_{drn} = m_m + m_c \tag{40}$$

Energy balance:

$$m_m h_m + m_c h_c = m_{drn} h_{drn} \tag{41}$$

This set of equations will be used to calculate the ice-inventory in the ice-condenser compartment.

Application

With the assumptions made for the blowdown period, the total heat removal can be found. From Equation 35 we see that

$$m_c = m_{BD} - \frac{q}{h_{f_g}} \tag{42}$$

substituting this in Equation 36 gives

$$q_{ice} + m_c h_c = m_{BD} h_{BD} - q \tag{43}$$

For the long-term period, q_{ice} is defined from the same equations and from Equation 37. From Equation 35

$$m_c = m_{s,in} - m_{s,out} - \frac{q}{hfg} \tag{44}$$

Equation 37 can be solved because the exit temperature of the steam and air mixture are specified and the steam is assumed to be saturated. Substituting these results in Equation 36 gives

$$q_{ice} + m_c h_c = m_s h_{s,in} - m_s h_{s,out} + m_a (h_{a,in} - h_{a,out})^{-q} \tag{45}$$

Substitution of Equation 39 in Equation 41 yields:

$$m_m h_{ice} + q_{ice} + m_c h_c = m_{drn} h_{drn} \tag{46}$$

and substitution of Equation 40 into Equation 46 gives

$$m_m (h_{drn} - h_{ice}) = q_{ice} + m_c h_c - m_c h_{drn} \tag{47}$$

Since the ice condenser drain water temperature is a specified input value for both the blowdown and long-term period, it follows from Equation 47 that m_m can be solved. Via Equation 38, the change in ice mass thus is solved.

Ice inventory in each of the six ice condenser sections is calculated to provide sequenced melted out of ice bed sections and therefore bypass of the ice condenser during melt out. Maldistribution to the six sections plus direct divider deck leakage can be inputted to the code.

7.0 STRUCTURAL WALL TEMPERATURE CALCULATION

During a postulated accident, heat is absorbed by the walls of the containment structure, as well as by interior support walls and relatively cold equipment inside the containment. There also may be considerable heat dissipation to the external air by steel vessel containment structures. In this analysis, only a slab geometry is considered, and heat transfer in any direction is neglected, with the exception of that perpendicular to the wall surface.

Figure 7-1 shows a typical multilayered wall. For illustration purposes, this wall is assumed to have two layers and to be in contact with the containment steam-air mixture on the inner surface. Walls may also be specified as having more than two layers. Each layer is divided into a small number of small elements ΔX wide (except for the two surface elements which are ΔX/2 wide). The thermal properties of each layer are assumed constant, and each element is assumed to be a uniform temperature. To obtain a spatially converged temperature gradient for different materials, the element width may be varied from layer to layer.

The conservation of energy equation is then written in finite-difference form for every element. Thus, for the inside surface element, the equation is:

$$\{\rho_W c_W \frac{\Delta X}{2}\}_1 \frac{dT_1}{dt} = H_{sW} (T_{s1} - T_1) + \{\frac{k_W}{\Delta X}\}_1 (T_2 - T_1) \qquad (48)$$

All temperatures, T, refer to element temperatures within the wall unless subscripted otherwise in these equations. In general, for the j-th interior element of the k-th layer:

$$[\rho_W c_W \Delta X]_k \frac{dT_j}{dt} = [\frac{k_W}{\Delta X}]_k [T_{j+1} - 2T_j + T_{j-1}] \tag{49}$$

It is further assumed that there is no energy storage in the "gap" between the k^{th} and $(k+1)^{th}$ layer in the wall, and an appropriate gap heat transfer coefficient is specified.

At the wall exterior surface, the energy equation includes a term for incident solar heat flux, as well as the heat transfer to an atmosphere temperature.

The heat removal rate from the containment steam-air atmosphere is defined as:

$$q = H_{sW} A_W [T_{s1} - T_1] \tag{50}$$

Summing equation 50 overall walls per compartment results in the energy removal terms used in the energy equations.

A similar equation is written for the heat removal rate from the sump water system, namely:

$$q_W = H_{wW} A_W [T_{w2} - T_1] \tag{51}$$

The current LOTIC code model accounts for structural heat transfer by compartment through the three analysis phases.

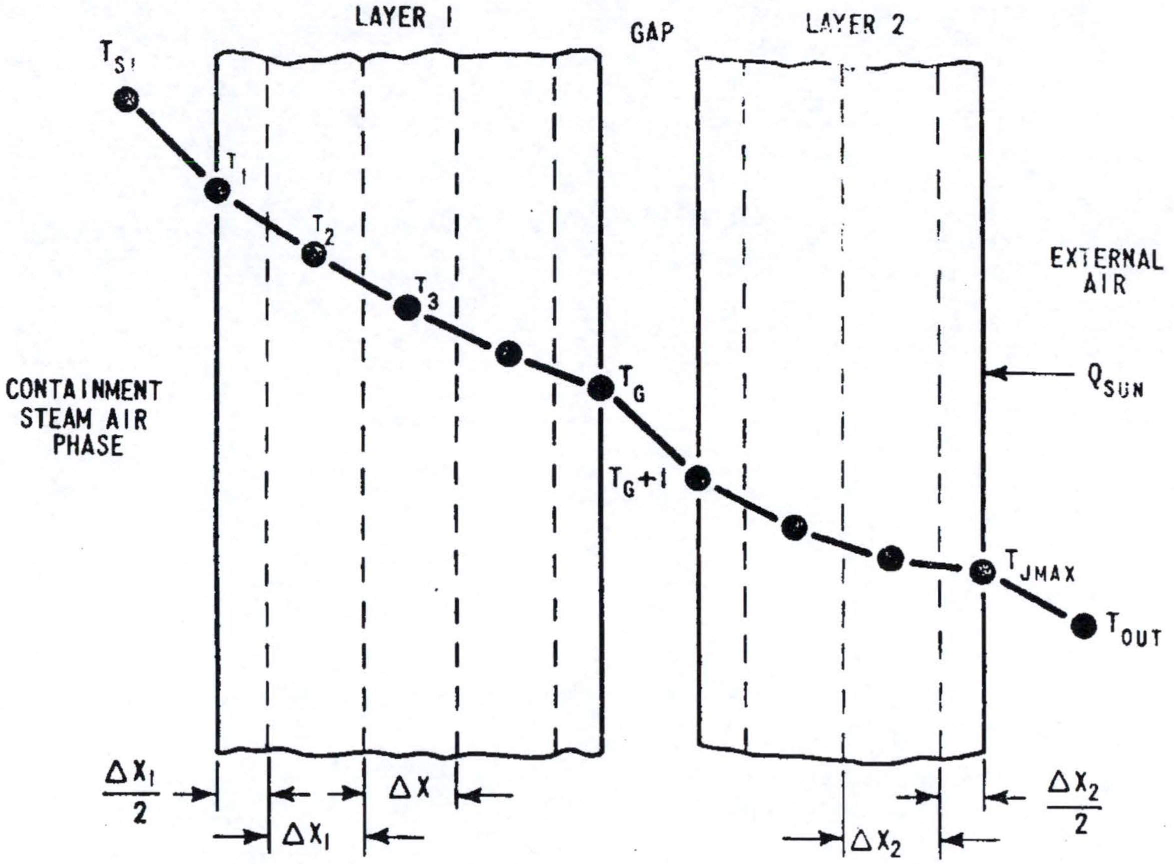


Figure 7-1 Cross Section of Typical Containment Wall

6067-14

8.0 HEAT TRANSFER COEFFICIENTS

Experimental data indicate the presence of high heat transfer rates between the containment atmosphere and the containment structures during the blowdown period due to the turbulence sweeping along the walls and the negligible thermal resistance of the thin condensate film layer present. Following blowdown, the condensing film heat transfer coefficient decreases to a smaller value. The condensate film thickness is then fully developed, and a stagnant air layer forms next to the cold surfaces, restricting the flow of steam.

The LOTIC code has the options of specifing heat transfer coefficients as a function of time or calculating a film coefficient similar to that employed in the COCO code for analysis of "dry" containments.

The heat transfer coefficient to the containment structure is calculated by LOTIC based primarily on the work of Tagami.(1) From this work it was determined that the value of the heat transfer coefficient increases parabolically to peak value at the end of blowdown and then decreased exponentially to a stagnant heat transfer coefficient which is a function of steam to air weight ratio.

Tagami presents a plot of the maximum value of h as a function of "coolant energy transfer speed," defined as:

$$\frac{\text{total coolant energy transferred into containment}}{\text{(containment vessel volume) (time interval to peak pressure)}}$$

From this the maximum of H for steel is calculated:

$$H_{max} = 75 \left[\frac{E}{t_p V}\right] 0.60 \qquad (52)$$

H_{max} = maximum value of H (Btu/hr ft^2°F)

t_p = time from start of accident to end of blowdown (sec)

The parabolic increase to the peak value is given by:

$$H_s = H_{max} \sqrt{\frac{t}{t_p}} \quad 0 \leq t \leq t_p \qquad (53)$$

H_s = heat transfer coefficient for steel (Btu/hr ft^2°F)

t = time from start of accident (sec)

The exponential decrease of the heat transfer coefficient is given by:

$$H_s = H_{stag} + [H_{max} - H_{stag}]\, e^{-.05\,[t-t_p]} \quad t > t_p \qquad (54)$$

where

$H_{stag} = 2 + 50\chi \quad 0 \leq \chi \leq 1.4$

H_{stag} = H for stagnant conditions (Btu/hr ft^2°F)

χ = steam to air weight ratio in containment

For concrete the heat transfer coefficient is taken as 40% of the value calculated for steel during the blowdown phase.

