ENCLOSURE 1

KEWAUNEE RESPONSE TO A POTENTIAL LOSS OF RHR COOLING DUE TO A LOSS OF ALL AC POWER WHILE AT REDUCED INVENTORY CONDITIONS

32 pages follow

Kewaunee Response to a Potential Loss of RHR Cooling Due to a Loss of All AC Power While at Reduced Inventory Conditions

R. Ofstun
Westinghouse Electric Company

March 2005

Author: Richard P. Ofstun
R. Ofstun

Reviewer: Eric R Frantz
E. R. Frantz

1.0 Introduction

During a recent outage, NMC personnel discovered that the Kewaunee containment equipment hatch could not be closed in a timely manner while the reactor coolant system (RCS) was in a reduced inventory condition. The equipment hatch was eventually closed after some rails designed for the replacement reactor vessel (RV) head were removed.

A pressurizer safety valve was removed prior to draindown to provide a steam vent path in the event residual heat removal (RHR) cooling was lost. After draindown, the RV flange studs were de-tensioned to allow removal of the RV upper head. If RHR cooling were lost under these conditions, the RCS would begin to heat up and eventually boil. Steam would be released to containment through the RV flange gap and the pressurizer safety valve piping. If the core were to uncover, an open equipment hatch could provide a potential release path to the environment.

Westinghouse was requested to provide conservative analyses for the time to boiling, the steaming rate, the time to core uncovery, and the containment temperature and humidity response under the conditions described above. This letter documents those analyses.

This analysis is applicable to a generic 2-loop plant at a decay heat level of 8 MWth. An additional case at 6.82 MW was also analyzed. Several conservative modeling assumptions were made to allow the results to bound the Kewaunee plant response to a loss of RHR cooling at reduced inventory conditions.

2.0 Assumptions

A generic 2-loop RCS model was used to analyze the Kewaunee response to the loss of all AC power and subsequent loss of RHR cooling at reduced inventory conditions. It was assumed that there were no substantial differences in the water volume distribution or component elevations between the generic 2-loop RCS model and the Kewaunee plant. This assumption is reasonable based on the heat-up volume comparison documented in the recent Kewaunee Time to Boil Calculation. That calculation has a Kewaunee heat-up volume of 636.3 ft^3 at mid-loop versus 640 ft^3 for the generic 2-loop GOTHIC model. Also, the Kewaunee Model 54F SG tubes have more volume than the SG tubes in the generic 2-loop GOTHIC model (825 ft^3 vs. 654.5 ft^3). If the SG tubes are filled with water, this would help extend the time to boiling and potential core uncovery following a loss of RHR at reduced inventory conditions.

The steam from the pressurizer vent or flange would be released to containment as a relatively low velocity jet or plume. This type of release would induce a smaller global circulation than a high velocity jet (such as generated by a large LOCA). This would limit mixing and produce a somewhat stratified atmosphere inside containment. Because the Kewaunee equipment hatch is located below the possible steam release elevations (top of the pressurizer and reactor vessel flange), the lumped parameter containment model will provide a conservative estimate of the temperature response at the equipment hatch location.

3.0 Acceptance Criteria

There are no formal acceptance criteria for this analysis. The consequences of a potential loss of RHR event at reduced inventory conditions can be mitigated if the calculated time to core uncovery is greater than the time needed to close the equipment hatch. To allow the operators to close the equipment hatch, the local containment conditions around the hatch must remain habitable following the loss of RHR cooling.

4.0 Calculations

The GOTHIC code was selected for these analyses. GOTHIC is capable of modeling non-homogeneous, non-equilibrium two-phase flow conditions with non-condensable gas. It solves the mass, energy, and momentum equations for the multi-phase flow in lumped parameter and/or multi-dimensional geometries. GOTHIC is typically used for containment and auxiliary building analyses, but has been applied for modeling the RCS at reduced inventory conditions. Generic RCS models were developed for the WOG to perform loss of RHR cooling analyses at reduced inventory conditions. The RCS models were described in Reference 1 and model qualification results were presented in Reference 2. The GOTHIC RCS model methodology was qualified by comparison with FLECHT-SEASET natural circulation test data and comparison with results from other codes and hand calculations. NMC had originally requested plant specific GOTHIC analyses for Kewaunee, however, due to time constraints that request was changed to use the generic GOTHIC 2-loop RCS model instead.