In the absence of external spray, three methods are available in the code for film heat transfer coefficients between the wall exterior surface and the external environment. First and simplest, a constant value may be specified. A value of 0 Btu/hr ft^2°F is used to simulate adiabatic conditions such as insulation, symmetrical interior wall exposed on both sides, or the exterior of a thick concrete slab. Second, an input table can be used to specify the coefficient as a function of time. Third, a procedure described by MacAdams [2] has been incorporated in the code to calculate a combined radiation and convection coefficient based on simplified equations for heat transfer from short vertical plates to still air. The convection portion is given by:

$$H_c + \frac{0.19\,[\Delta T]^{1/3}}{3600} \qquad \text{for } 10^9 < X < 10^{12} \qquad (55)$$

$$H_c = \frac{0.29\,[\Delta T/L]^{.25}}{3600} \qquad \text{for } 10^4 < X < 10^9 \qquad (56)$$

where:

$$\Delta T = T_{JMAX} - T_{out} \tag{57}$$

The X is defined by MacAdams as being the product of the Grashof and Prandtl numbers. The term $(X/L^3 \Delta T)$ was curve-fitted as a function of film temperature by the following equation:

$$\left[\qquad \frac{T'_{out}}{\quad} + 59 \right] \quad (58) \quad (a,c)$$

The contribution of radiation is evaluated in the following manner:

$$\left[\qquad \right] \quad (59) \quad (a,c)$$

The radiation and convection terms are combined to get the overall film coefficient at the exterior surface:

$$\left[\qquad \right] \quad (60) \quad (a,c)$$

For large values of vertical height L, H_c becomes independent of wall height and is a function of temperatures only. The above procedure should therefore also apply satisfactorily for comparatively high vertical walls.

9.0 ENGINEERED SAFEGUARD SYSTEMS

9.1 DESCRIPTION

The Engineered Safeguard Systems modeled in the program consist of a Safety Injection System and a Spray System. Because of decay heat produced by the reactor core after a loss-of-coolant accident, cooling water has to be supplied to the core by the Safety Injection System. Under the assumption that this cooling takes place by boiloff of the Safety Injection water, energy is added to the containment atmosphere. However, by means of the Spray system, the energy content of the containment atmosphere is reduced and absorbed by the containment sump water. Initially, the system draws in water from the Refueling Water Storage Tank for spray. After this tank is empty it is then switched to the containment sump water.

A schematic of the System as encoded in the LOTIC program is shown in Figure 9-1 for the initial period, and in figure 9-2 for the recirculation period.

The time for the System to switch to recirculation is either input or determined by the capacity of the Refueling Water Storage Tank and the combined flow rates of the spray, residual, high head and charging pumps.

The flow distribution in the System is governed by factors applied to the branch points A through E of the pipe system as depicted in Figure 9-3. The factors are supplied via input data. The option exists for a change of any of the factor values during the problem time.

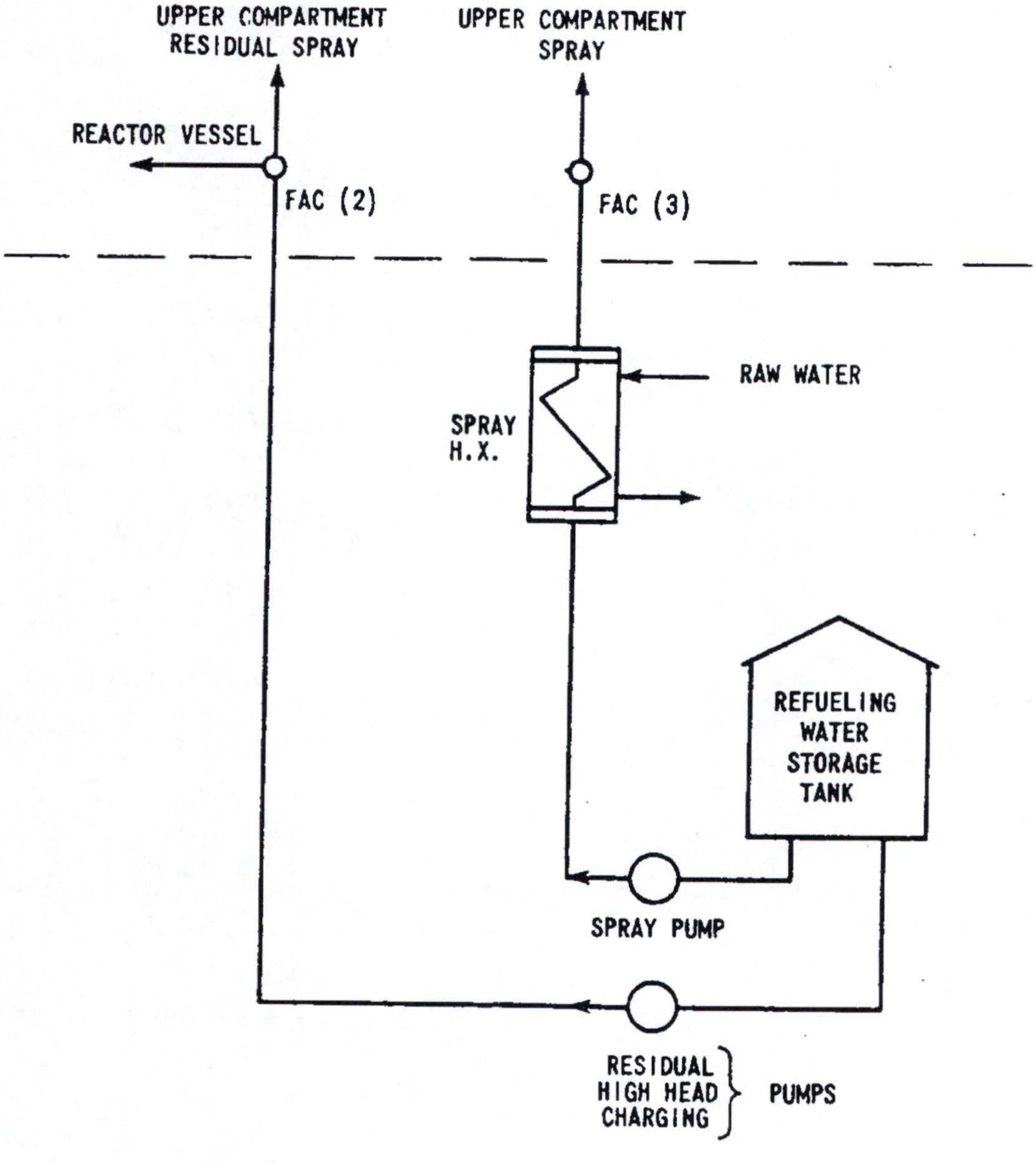


Figure 9-1 Safety Injection and Internal Spray System Before Recirculation

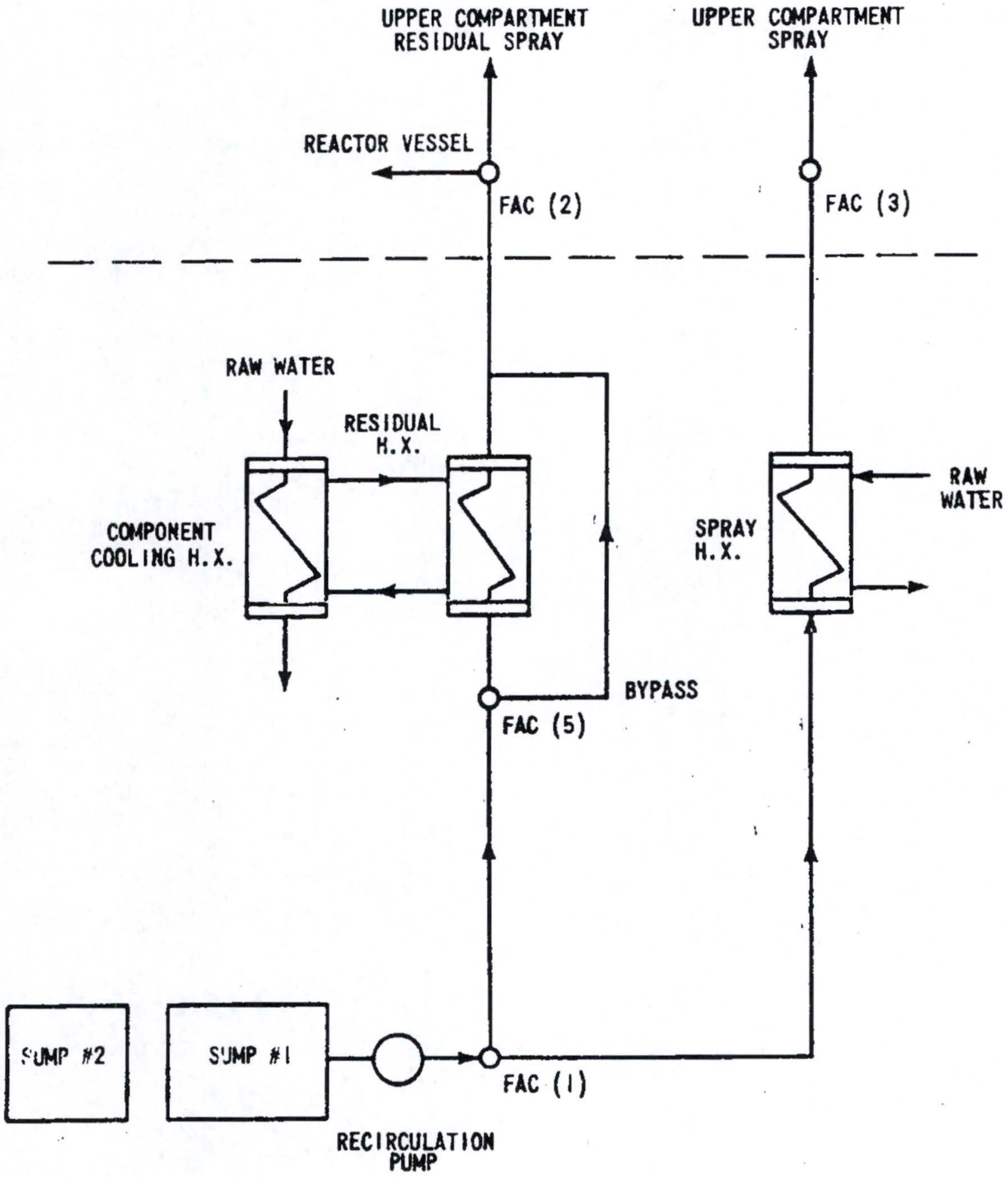


Figure 9–2 Safety Injection and Internal Spray System During Recirculation

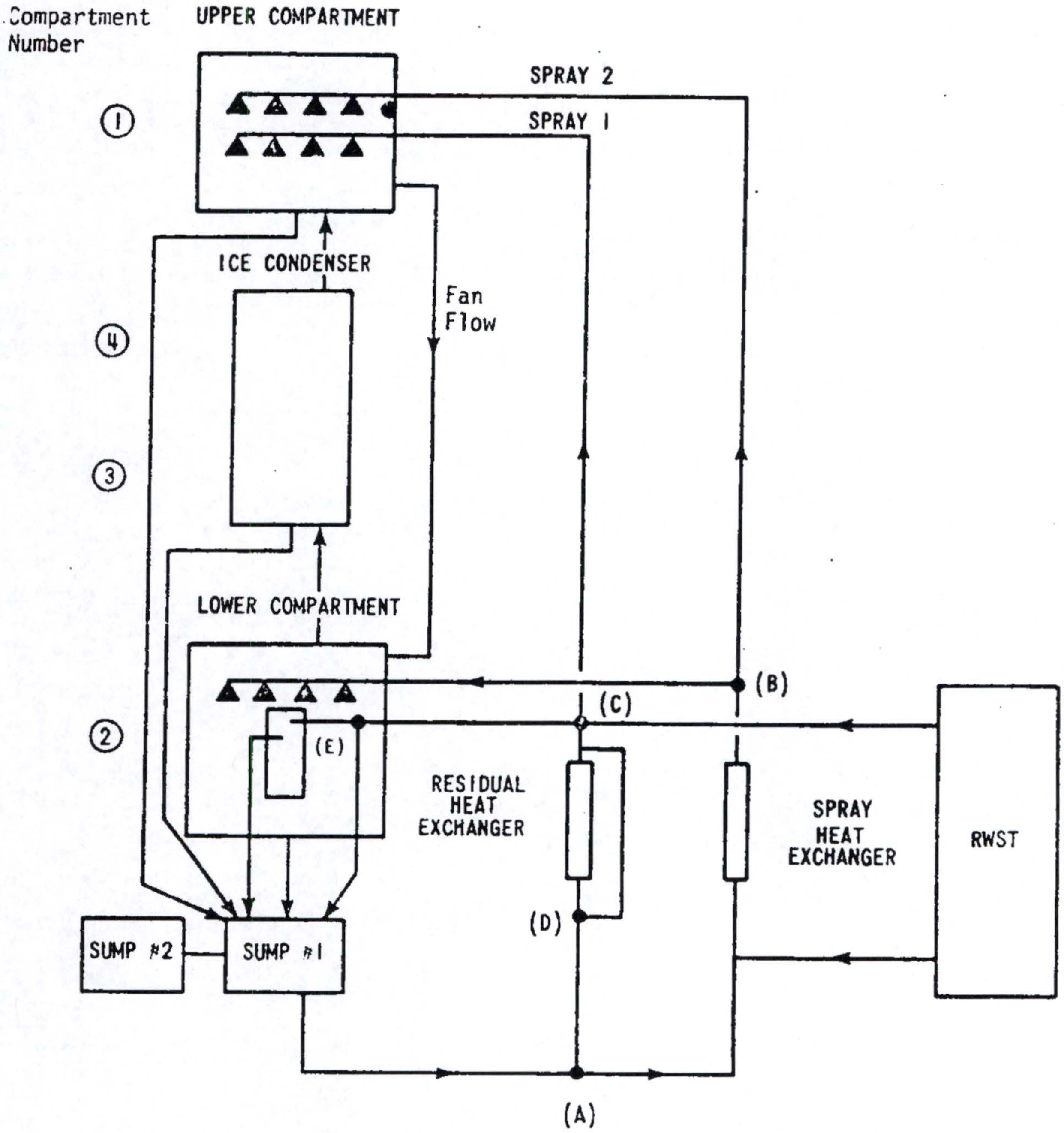


Figure 9-3
Safety Injection and Internal Spray Piping System

9.2 HEAT EXCHANGERS

The heat exchangers as programmed are one of the following type:

The component-cooling heat exchanger has counterflow, with the raw water flowing on the tube side.

The residual heat exchanger is a U-tube heat exchanger, with the safety injection and spray water on the tube side.

The spray heat exchanger is a U-tube or counterflow heat exchanger.

The performance equations are as follows:

(For a U-tube type)

[ ] (61) (a,c)

(For a counterflow type)

[ ] (62) (a,c)

where

[ ] (63) (a,c)

(64) (a,c)

The working forms of the equations are:

For the spray heat exchanger, Equation 61 is written as

[ ] (65) (a,c)

If the spray heat exchanger is identified as being of the counterflow type, Equation 62 is applied and written as

[ ] (66) (a,c)

This can be solved directly, as the term UA for each heat exchanger is specified by input data and P follows from Equation 63, where m_{co} = m_{raw}, and m_{ho} equals either the spray pump flow or the recirculation flow multiplied by the appropriate flow distribution factor.

From Equation 64

[ ] (67) (a,c)

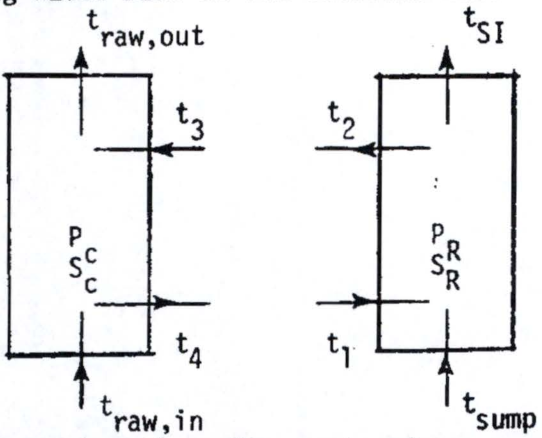
where $t_{ho,in}$ is either the refueling tank water temperature of the sump water temperature.

The spray water temperature now follows from Equation (3-3)

[ ] (68) (a,c)

The safety injection and residual spray temperature resulting from the combination of component cooling and residual heat exchangers is calculated as follows: The values of S for the residual and component-cooling heat exchangers follow from Equations 61 and 62, respectively, or their equivalent forms Equations 65 and 66, respectively. These equations can also be solved directly.

For the residual heat exchanger, P_R follows from Equation 63, m_{co} being the component-cooling water flow rate to the residual heat exchanger and $\dot{m}_{ho}$ is either the flow from the refueling water storage tank or part of the recirculation flow. For the component-cooling heat exchanger, P_C follows also from Equation (61), m_{co} is now the raw water flow and m_{ho} is the component-cooling water flow of the residual heat exchanger.



The temperature equations (see figure above) can now be written as
(For the component cooling water heat exchanger)

$$\left[\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\right]$$

(69) (a,c)

(70)

(For the residual heat exchanger)

$$\left[\qquad\qquad\qquad\qquad\qquad\right]$$

(71) (a,c)

(72)

(For the component cooling water flow)

$$\left[\qquad\qquad\right]$$

(73) (a,c)

(74)

The unknowns of this set of equations are t_1, t_2, t_3, t_4, $t_{raw,out}$ and t_{SIS}.

By elimination there follows

$$\left[\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\right]$$

(75) (a,c)

where:

(76)

9.3 INTERNAL SPRAY SYSTEM

The internal spray system is built into the containment upper and lower compartments to reduce the energy content of the compartment atmospheres. A set of spray headers is therefore employed, and the spray water emerges from these headers in thin sheets or as small droplets. The heat-transfer area available in a spray is thus very large. Heat removal by the sprays is based on the assumption that the spray water temperature rises to the compartment steam-air temperature.

Ample evidence exists to justify a heat removal efficiency of 100% for spray within containment vessels post-accident. Experimental evidence is provided in BNWL-1084(3). In one particular run of the Containment Systems Experiment drop temperatures were measured at three separate elevations within the CSE vessel. As reported in BNWL-1084, "the temperature(s) measured.... (were) consistent with behavior expected if the drops were in thermal equilibrium with the vessel atmosphere at the three vertical positions." Containment atmospheric conditions varied markedly during the experiment, but no decrease in efficiency under different conditions was noted.

ORNL-TM-2412 (4) presents an analytical model developed to calculate the temperature transient within spray drops of various sizes falling in a post-accident containment atmosphere. Heat transfer processes of conduction, convection, and condensation are considered, and a fully-developed boundary layer is assumed to exist on the drops. Results are presented for a number of cases involving parametric variations of drop diameter, atmospheric temperature, and initial drop temperature. The results presented "justify the conclusion that water introduced into a full-size containment building as sprays will attain temperature equilibrium with the building atmosphere." The approach to thermal equilibrium is shown to be much more rapid for small drops than for large ones. The fine droplets produced by the Spraco 1713A spray nozzle (geometric mean diameter = 282 microns) will reach thermal equilibrium with the surrounding atmosphere even more quickly than the drops considered in ORNL-TM-2412.

The governing equations for the internal spray system are provided in Equations (12), (13), and (14).

9.4 TWO SUMP MODEL

The active sump in the ice condenser containment may not have a large enough capacity to contain all the water of the reactor coolant system, the melted ice, and the refueling water storage tank. The excess water is spilled and is no longer available (inactive sump) for the safety injection or spray system. The maximum value of the active sump can be specified by input data.

The water mass and temperature in the sump is calculated as follows:

$$M_{sump,\,N} = M_{sump,\,0} + (\Sigma m_{drn} - m_{sis} - m_{spill})\,\Delta t \tag{77}$$

the summation is for all the flows entering the sump.

$$H_{sump,\,N} = \frac{H_{sump,\,0} + [\Sigma m_{drn} h_{dm} - (m_{sis} - m_{spill})\,h_{sump,\,0}]\Delta t}{M_{sump,\,0} + (\Sigma m_{drn} - m_{sis} - m_{spill})\,\Delta t} \tag{78}$$

The water volume follows now from

$$V_{sump} = M_{sump,\,N}/v_{w} \tag{79}$$

If the sump water volume is greater than the specified maximum volume, the spilling flow follows from

$$m_{spill} = (M_{sump,\,N} - \frac{V_{max}}{V_{w}})\,\Delta t \tag{80}$$

and the water mass is reset to

$$M_{sump,\,N} = \frac{V_{max}}{V_{W}} \tag{81}$$

This process is representative of the spill over into the pipe trench area after the sump inside the crane wall if filled. The water mass and temperature of the spilled water sump is calculated analogous to the main sump, the entering flow being the spilling flow having a temperature calculated by Equation (78).

The approach is conservative as the smaller active volume of this model heats more rapidly than an all inclusive sump and this causes higher spray temperatures during the recirculation phase of the accident.