The generic 2-loop RCS model, that was used to perform Functional Test 3 in Reference 2, was upgraded to GOTHIC version 7.2 and modified to run the following postulated loss of RHR cooling cases for Kewaunee.

Case 1 Decay heat at 8 MW, RCS level at 6-inches below the flange, SG tubes filled with water, RCS average temperature of 117 F, RCS vented through a pressurizer safety valve pipe. The steam vent path was connected to a modified Kewaunee containment model that was initialized to a temperature of 80 F and vented to atmosphere. The equipment hatch was assumed to be closed 84 minutes after the loss of RHR cooling. The purpose of this case was to provide an analysis of the Kewaunee RCS and containment response to a loss of AC power and RHR cooling at 3 days after shutdown.

Case 2 Decay heat at 6.82 MW, RCS level at 6-inches below the flange, SG tubes filled with water, RCS average temperature of 114 F, RCS vented through a pressurizer safety valve pipe, studs de-tensioned and the flange gap open with an area of 0.1226 ft^2. The steam vent paths were connected to a modified Kewaunee containment model that was initialized to a temperature of 80 F and vented to atmosphere. The equipment hatch was assumed to be closed 84 minutes after the loss of RHR cooling. The purpose of this case was to provide an analysis of the Kewaunee RCS and containment response to a loss of AC power and RHR cooling at 4 days, 9 hours and 50 minutes after shutdown. This is representative of an early time when the RCS could be in this configuration with the RV head de-tensioned.

4.1 INPUT

4.1.1 Decay Heat Rate

The outage timeline of events was provided by NMC (Appendix A). The Kewaunee core decay heat at 3 days after shutdown is estimated below.

3 days = 3*3600*24 = 259200 sec
Core decay heat fraction is 0.419% at 300000 sec after shutdown (Reference 3)
Core decay heat fraction is 0.483% at 200000 sec after shutdown (Reference 3)
Core decay heat fraction at 3 days = 0.483 - (0.483 – 0.419)/100000*59200 = 0.445%
A conservative value of 0.45% will be used to calculate the core decay heat rate.
Qdecay = 1772 MW*0.0045 = 7.974 MW.

The decay heat input in Function Table 1 was changed to use a conservative core decay heat value of 8 MW (7584.5 BTU/s) for analysis Case 1.

The time after shutdown was increased to 4 days, 9 hours and 50 minutes for Case 2 and the decay heat input for Function Table 1 was changed to use the value calculated below.

t = 3600*(24*4+9)+50*60 = 381000 sec
Core decay heat fraction is 0.377% at 400000 sec after shutdown (Reference 3)
Core decay heat fraction = 0.419 - (0.419 - 0.377)/100000*81000 = 0.385%
Qdecay = 1772 MW*0.00385 = 6.82 MW.

4.1.2 Flange Gap Model

If the RV head is de-tensioned, and the RCS begins to boil, the increasing pressure will cause the head to lift and allow steam to vent around the flange gap. Plant specific data for Kewaunee flange gap was not available, so data from a 4-loop vessel was scaled to the 2-loop vessel using the ratio of the vessel diameters. The flange gap equivalent flow area does not vary much for a flange separation of between 0.25 and 1.5 inches, however the differential pressure needed to lift and hold the RV head 0.5 inches above the flange is greater than can be obtained with the RCS vented through the pressurizer safety valve pipe. The flange gap equivalent flow area for a 4-loop plant with a maximum separation of 0.5-in was calculated to be 23 in^2. The scaled flange gap flow area for this analysis was:

Area = 23*(157.25/205)/144 = 0.1226 ft^2

A flow path was added to the upper plenum at an elevation of 22.24 ft (this is the elevation of the top of the downcomer volume in the generic 2-loop plant model) to model the flange gap for analysis Case 2. The actual elevation of the Kewaunee flange mating surface is approximately 0.8 ft higher, so the results will be conservative. A typical loss coefficient of 1.5 was also used to model the effects of contraction and expansion through the flange gap. The input values used for the hydraulic diameter (0.5 ft) and the inertia and friction lengths (0.1 ft) were not important in this analysis because skin friction is small and is covered by the loss coefficient input value.

4.1.3 Pressurizer Safety Valve Model

The pressurizer manway vent area was replaced with the safety valve piping area for analysis Cases 1 and 2. The Kewaunee safety valve pipe area was provided (Appendix A). The area is 28.27 in^2 or 0.19632 ft^2. A hydraulic diameter of 0.5 ft, inertia and friction lengths of 10 ft, and a loss coefficient of 1.4 were also used to model the safety valve pipe. The input for flow path 30 of the generic 2-loop RCS model was revised to use this information.

4.1.4 RCS Initial Conditions

The customer provided information on the actual Kewaunee plant conditions at 3 days and 4.5 days after shutdown (Appendix A). The fluid level was 6-in below the flange and the RCS average temperature was less than 120 F.

With the reactor vessel water level at 6-inches below the flange elevation, the RCS loops and SG tubes would still be filled with water. Having water filled SG tubes will significantly impact the transient response (time to boil, time to core uncovery, amount of steam/water released to containment, etc.) since natural circulation flow around the loops can occur.

The RCS average temperature at 3 days after shutdown was approximately 117 F, and at 4.5 days it was approximately 114 F.

The important RCS elevations for the GOTHIC model are tabulated below:

Top of Fuel	12 ft
Bottom of Hot Leg	15.72 ft
Mid-Loop	16.93 ft
Top of Hot Leg	18.14 ft
Flange	22.24 ft

The water level was adjusted by changing the water volume fraction input values in the GOTHIC initial conditions table. The RCS loops, SG inlet plenum, outlet plenum, and tubes are all full of water, so their volume fraction input values are 1.0. To obtain a downcomer water level that is 0.5-ft below the flange, the water fraction input value for downcomer cell 1s7 was calculated as follows:

$$VF = (\text{cell top} - 0.5 - \text{cell bottom})/(\text{cell top} - \text{cell bottom})$$
$$= (22.24 - 0.5 - 18.135)/(22.24 - 18.135) = 0.8782.$$

To obtain an upper plenum water level that is 0.5-ft below the flange, the water volume fraction input values for upper plenum cells 2s19, 2s20, and 2s21 were calculated as:

$$VF = (\text{cell top} - 1.0 - \text{cell bottom})/(\text{cell top} - \text{cell bottom})$$
$$= (22.74 - 1.0 - 18.135)/(22.74 - 18.135) = 0.7828.$$

The RCS average temperature was adjusted by changing the initial thermal conductor temperatures, initial water temperatures, service water temperature, CCW flow rate, and RHR flow rate. The RCS thermal conductor and fluid temperatures were changed to 105 F for Tcold, 125 F for Thot, and 120 F for the SG secondary fluid. The service water temperature was reduced to 40 F, the CCW flow rate was increased to 500 lbm/s, the RHR bypass flow rate was reduced to 0.0 lbm/s (by setting flow path 42 and 43 loss coefficients to 1.0E18), and the RHR flow rate was increased (by reducing flow path 44 and 45 loss coefficients to 200). These changes established an average temperature of about 118 F for Case 1 and 114 F for Case 2.

4.1.5 Containment Model

The Kewaunee containment model was modified and used in analysis Cases 1 and 2. The spray and break flow boundary conditions were removed. The safety valve pipe vent flow path was connected to the lumped parameter containment volume. A flow path representing the flange gap opening from the RCS to the containment (flow path 64) was modeled for Case 2. The film and mist heat and mass transfer options of the diffusion layer model (DLM) correlation were removed (per the NRC SER) and the containment heat sink temperatures were initialized at 80 F. The containment initial conditions were also changed: the pressure was set to 14.7 psia, the temperature was set to 80 F, and the humidity was set to 50%. These were typical values at the time the hatch was open.

A flow path representing the open containment equipment hatch was connected to a constant pressure boundary condition representing the atmosphere. The customer provided information regarding the modeling of the equipment hatch (Appendix A). The equipment hatch flow area and hydraulic diameter input values were set to 314 ft^2 and 20 ft. Also, a quick close valve with a flow area of 314 ft^2 and a corresponding trip was added to the equipment hatch flow path to model closure of the hatch at 84 minutes after the loss of AC power.

4.2 EVALUATIONS, ANALYSIS, DETAILED CALCULATIONS AND RESULTS

Two cases were evaluated to determine the impact of a potential loss of AC power at reduced inventory conditions. In both cases, a pressurizer safety valve was assumed to have been removed to provide a vent path for steam in the event RHR cooling was lost and the core started to boil. Both of the cases were run using the modified generic 2-loop RCS model described in Section 4.1 above. Each case assumed a loss of AC power at 900 seconds in the transient.