10.0 AUXILIARY EQUATIONS

10.1 RESIDUAL HEAT

For the ECCS back pressure analysis the decay heat rates employed are consistent with the requirements of Section I of Appendix K of 10CFR50. For the ECCS analysis, post blowdown mass and energy flow rates are supplied as LOTIC code input and the LOTIC code residual heat option is not used.

The WNES residual heat standard is also incorporated as an option in the code for the total energy release rate from isotope decay following shutdown of the current generation of thermal reactors fueled with uranium (U-235 enriched). The three major contributors of energy are:

a. Fission-product decay heat,
b. U-238 capture decay, and
c. residual fissions.

The fission-product residual heat uses a combination of the proposed ANS Sub-committee-5 data and calculations by the WNES Radiation Analysis personnel for finite fuel region cycle times of 24,000 EFPH, 16,000 EFPH, and 8,000 EFPH.

10.2 ZIRCONIUM-WATER REACTION HEAT

The energy produced by a zirconium-water reaction in the core can be supplied as a time-dependent table. The energy is added to the residual heat, and thus results in an additional steam release into the lower compartment.

The boil-off from the core due to residual heat and an eventual zirconium-water reaction is calculated as follows:

$$m_{boil-off} = q / (h_s - h_w) \tag{82}$$

where h_s is the steam enthalpy at the existing lower compartment conditions and h_w is either the enthalpy of the water in the core or the enthalpy of the safety injection water put into the core. All other safety injection is spilled to the sump without removing heat.

If the effective safety injection option is used and the safety injection system is supplying water to the core, an energy balance is performed to calculate the enthalpy of the spilling safety injection water from the core.

$$h_{sp} = (m_{SIS} h_{SIS} + q)/m_{spill} \tag{83}$$

In case the calculated enthalpy is greater than the enthalpy corresponding to that of saturated water at the lower compartment condition, the steam boil-off is calculated by

$$m_{boil-off} = (m_{SIS} (h_{SIS} - h_{w,sat}) + q\}/h_{fg} \tag{84}$$

The remaining spilling water is at the saturated liquid condition.

10.3 MASS AND ENERGY RATE TABLES

An option is provided to supply a table of post blowdown mass and energy releases to the lower compartment atmosphere and sump. Core boiloff rates and sump spillage rates indicative of the safety injection system performance can be supplied as a function of time. The values are handled in the following manner:

1. The effective amount of saturated steam boiloff is calculated based on the steam mass and energy release rates.

2. Spillage to the sump is added to the active lower compartment sump at the energy content supplied. If this option is specified the normal safety injection flows are not used until after the last table value.

10.4 CORE BOILOFF SPLIT AND SAFETY INJECTION QUENCH

An option is provided to calculate the net core boiloff rate and spillage rate to the sump based upon decay heat input to the core. The fraction of the energy or steam flow that goes to the broken RCS loop is specified as input. The remaining core energy flows into the unbroken RCS loops where the safety injection flow may quench a part or all this steam flow. Any steam not condensed is added to the steam flow from the broken loop and safety injection water is spilled at saturated conditions. If the safety injection flow is sufficient to quench all the steam in the intact loops, an energy balance is performed to calculate the enthalpy of the spilling safety injection water.

11.0 COMPUTER CODE DESCRIPTION

11.1 GENERAL DESCRIPTION

The mathematical model described in this report has been implemented as a digital computer code having the name LOTIC (Long-Term Ice Condenser Code). The input data consists of geometric, engineered safeguard system design and energy and mass release into the containment information. The format for input is discussed in the next section of this report. The output data are divided into three types. The "long-form" output is a tabulation, at a given instant, of all important data for all elements. These data include pressures, temperatures, air and steam masses, mass flow rates, volumes, ice mass, etc. The "short-form" output is a tabulation, appearing at intervals among the long-form printouts, of gauge pressure in the containment, temperature of lower-upper compartment, the two sumps, and the containment spray temperatures for a sequence of forty time-steps. Typically, the time interval between two successive entries in a short-form printout is smaller than the time interval between successive long-form printout, but larger than the calculational time-step. Hence, the short-form printout allows the analyst to conveniently obtain a more detailed picture of the variation of pressure and temperature in time. Finally, the output is also available in the form of computer-prepared plots of pressure versus time for all elements.

11.2 FLOW DIAGRAM AND SUBROUTINE LIST

Figure 11-1 shows the computer code flow diagram for the LOTIC code. Table I lists the major and minor subroutines used in the LOTIC code.

11.3 INPUT DATA DESCRIPTION

Table I provides a list of LOTIC code subroutines.

Table II provides an input data description for the code.

FIGURE 11-1

LOTIC FLOW DIAGRAM

(a

Proprietary

Information

Deleted

TABLE I

LOTIC CODE SUBROUTINES

(a,c)

Proprietary information deleted

TABLE I (Continued)

(a,c)

Proprietary information deleted

TABLE II

LOTIC INPUT DATA DESCRIPTION

Card I.D.	Format	Symbol	Definition
1 and 2 (titles)	12A6		Heading (title for computer printout and plots (two title cards required)
3 (program control parameters)	7E10.4	CT(1)	End of problem time (sec)
		CT(2)	Maximum computer time allowed for the problem (min)
		CT(3)	The print subroutine is called after every CT(3) time step. This variable determines the number of time steps between the print steps. (After the print subroutine is called 40 times, a minor printout will occur for the previous 40 print step.)
		CT(4)	After the print subroutine is called CT(4) times, a major printout will occur. (If CT(3) =3. and CT(4)=10., a major printout will result after 30 time steps.)
		CT(5)	For temperature and pressure plots, CT(5)=1. To suppress plotting, CT(5)=0. The end time on the log (time) axis is equal to the last time entry of the time step tables.
		CT(6)	If CT(6)=0., wall temperature will not print; if CT(6)=1., temperatures will be printed. (To be used only when wall data cards are included.)
		CT(7)	Opiton for controlling spray heat exchanger when taking spray from refueling water storage tank (RWST). If CT(7)=0., spray heat exchanger cooling of RWST flow is used. If CT(7)=1., there is no cooling of RWST spray flow.
4 (program	7E10.4	CT(8)	Volume percent of ice compartment filled with air during blowdown

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
control parameters)		CT(9)	Containment pressure during blowdown (psig)
		CT(10)	Dead-ended volume location; If CT(10)=2., the volume is converted to lower compartment volume at the dead ended volume purge rate specified. If CT(10)=1., the volume is a part of the upper compartment.
		CT(11)	Reactor thermal output (Mw). This value is required for the decay heat option using the WNES residual heat standard. If decay heat is not used, CT(11)=0.
		CT(12)	Core boiloff option: CT(12)=0., boil off is considered, with SIS making up for boil-off and remainder of SIS spilled to sump. If CT(12)=1., credit is taken for SIS in suppressing the core decay heat boil-off. If CT(12)-1.0 Post blowdown Mass & Energy table is used.
		CT(13)	Initial energy in the reactor coolant (RCS) system, Btu (this is used only with wall option and is used in wall film coefficient calculation).
		CT(14)	Time of initial containment system peak pressure during or following blowdown, sec. (This is used only with wall option and is used in wall-film coefficient calculation).
5 (program control parameters)	7E10.4	CT(15)	Time (sec) to start using decay heat curve and/or zirc tables when the optional post blowdown mass and energy table is used CT(12).
		CT(16)	Spare
		CT(17)	Spare

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		CT(18)	Spare
		CT(19)	Spare
		CT(20)	Spare
		CT(21)	The fraction of the energy that goes out the broken loop after time of CT(15). SIS suppressing of remaining energy when CT(12) <0.

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
6 (tabular data control parameter)	7I3	NWALL	Total number of compartment walls. (Equipment in the compartments such as the bridge crane, steel beams, etc. may be represented as a separate wall-maximum of 20 walls).
		NTSTB	Number of points in the time step control table (maximum of 20).
		NBRKT	Number of break flow tables used (maximum of 4 tables with 14 points per table)
		NQHFT	Number of heat addition tables used (maximum of 4 tables with 14 points per table-first two tables for lower compartment, second two tables for upper compartment).
		NAIRT	Number of air addition tables used (maximum of 4 tables with 14 points per table-first two tables for lower compartment, second two tables for upper compartment).
		NZICT	Number of zirconium-water reaction tables used (maximum of 2 tables with 14 points per table)
		NFHTC	Number of time dependent film heat transfer coefficient tables for inner wall surface (maximum of 8 tables with 14 points per table).
ompartment ll data-1)			One card is required for each wall. The maximum number of cards is determined by the variable NWALL on card 5.
	8X, 4I3, 4E10.3	KELM(I)	Wall identification with respect to compartment; 1=upper compartment 2=lower compartment, 3=ice condenser.
		KMAX(I)	Number of individual layers (material layers) which make up the wall (maximum of 9 layers per wall).

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		ITBL(I)	Identification number for time dependent inner wall surface film heat transfer coefficient. The range of numbers is from 1 to 8. Negative numbers specify the Tagami heat transfer coefficient correlation (-2 for convrete and -1 for steel) which is contained in the code. Positive numbers refer to the user specified time dependent film heat transfer coefficient tables.
		IWTBL(I)	If IWTBL(I): (=1), the wall is in contact with the steam-air compartment atmosphere mixture; (= -1), the wall is in contact with sump water.
		TAIR(I)	Environmental temperature in contact with the outer wall surface, °F.
		WAREA(I)	Wall heat transfer surface area, Ft^2
		HGHT(I)	Vertical height of wall, ft. (used only for calculating convection heat transfer coefficient on outer surface-suggested value is 1 ft)
		TINT(I)	Initial wall temperature, °F (assume to be uniform at time =0).
(Compartment wall data-2)			These cards contain information pertaining to the individual layers which make up a wall. One card is required for each layer. (Minimum of one layer per wall and a maximum of nine layers; number of layers is specified by the variable KMAX(I).
	14X, 2I3 5E10.4	IN(I,K)	Number of nodes in the K-th layer of I-th wall (minimum of 2 nodes and maximum of 20 per layer).
		NT(I,K)	This variable determines the mode of heat transfer on the outer

Card I.D.	Format	Symbol	Definition
			surface of the wall layers. For a wall that is made up of several layers, NT(I,K)=0 if it is an inner layer. If the wall layer is on the outside (outer wall surface) and there is time dependent heat transfer or an external spray, the NT(1,K)=1.
		DELX(I,K)	Thickness of k-the layer, ft.
		THCØN(I,K)	Thermal conductivity of K-th layer, Btu/hr'ft-°F.
		RHØCP(I,K)	Product of endsity and specific heat (ρCp) for K-th layer, Btu/Ft^3-°F.
		HGAP(I,K)	This variable represents the heat transfer coefficient between the K and K+1 wall layers or the outermost wall layer and the outside atmosphere, Btu/hr-ft^2-°F, and it can have a positive zero, or negative value. (a) A positive value specifies a constant heat transfer coefficient (for paint-to-steel or paint-to-concrete, HGAP(I,K)=10^4) (b) A zero value specifies an adiabatic wall, i.e., no heat transfer (for outside wall only) (c) A negative value specified convection and radiation from a vertical plate to outside air (if HGAP(I,K)=1, the program calculates the proper heat transfer coefficient).
(external all surface eat transfer ontrols)			The following three cards provide data for time dependent external wall heat transfer and for external wall spray. The cards are not required if the previously defined variable NT(I,K)=0, i.e., the wall is adiabatic.
	2I3	NHGAP(I)	Number of values in the film heat transfer coefficient table for each outside wall layer (maximum of 10 values per wall). If NHGAP(I) =0, there is no time dependent wall heat transfer, and wall heat transfer cards (TIGAP(K,I) and HGAPT(K,I) are not required.