In Case 1, the reactor vessel head had not yet been de-tensioned at the time AC power was assumed to have been lost. Because the SG tubes were full of water and the flange gap was closed, natural circulation flow was established after RHR cooling was lost. The RCS temperature increased and, under natural circulation, the rest of the core decay heat was transferred to the secondary (Figure 4.2-4). The RCS pressure increased (Figure 4.2-2) and pressurizer level increased (Figure 4.2-6) as thermal expansion forced water into the pressurizer. For Case 1 (with 8 MW decay heat at 3 days after shutdown), boiling began about 75 minutes after RHR was lost.

The RCS pressure and pressurizer level continued to increase as more water was displaced into the pressurizer after the RCS began to boil. Some of the core decay heat continued to be transferred to the secondary via condensation of steam in the SG tubes and the SG secondary reached the boiling point at about 12000 seconds (Figure 4.2-4).

The pressurizer also filled water solid around 12000 seconds. A 2-phase mixture was pushed out the safety valve pipe vent path from about 12000 seconds to around 17000 seconds. Only steam was vented after 17000 seconds; the steaming rate inside containment at this time was about 4 lbm/s (Figure 4.2-3).

The flow rate through the open equipment hatch was very small and stopped after the hatch was closed at 5940 seconds (Figure 4.2-10).

Containment pressure, temperature and humidity didn't begin to increase until after the pressurizer began to vent steam around 12000 seconds (Figures 4.2-7, 8, and 9).

The water level in the hot and cold legs and SG tubes began to decrease rapidly just after the pressurizer filled water solid. The cold legs emptied and the hot leg level decreased to the top of the surge line elevation (17.2 ft). The hot leg level remained near the top of the surge line until the SG tubes were completely drained. This occurred at about 17000 seconds. After this, the hot leg level began to also fall to the bottom of the pipe, allowing steam to pass through the pressurizer.

From Figure 4.2-1, the water level in the RV upper plenum decreased to the top of the fuel elevation (12 ft) at 20500 seconds. Subtracting 900 seconds for steady state yields a conservative estimate for the time to start uncovering the top of the fuel of 5.44 hours.

Case 1 was terminated at about 28000 seconds, after the collapsed core level had fallen below the 6-ft elevation.

In Case 2, AC power was assumed to have been lost after the reactor vessel head had been de-tensioned. With the flange gap open, the RCS did not pressurize appreciably and was unable to establish natural circulation after RHR cooling was lost. The RCS temperature increased and for Case 2 (with 6.8 MW decay heat at 4.5 days after shutdown), boiling began about 35 minutes after RHR was lost.

Some of the core decay heat was transferred to the SG secondary (Figure 4.2-14), but most of it went into heating the RCS and producing steam, which was released through the RV flange gap (Figure 4.2-13). Unlike Case 1, the steam is easily vented through the RV flange gap and the pressurizer does not flood (Figure 4.2-16). Therefore, instead of being pushed into the pressurizer, all of the water in the SG tubes, plenums, and hot legs is available for boil off.

The upper plenum collapsed water level slowly decreased until it was just above the middle of the hot leg pipe, more than 4-ft above the top of the fuel (Figure 4.2-11). Water in the upside SG tubes began to drain back through the hot legs and into the RV upper plenum, and water in the downside SG tubes began to drain back to the RV downcomer (Figure 4.2-15).

The steam released through the flange gap caused the containment temperature to increase faster in Case 2 than Case 1 (Figure 4.2-17). The flow rate through the open equipment hatch was very small and stopped after the hatch was closed at 5940 seconds (Figure 4.2-20). Containment pressure began to increase soon after the equipment hatch was closed (Figure 4.2-18).

Case 2 was run for 33000 seconds, however, there was a problem with the plot output data after 19000 seconds. The plotting problem did not affect the calculated results. At 33000 seconds, the steaming rate was relatively constant (about 4 lbm/s), and the volume of water in the upper plenum was approximately the same as it was at 19000 seconds (the end of the plot data). Therefore, the upper plenum collapsed water level was still more than 4-ft above the top of the fuel at 9 hours after the loss of AC power.

The time of core uncovery can be estimated knowing the water volume above the top of the fuel and the steaming rate. The total water volume above the top of the fuel elevation is the sum of the water volume in the SG tubes, SG inlet and SG outlet plenums, pressurizer, hot legs, and upper plenum. The sum of the water volume in just the SG tubes and SG plenums at 19000 seconds is calculated below:

Water Volume = Number of cells*water volume fraction/cell*cell volume

SG Inlet Plenum Water Volume = 0.973*131	= 127.5 ft^3
SG Upside Tube Water Volume = 5.81*41.58	= 241.6 ft^3
SG Downside Tube Water Volume = 5.14*41.58	= 213.7 ft^3
SG Outlet Plenum Water Volume = 1.0*131	= 131 ft^3
SG Inlet Plenum Water Volume = 0.766*131	= 100.3 ft^3
SG Upside Tube Water Volume = 4.78*41.58	= 198.8 ft^3
SG Downside Tube Water Volume = 3.89*41.58	= 161.7 ft^3
SG Outlet Plenum Water Volume = 1.0*131	= 131 ft^3
Total Water Volume in SG Tubes/Plenums	= 1305.6 ft^3

The total water mass in the SG tubes and plenums is about 1305.6 ft^3 * 59 lbm/ ft^3 = 77000 lbm. Assuming a conservative steaming rate of 5 lbm/s through the flange gap, the additional time needed to boiloff just the water in the SG tubes and SG plenums is about 15400 seconds. This does not even consider the water remaining in the pressurizer, hot legs or upper plenum. Therefore, the time needed for the upper plenum collapsed fluid level to decrease to the top of the fuel is greater than 19000+15400 = 34400 seconds. This is greater than 9 hours after the loss of all AC power and subsequent loss of RHR cooling.