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		NSPRA(I)	External spray option on the outer wall surface; NSPRA(I)=0 external spray is not used and spray description cards (QEXSPR(I), etc.) are not required; NSPRA(I)= 1, external spray is used, and spray description cards must be provided.
(external wall surface heat transfer coefficient tables)	6E10.4	TIGAP(K,I)	Time at which the K-th outer wall heat transfer ceofficient begins to apply, sec.
		HGAPT(K,I)	Heat transfer coefficient for outerwall at time TIGAP(K,I), Btu/hr-ft^2-°F.
(external wall surface spray parameter)	6E10.4	QEXSPR(I)	External wall surface spray flow rate, gpm.
		TEXSPR(I)	Temperature of external spray water, °F.
		PEXSPR(I)	Atmospheric pressure at outer wall surface, psia (used to determine spray boiling temperature).
		TSTART(I)	Time for initiation of external spray, sec.
		TISTØP(I)	Shutoff time for external spray sec.
		HSUBEX(I)	Heat transfer coefficient between outer wall surface and spray water based on mean temperature differences, Btu/hr-ft^2-°F.
(inner wall heat transfer coefficient table)	8I3	IMHTC(M)	Number of values in the M-th inner wall surface film heat transfer coefficient table maximum of 8 tables with 14 values per table).
	6E10.4	TFHTBL(I,M)	Time at which the I-th inner wall film heat transfer coefficient begins to apply, sec (maximum of 14 values per table).

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		HTMTBL(I,M)	Inner wall film heat transfer coefficient at time TFHTBL(I,M) Btu/hr-ft^2-°F.
(time step table)	6E10.4	TDLTB(I)	Time at which the I-th time step size begins to apply, sec (maximum of 20 values).
		DELTB(I)	Time step size at time TDLTB(I), sec.
(break flow table)	6I3	NPNBT(I)	Number of values in the I-th break flow-energy vs time table (maximum of 4 tables with 14 values per table)
	6E10.4	TBKTBL(I)	Time at which the I-th break mass flow rate and total enthalpy flow rate begins to apply, sec.
		BRKFLØ(I)	Break mass flow rate at time TBKTBL(I), lbs/sec.
		BRKENG(I)	Break total enthalpy flow rate at time TBKTBL(I), Btu/sec.
(heat addition table)			The heat addition table data are not required if NQHET=0 on card 5. The first two tables are for lower compartment and second two tables are for upper compartment.
	6I3	NPNHET(I)	Number of points on the I-th heat addition rate table (maximum of 4 tables with 14 values per table).
	6E10.4	TNHETB(I,N)	Time at which the N-th heat addition rate applies, sec.
		QNHET(I,N)	Heat addition rate at time TNHETB(I,N), Btu/sec.
(air addition table)			The air addition table data are not required if NAIRT=0 on card 5. (The first two tables are for air addition to the lower compartment and the second two tables are for air addition to the upper compartment.

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
	4I3	NPNAIT(I)	Number of values in the I-th addition table (maximum of 4 tables with 14 values per table).
	6E10.4	TNAITB(I,N,)	Time at which the N-th air addition mass flow rate and air temperature apply, sec.
		EMAIT(I,N)	Air addition mass flow rate at time TNAIBT(I,N), lbs/sec.
		TAIRT(I,N)	Air addition temperature at time TNAIBT(i,N), °F.
(Mass & energy release rate table)			Post blowdown steam mass and energy and spill mass and energy rates.
	I3	NPBRKT	Number of points in mass-energy table. 40 points maximum.
	5E10.4	TBRKT	Time at which mass and energy rates applies, seconds.
		BRKTM	Mass of steam release to lower compartment, lb/sec.
		BRKTE	Energy of steam release to lower compartment, Btu/sec.
		SPILLM	Mass of spilled liquid to lower compartment sump, lb/sec.
		SPILLE	Energy of spilled liquid to lower compartment sump, Btu/sec.
(zirc heat table)			The zirconium-water reaction table data are not required if NZICT=0 on card 5. These data may be used as a substitute for the WNES residual heat standard or as a method of supplying the zirconium-water reaction heat in addition to decay heat. (The decay heat control parameters is CT(11) on card 4.)
	2I3	NPNZIT(I)	Number of points in the I-th zirconium-water reaction table (maximum of 2 tables with 14 points per table).

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
	6E10.4	TNZIBT(I,N)	Time at which the I-th value of the zirconium-water reaction heat addition rate applies, sec.
		QNZIBT(I,N)	Zirconium-water reaction heat addition rate at time TNZIBT(I,N), Btu/sec.
compartment initial conditions			The following initial condition data are required for each of the five compartment volumes in the order given below. 1. upper compartment 2. lower compartment. 3. ice compartment where ice has melted (initially this compartment has a zero volume). 4. ice filled portion of ice compartment. 5. dead-ended compartment.
	5E10.4	VØLM(I)	Volume of atmosphere in I-th compartment, ft^3.
		PTØT(I)	Atmospheric pressure in I-th compartment, psia.
		TEMP(I)	Initial atmospheric temperature in I-th compartment, °F.
		REHU(I)	Relative humidity in I-th compartment, (percent).
		TEX(I)	Temperature of steam and air mixture leaving the I-th compartment, °F.
afety in- ection and nternal pray	7E10.4	GRFST	Refueling water storage tank capacity, gal.
		TRFST	Refueling water storage tank temperature, °F.
		RHPUMP	Residual heat pump volume flow rate (injection phase) gpm.
		HHPUMP	High head pump volume flow rate (injection phase), gpm.

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		CHPUMP	Charging pump volume flow rate (injection phase), gpm.
		SPPUMP	Spray pumps volume flow rate (injection phase), gpm.
		QSUMP	Sump pump volume flow rate (recirculation phase total flow), gpm.
(heat exchanger parameter-1)	6E10.4	UASPHX	Spray heat exchanger UA in millions Btu/hr-°F.
		UACCHX	Component cooling water heat exchanger UA, in millions Btu/hr-°F.
		UAREXH	Residual heat exchanger UA, in millions Btu/hr-°F.
		QSHSPR	Residual heat exchanger shell side volume flow rate, gpm.
		QTUCC	Component cooling water heat exchanger tube side volume flow rate, gpm.
		QSHRE	Residual heat exchanger shell side volume flow rate, gpm.
(heat exchanger parameters-2)			The following data permit shell-side-to-shell-side coupling of a component cooling heat exchanger to the spray heat exchangers.
	2E10.4,I3	UACCHXZ	Spray component cooling heat exchanger UA, in millions of Btu/hr-°F.
		QTUCCZ	Spray component cooling heat exchanger UA, in millions of Btu/hr-°F.
		IDAN	Spray component cooling heat exchanger identification: 0=no component cooling heat exchanger, 1=U- tube component cooling heat exchanger 2= counter flow component cooling heat exchanger.

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
(cooling tower/ pond water parameters)			An option has been provided which allows the raw water to be taken from a cooling pond which is fed by cooling tower that returns to the pond a constant flow of water at a constant temperature. The cooling tower back flow is mixed with the original pond contents to give a source of raw water at a changing intermediate temperature. (If the option is not to be used, the cooling tower flow rate and pond volume may be input as any large numbers but the temperature of the cooling tower flow must be the exact value of the raw water temperature).
	4E10.4,I3	RWAT	Raw water temperature, °F.
		QBACK	Cooling tower to pond volume flow rate, gpm.
		TBACK	Cooling tower back flow water temperature, °F.
		GALRWT	Cooling pond volume, gal.
		IDEN	Spray heat exchanger identification: (IDEN=1) U-tube type heat exchanger, (IDEN=2) counterflow type heat exchanger
(safety injection system (SIS) parameters)	6E10.4	TSIST	Safety injection system start time, sec.
		TFANS	Start time for first recirculation fan, sec.
		TSUMS	Start time for sump recirculation pumps, sec (The recirculation pump starts when the refueling water storage tank is empty or at TSUMS which ever occurs first).
		QFAN	Volume flow rate for first recirculation fan, cfm.
		VSUMAX	Volume of active lower compartment sump, ft^3

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
		PURGE	Volume flow rate purged from the dead-ended compartment, cfm (This variable is used only if the dead-ended compartment is specified to be a part of the lower compartment. (See variable CT(10) on card 4).
(second recirculation fan parameters)	2E10.4	TFANS2	Start time for second recirculation fan, sec.
		QFAN2	Volume flow rate for second recirculation fan, cfm.
(safety injection system flow distribution)			The flow distribution in the safety injection and spray systems at the various branch points is specified by flow factors. The flow rate in one branch line is determined by multiplying the line flow rate feeding the branch by a flow factor. (0≤ flow factor ≤1.) The flow rate in the adjacent branch line is the feed line flow rate times the quantity one minus the flow factor. Please refer to figure 1 to determine the branch point locations.
	7E10.4	FAC(I,1)	Branch flow distribution factor before time TFAC(I), I=1, 7 (branch factor FAC(7,1) is currently not used), dimensionless.
	7E10.4	TFAC(I)	Time at which branch flow distribution factor is changed from FAC(I,1) to FAC(I,2). If the branch factor does not change, TFAC(I)=0. (Note that the time for each branch flow distribution factor to change from FAC(I,1) to FAC(I,2) is a separate piece of data, i.e., I-1,7), sec.
	7E10.4	FAC(I,2)	Branch flow distribution factor after time TFAC(I), dimensionless (seven values are required).