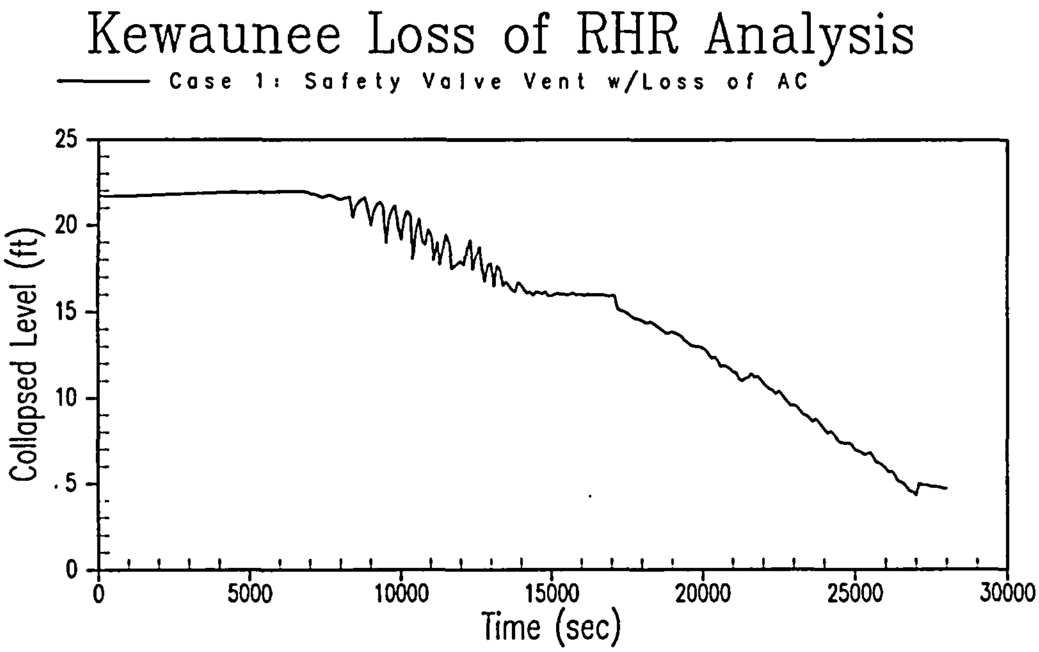

Figure 4.2-1 – Core Collapsed Level

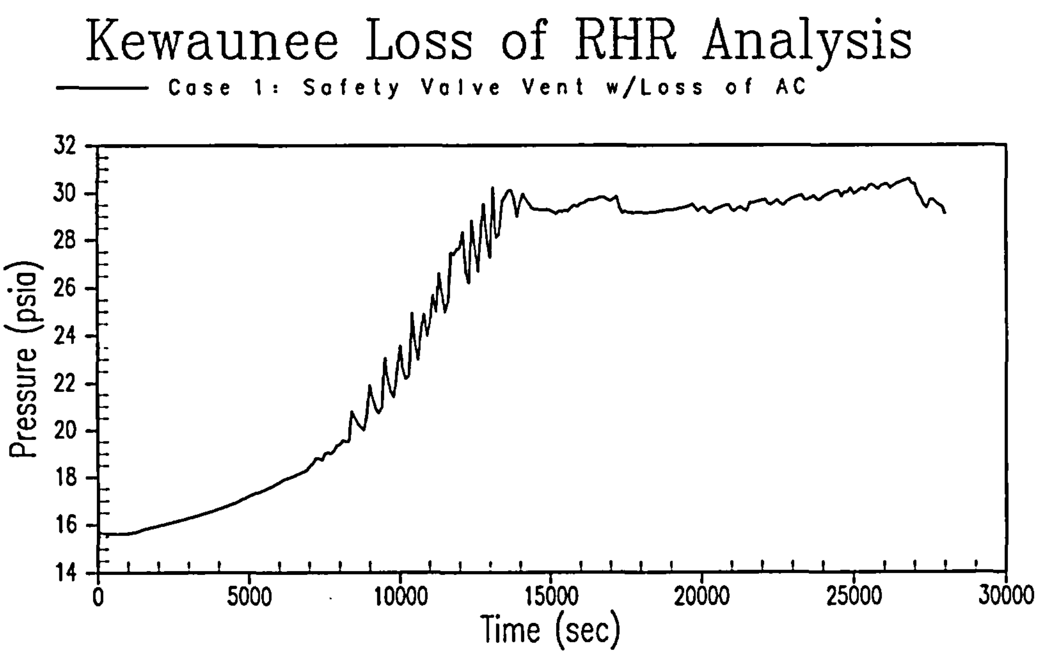

Figure 4.2-2 – Upper Head Pressure

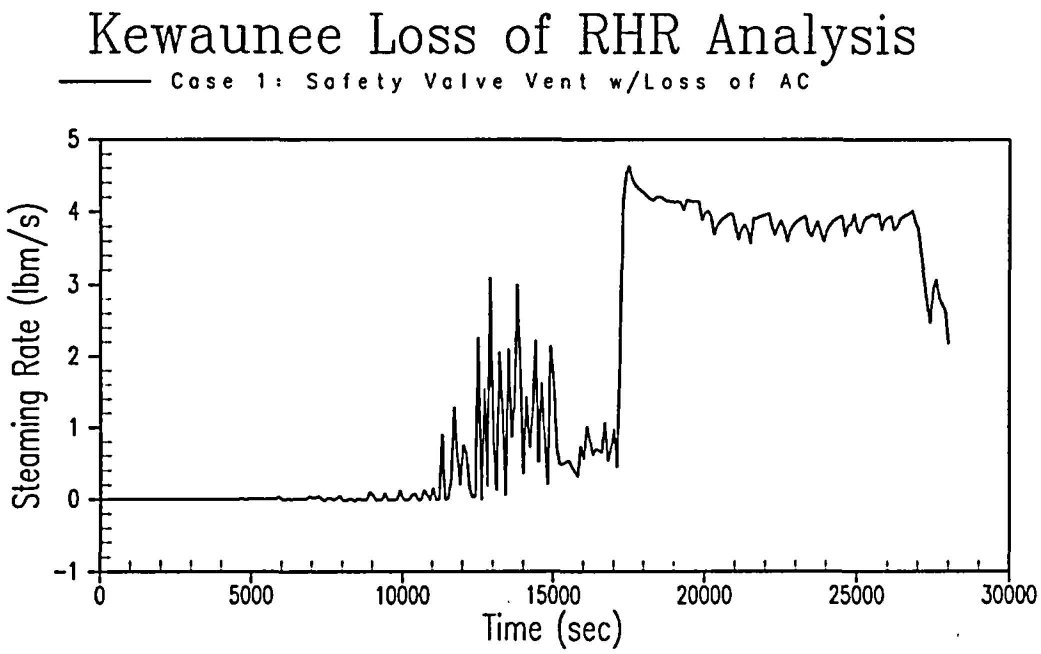