LOTIC INPUT DATA DESCRIPTION (Cont)

Card I.D.	Format	Symbol	Definition
(ice condenser flow distribution)	E10.4	TDIS	Time at which ice condenser flow distribution factors change from FDIS(I,1) to FDIS(I,2), sec (Note: all flow distribution factors for the ice condenser change at time TDIS), sec.
(ice condenser flow distribution-)	7E10.4	FDIS(I,1)	Flow distribution factor in each ice condenser section after time is greater than TDIS, ΣFDIS(I,2)= 1. (This set of flow distribution factors determines the ice condenser flow distribution during blowdown. There must be six flow distribution factors for the ice condenser and sum must equal 1.0.
(ice condenser flow distribution-3)	7E10.4	FDIS(I,2)	Flow distribution factor in each ice condenser section after time is greater than TDIS, ΣFDIS(I,2)= 1. (A seventh flow distribution factor is usually included in the group. It represents the deck leakage between the lower and upper compartments). Sum of distribution factors must equal 1.0.
(ice condenser angular section)	6E10.4	ANGE(I)	These data represent the number of ice condenser inlet door parts per ice condenser angular section. (The values used are usually 2.75, 3.25, 6.50, 4.50, 3.50 and 3.50. These data should be the same for corresponding TMD and LØTIC calculations).
(ice condenser parameters)	5E10.5	EMIC	Total initial ice condenser ice mass, lb.
		ELIC	Initial ice bed vertical length, ft (usually 48 ft).
		HDR(9)	Ice condenser drain water temperature during blowdown, °F.
		TDRIC	Time at which ice condenser drain temperature changes from HDR(9) to HDR(10), sec (usually 10-sec-determined by time required for blowdown).

Card I.D.	Format	Symbol	Definition
		HDR(10)	Ice condenser drain water temperature after blowdown, °F.

SECTION 12

NOMENCLATURE

Variables

A	Surface area, ft^2
c	Specific heat, Btu/lbm°F
E	Energy, BTu
H	Heat transfer coefficient, Btu/sec-ft^2-°F
h	Enthalpy, Btu/lbm
K	Thermal conductivity, Btu/sec-ft-°F
M	Mass, lbm
m	Mass flow rate, lbm/sec
P	Dimensionless temperature group
p	Pressure, lbf/in^2
q	Heat addition or removal rate, BTu/sec
R	Gas constant, lbf-ft^3/in^2-lbm-°R
S	Dimensionless temperature group
T	Temperature, °F
t	Time, seconds
Δt	Time step/size, seconds
UA	Overall heat transfer coeff, BTu/sec-°F

NOMENCLATURE

(Cont.)

u	Internal energy, Btu/lbm
v	Specific volume, ft^3/lbm
V	Volume, ft^3
W	Mechanical Work, BTu/sec
X	Grashof times Prandlt number
ΔX	Wall element width, ft.
ε	Emissivity
θ	Temperature, °R
ρ	Density, lbm/ft^3
σ	Stefan-Boltzmann constant (0.1713×10^{-8} Btu/ft^2-hr-$°R^4$)

Subscripts

a	Air
BD	Blowdown
C	Component Coolint
c	Condensate
co	Cold
drn	Drain

NOMENCLATURE

(Cont.)

fg	Vaporization
ho	Hot
ice	Ice
in	Entering a control volume
k	Refers to the k-th layer in a wall
m	Melted ice
N	New
O	Old
out	Leaving control volume
raw	Raw Water
R	Residual
s	Steam
sat	Saturated
sp	spilling
spray	Spray
sump	Sump
sys	System
sis	Safety injection System

NOMENCLATURE

(Cont.)

w	Water
wW	Water to Walls
1	Refers to steam - air volume
2	Refers to sump water volume

Operations

$\frac{d}{dt}$	Derivative with respect to time
Σ	Summation
Δ	Increment

13.0 REFERENCES

1. Tagami, Takasi, Interium Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June, 1965 (No. 1).

2. MacAdams, W. H., "Heat Transimssion, 3rd Edition, Chapter 7, Pages 172-174.

3. "Nuclear Safety Quarterly Report February, March, April, 1969, for Nuclear Safety Branch of USAEC Division of Reactor Development and Technology," Battelle Memorial Institute, June, 1969, p. 2.20-2.24.

4. Parsly, L. F., "Design Considerations of Reactor Containment Spray Systems - Part VI. The Heating of Spray Drops in Air-Steam Atmospheres," ORNL-TM-2412, Part VI, Oak Ridge National Laboratory, January, 1970.

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Our ref: LTR-NRC-17-56

July 5, 2017

Subject: Submittal of RAI Response Regarding WCAP-8354-P-A & WCAP-8355-A, "Long Term Ice Condenser Containment Code - Lotic Code"

Reference: Ekaterina Lenning to James A. Gresham, "Request for Additional Information Re: Westinghouse Electric Company letter 'Changes in Westinghouse WCAP-8354-P-A & WCAP-8355-A, Long Term Ice Condenser Containment Code - Lotic Code' (TAC No. MF9354)" June 6, 2017

The purpose of this letter is to transmit a response to the Nuclear Regulatory Commission's request for additional information (RAI) in the reference above. LTR-NRC-17-56 NP-Attachment provides this response.

The attached information is non-proprietary.

Correspondence concerning this submittal should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Suite 310, Cranberry Township, Pennsylvania 16066.

JA Gresham

James A. Gresham, Manager
Regulatory Compliance

Enclosures

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LTR-NRC-17-56 NP-Attachment

RAI Response Regarding WCAP-8354-P-A & WCAP-8355-A, "Long Term Ice Condenser Containment Code - Lotic Code"

In Section 5.2, page 5.2-6 of WCAP-8354-P-A and WCAP-8355-A, the following logic for the calculation of the instantaneous containment pressure (pressure between two consecutive time steps) is being revised:

FROM

[1] *If the expanding volume is smaller than the lower compartment volume, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.*

[2] *If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions.*

[3] *If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.*

TO

[1] *If the expanding volume is smaller than the lower compartment volume and ice-empty part of the ice compartment, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.*

[2] *If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.*

SRXB-RAI 1 – The addition of "ice-empty part of the ice compartment" in [1] appears to be a significant change in the total volume (lower compartment volume + ice–empty volume) which is compared with the expanding volume, because the ice–empty volume varies from zero (or a small volume) to the full volume of the ice-compartment during the depressurization phase. Provide a quantitative impact of this change on the entire pressure response, including the peak pressure, by performing a sensitivity analysis for the most bounding ice-condenser plant in the United States.

Westinghouse Response: A temporary version of the LOTIC1 code was created to model the treatment of the lower compartment volume as it is currently described in WCAP-8354-P-A. The lower compartment conditions were considered in the system pressure calculation of this temporary LOTIC1 code version after the air bubble had expanded to fill the lower compartment.

The currently most limiting containment model input deck for the peak pressure case was used with this temporary LOTIC1 code version to generate a transient pressure response for a sensitivity comparison with the base case analysis results.

The calculated peak pressure from the base case analysis is 11.2053 psig. The calculated peak pressure from the sensitivity case is 11.1966 psig, which is 0.0087 psi lower. A comparison of the transient containment pressure, temperature, and sump temperature results for the two cases is shown in Figures 1 through 4 that follow. Changing how the lower compartment conditions are modeled during the bubble expansion period has a negligible effect on the calculated results.

SRXB-RAI 2 – Please explain what is meant by: [2] *If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions.*

Westinghouse Response: As shown on page 4-2 of WCAP-8354-P-A, the LOTIC1 pressure equation is:

$$\text{Psys} = \frac{Ma + \sum_{i=1}^{n} \frac{PsiVi}{Ra(Tvi + 460)}}{\sum_{i=1}^{n} \frac{Vi}{Ra(Tvi + 460)}}$$

where Ma is the total air mass in the system, Ps is the steam partial pressure, V is the free volume, Tv is the vapor temperature, and Ra is the universal gas constant for air. The summation is calculated over the number of active volumes, n, which depend on the time after blowdown. After blowdown, all of the air is located in the upper compartment and ice-bed of the ice condenser compartment, so these are the active volumes that are considered in the system pressure equation.

The volume of the air bubble in the lower compartment begins to grow after the fans are started. The methodology report states that the lower compartment conditions (volume, air mass, steam partial pressure, and temperature) are to be included in the system pressure calculation after the air bubble volume exceeds the volume of the lower compartment. Although this is described in the methodology report, the current LOTIC1 code version does not include the lower compartment conditions in the system pressure calculation until after the bubble has completely filled the ice-empty section of the ice condenser volume; then the summation includes all of the active volumes including the lower compartment and ice-empty section of the ice condenser.

SRXB-RAI 3 – If the condition [1] is not met, i.e., expanding volume is greater than or equal to the lower compartment volume and ice–empty part of the ice compartment, what would be the system pressure based on?

Westinghouse Response: After the air bubble has expanded to fill the ice-empty part of the ice condenser, the system pressure is based on the combined conditions (volume, air mass, partial pressure, and temperature) in all of the active volumes (i.e. all volumes except the dead ended compartment).

SRXB-RAI 4 – The above referenced states:

A source code inspection revealed that the lower compartment conditions are not included until the end of the depressurization period. It has been determined that the affected portion of the transient is very short, and including the lower compartment conditions in the calculation would have a negligible impact on calculated containment conditions. Code updates regarding this issue would provide no improved transient behavior or influence on the limiting time of the event nor increase in nuclear safety.

Please state by what method it was determined that the affected portion of the transients (containment pressure, containment temperature, and sump temperature) would have a negligible impact. Provide quantitative results by performing sensitivity study showing negligible effect on the above transients and their peak values for the most bounding ice-condenser plant in the United States.

Westinghouse Response: Engineering judgment was originally used to determine that making this change would have a negligible impact on the analysis response. See the response to SRXB-RAI-1 for the requested quantitative results comparison.

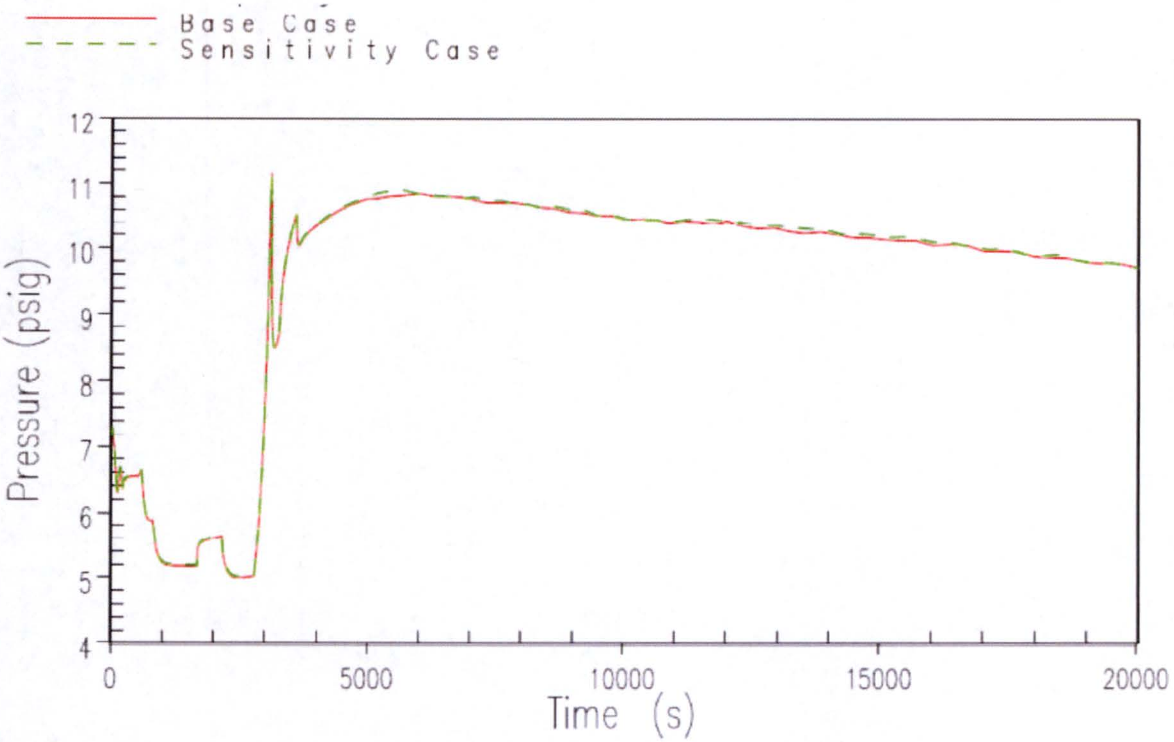

Figure 1 Containment Pressure Comparison

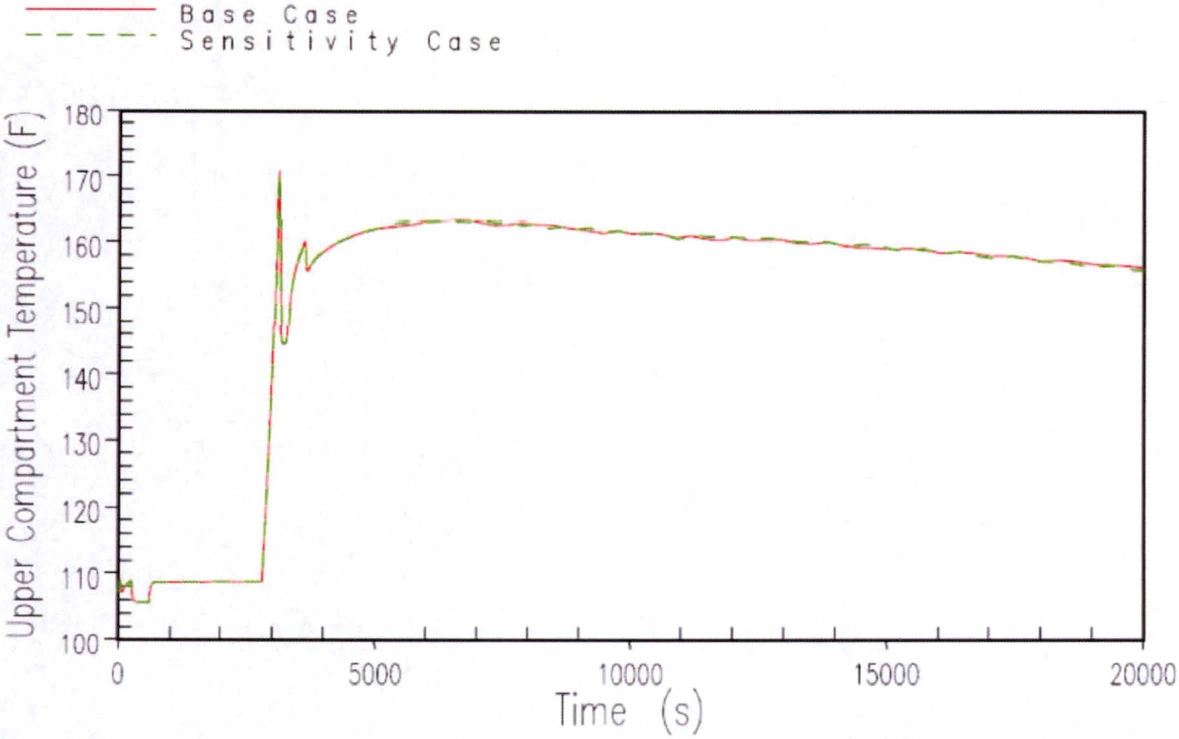

Figure 2 Upper Compartment Temperature Comparison

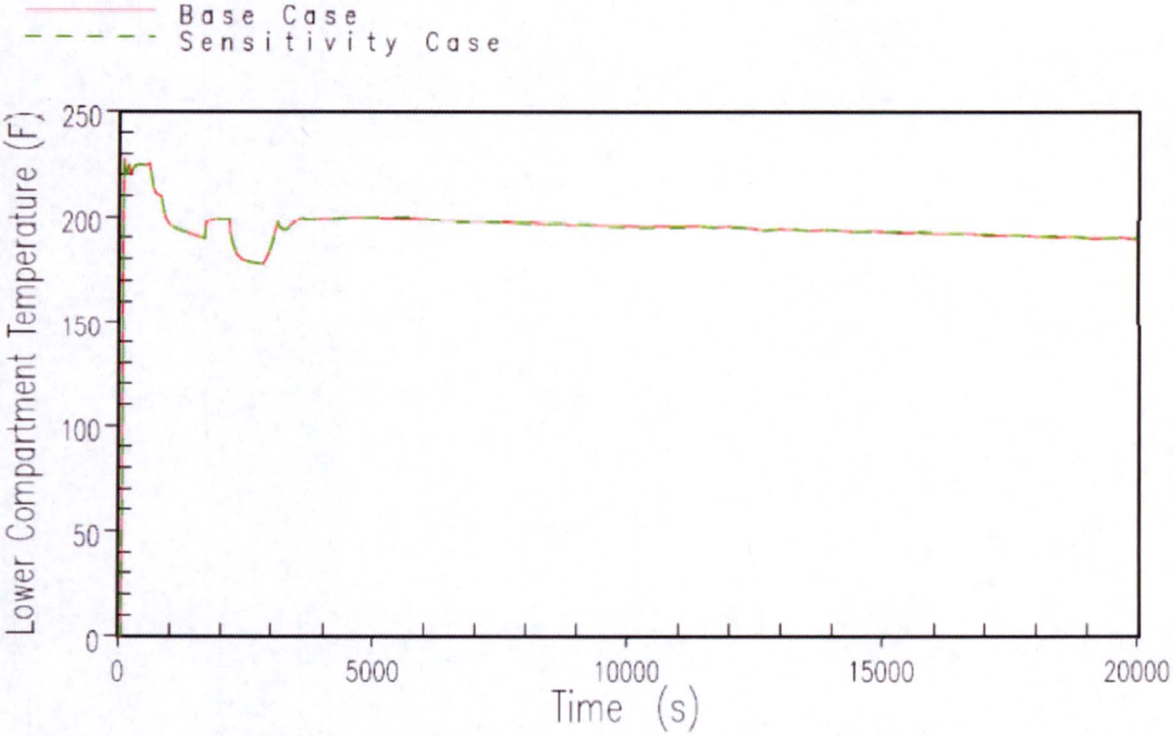

Figure 3 Lower Compartment Temperature Comparison

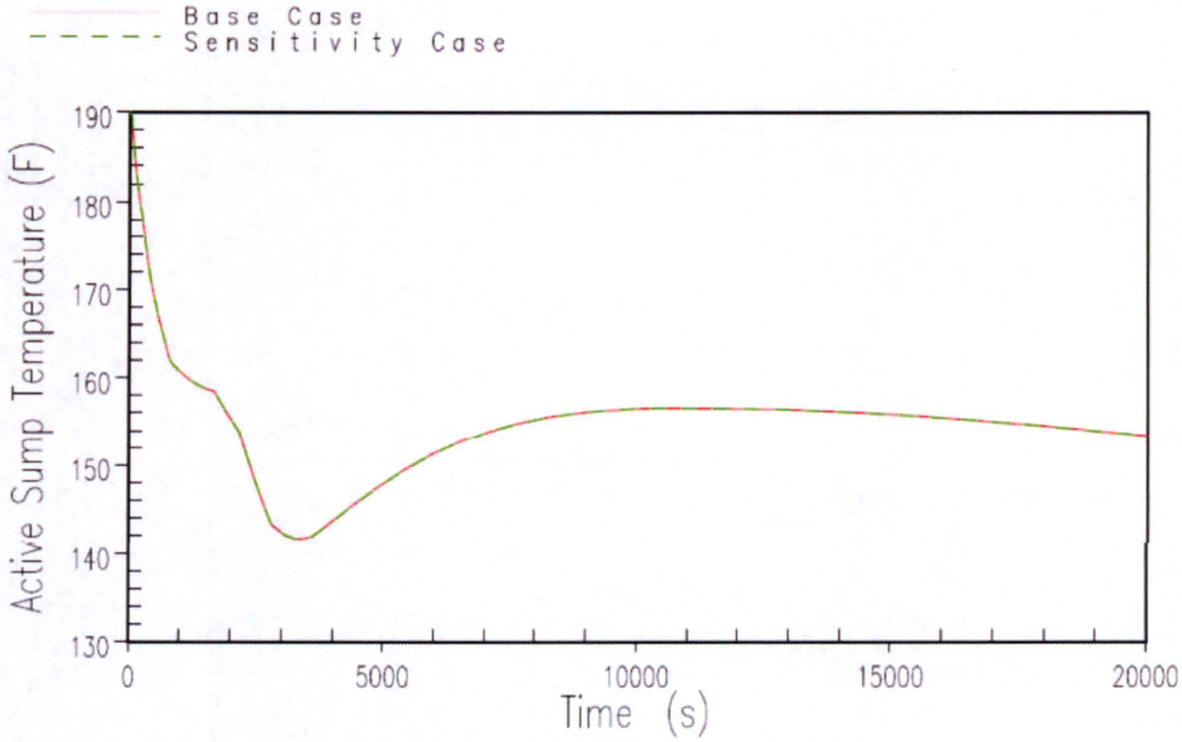

Figure 4 Sump Temperature Comparison

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

June 6, 2017

Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RE: WESTINGHOUSE ELECTRIC COMPANY LETTER "CHANGES IN WESTINGHOUSE WCAP-8354-P-A & WCAP-8355-A, "LONG TERM ICE CONDENSER CONTAINMENT CODE - LOTIC CODE" (TAC NO. MF9354)

Dear Mr. Gresham:

By letter dated February 1, 2017 (Agencywide Documents Access and Management System Accession No. ML17034A376), Westinghouse Electric Company (Westinghouse) submitted to the U.S. Nuclear Regulatory Commission (NRC) a letter for review dated February 1, 2017, "Errata for WCAP-8354-P-A (Proprietary) and WCAP-8355-A (Non-Proprietary), 'Long Term Ice Condenser Containment Code - LOTIC Code.'" Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. Westinghouse committed to the 60-day response timeframe for RAIs once received. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-3151.

Sincerely,

Ekaterina Lenning, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure:
RAI Questions (Non-Proprietary)

ML17130A736

U. S. NUCLEAR REGULATORY COMMISSION

REQUEST FOR ADDITIONAL INFORMATION FOR "CHANGES IN WESTINGHOUSE WCAP-8354-P-A & WCAP-8355-A LONG TERM ICE CONDENSER CONTAINMENT CODE - LOTIC CODE" LETTER

WESTINGHOUSE ELECTRIC COMPANY

PROJECT 700

INTRODUCTION

The NRC staff has reviewed the change proposed in Section 5.2, page 5.2-6 of WCAP-8354-P-A and WCAP-8355-A in the above referenced letter regarding the correction of discrepancy between the description of the methodology and its implementation in Westinghouse Electric Company (Westinghouse) LOTIC code for the long term ice condenser containment loss-of-coolant accident (LOCA) analysis.

A brief summary of the method used for the determination of containment pressure profile during the depressurization phase of LOCA, from the end of the blowdown to the establishment of recirculation flow between the control volumes, described in Section 5.2 of WCAP-8354-P-A and as understood by the NRC staff is as follows:

During the phase between the end of blowdown and the establishment of recirculation, nitrogen blowdown from accumulator occurs, reactor coolant system steam boil-off is initiated, and the engineered safety feature systems (recirculation fan, safety injection, and spray systems) come into operation. In this phase, the lower compartment starts to be filled with the upper compartment atmosphere at the fan flow rate. The analysis assumes an expanding volume displacing the atmosphere present in an open cylinder which does not assume mixing of the expanding volume and the atmosphere in the cylinder inferring unequal temperature for the two volumes and uniform pressure in the cylinder. The expanding volume has an atmosphere of water, steam, and air. The only flow leaving this volume is the steam which is condensing. The mass and energy balance equations for the expanding volume are combined into one equation. The resulting equation is directly integrated between two instants, while the pressure is kept constant over the integration period, equal to the value at the lower boundary of the interval. At instant 1, the pressure, temperature, and volume are known. An iterative process based on Newton's method is applied and after meeting the error criteria in an iteration, the water mass in the volume is calculated. With known masses and specific enthalpies in the expanding volume, the instantaneous total enthalpy in the volume is calculated, and continues with next time step iteration.

In Section 5.2, page 5.2-6 of WCAP-8354-P-A and WCAP-8355-A, the following logic for the calculation of the instantaneous containment pressure (pressure between two consecutive time steps) is being revised:

FROM

[1] *If the expanding volume is smaller than the lower compartment volume, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.*

[2] *If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions.*

[3] *If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.*

TO

[1] *If the expanding volume is smaller than the lower compartment volume and ice-empty part of the ice compartment, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.*

[2] *If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.*

REQUESTS FOR ADDITIONAL INFORMATION (RAIs)

SRXB-RAI 1

The addition of "ice-empty part of the ice compartment" in [1] appears to be a significant change in the total volume (lower compartment volume + ice-empty volume) which is compared with the expanding volume, because the ice-empty volume varies from zero (or a small volume) to the full volume of the ice-compartment during the depressurization phase. Provide a quantitative impact of this change on the entire pressure response, including the peak pressure, by performing a sensitivity analysis for the most bounding ice-condenser plant in the United States.

SRXB-RAI 2

Please explain what is meant by: [2] *If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions.*

SRXB-RAI 3

If the condition [1] is not met, i.e., expanding volume is greater than or equal to the lower compartment volume and ice-empty part of the ice compartment, what would the system pressure be based on?