Figure 4.2-3 – Steaming Rate

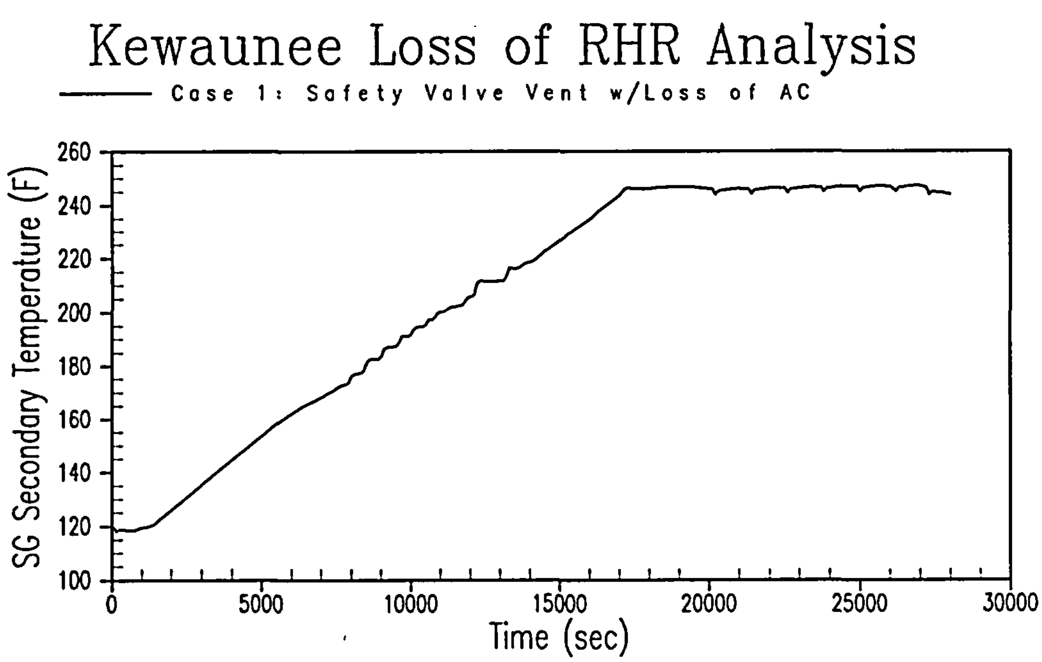

Figure 4.2-4 – SG Secondary Temperature

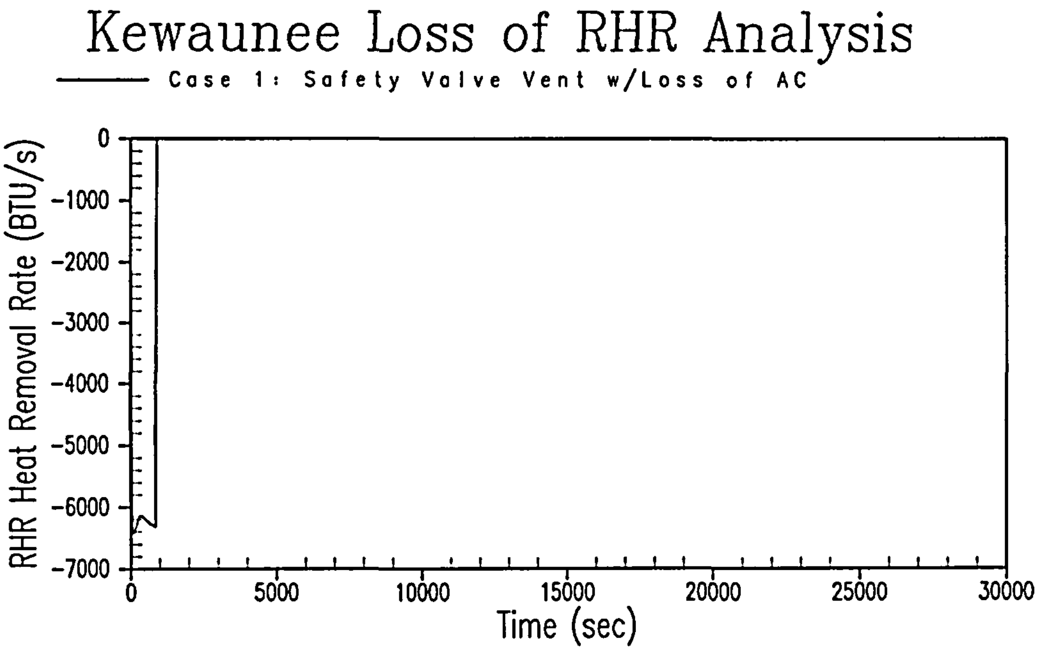