SRXB-RAI-4

The above referenced states:

> *A source code inspection revealed that the lower compartment conditions are not included until the end of the depressurization period. It has been determined that the affected portion of the transient is very short, and including the lower compartment conditions in the calculation would have a negligible impact on calculated containment conditions. Code*

updates regarding this issue would provide no improved transient behavior or influence on the limiting time of the event nor increase in nuclear safety.

Please state by what method it was determined that the affected portion of the transients (containment pressure, containment temperature, and sump temperature) would have a negligible impact. Provide quantitative results by performing sensitivity study showing negligible effect on the above transients and their peak values for the most bounding ice-condenser plant in the United States.

REFERENCE

Westinghouse Letter to U. S. Nuclear regulatory Commission (NRC) dated February 1, 2017, "Errata for WCAP-8354-P-A (Proprietary) and WCAP-8355-A (Non-Proprietary), 'Long Term Ice Condenser Containment Code - LOTIC Code'" (ADAMS Accession No. ML17034A376).

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LTR-NRC-17-9

February 1, 2017

Subject: Errata for WCAP-8354-P-A (Proprietary) and WCAP-8355-A (Non-Proprietary), "Long Term Ice Condenser Containment Code – LOTIC Code"

The Westinghouse LOCA M&E containment response methodology for ice condensers described in WCAP-8354-P-A and WCAP-8355-A (Reference 1) was approved in 1976. This methodology has been used to analyze containment responses for most of the ice condenser plants. As a result of ongoing code maintenance at Westinghouse, a discrepancy between the methodology and its implementation in the source code was discovered. The purpose of this memorandum is to notify you of our discovery and conclusions of our investigation, and supply a changed page for the topical report.

Section 5.2, page 5.2-6 of WCAP-8354 contains the following statement, "If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions." A source code inspection revealed that the lower compartment conditions are not included until the end of the depressurization period. It has been determined that the affected portion of the transient is very short, and including the lower compartment conditions in the calculation would have a negligible impact on calculated containment conditions. Code updates regarding this issue would provide no improved transient behavior or influence on the limiting time of the event nor increase in nuclear safety. Accordingly, for your information, please find attached an errata page to WCAP-8354-P-A and WCAP-8355-A which resolves this inconsistency.

Correspondence should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 3, Suite 310, Cranberry Township, Pennsylvania 16066.

JA Gresham

James A. Gresham, Manager
Regulatory Compliance

Attachments

cc:

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Kevin Hsueh (NRC)

bcc: James A. Gresham
Cheryl Robinson
Renee Giampole
Robert Oelrich, Jr.
Douglas W. Weaver
Sumit Ray

References:

1. WCAP-8354-P-A (proprietary) and WCAP-8355-A (non-proprietary), "Long Term Ice Condenser Code – LOTIC Code," April 1976.

Author:	James D. Smith* Product & Plant Licensing
Verifier:	Richard B. Lukas* Containment and Radiological Analysis
Approved by:	Edmond J. Mercier* Manager, Product & Plant Licensing

*Electronically approved records are authenticated in the electronic document management system.

Errata for WCAP-8354-P-A (Proprietary) and WCAP-8355-A (Non-Proprietary), "Long Term Ice Condenser Containment Code – LOTIC Code"

February 2017

(1 page attached)

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066

The known masses and specific enthalpies in the expanding volume enable determination of the total enthalpy for the volume.

and ice-empty part of the ice compartment

For the calculation of the temperature in the upper compartment, the same method as in the first part of this period is employed, taking into account the recirculation fan flow rate out of this compartment.

If the expanding volume is smaller than the lower compartment volume, the system pressure calculation is based on the upper compartment and the ice-filled part of the ice compartment.

~~If the expanding volume occupies the lower compartment, the pressure calculation then includes the lower compartment conditions.~~

If the expanding volume fills the lower compartment and the ice-empty part of the ice compartment, this calculation period is terminated.

During the second period, the ice inventory calculations are identical to those of the first period, as are the containment control volume mass distribution calculations. The latter calculation takes the diminishing steam-filled volume of the lower compartment into account.

The dead-ended volume of the lower compartment is treated as follows. In case it is a part of the upper compartment, no calculations are necessary.

When assigned to the lower compartment, and acting independently, the volume of the initial air in this compartment is calculated, assuming it is at the upper-compartment temperature with saturated steam in it. If a purge rate from the dead-ended volume is specified, the purging of the dead-ended volume starts with the start of the circulation fan, and the purge rate is added to the circulation fan flow. The decreasing dead-ended volume is thus calculated by Equation 27 with the same assumptions as mentioned above. The decrease of this volume is added to the lower compartment volume and the dead-ended volume becomes an integral part of the lower compartment.