Figure 4.2-5 – RHR Heat Removal

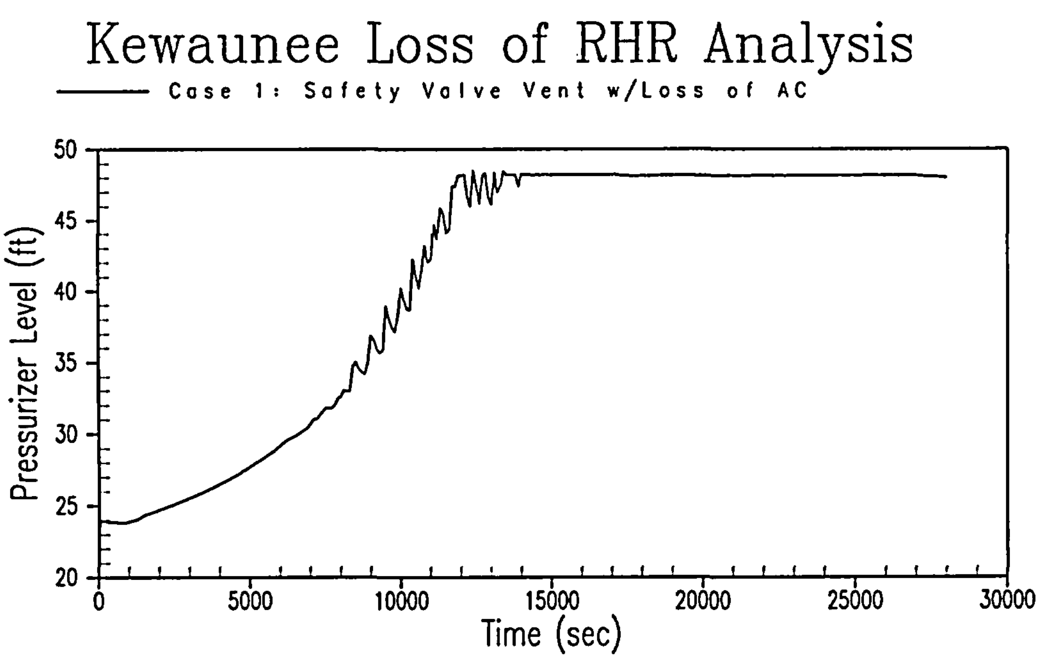

Figure 4.2-6 – Pressurizer Level

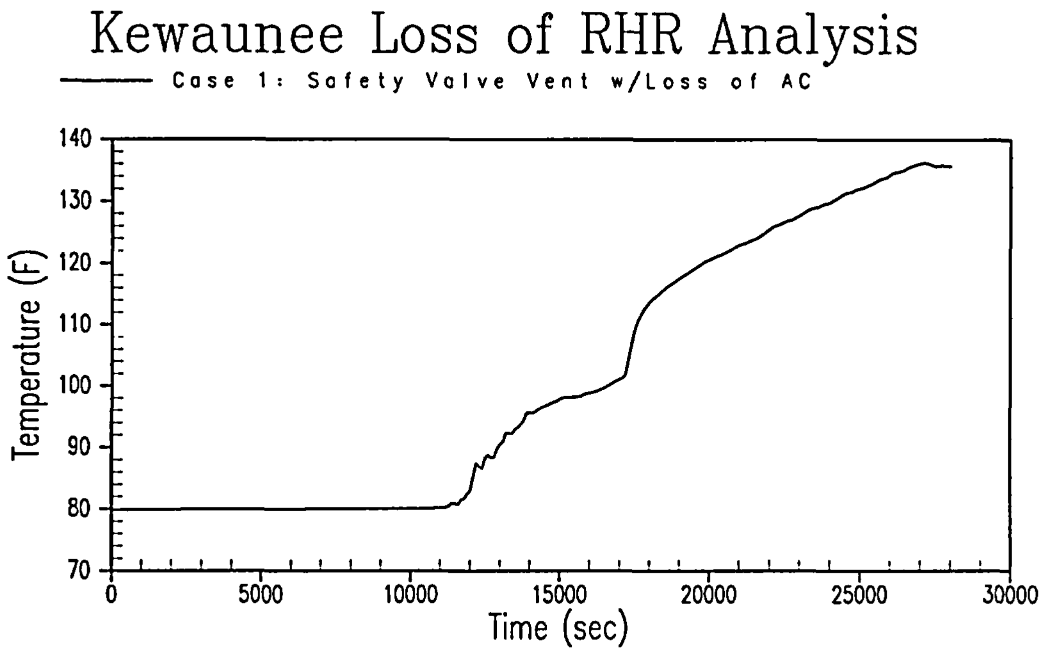

Figure 4.2-7 – Containment Temperature

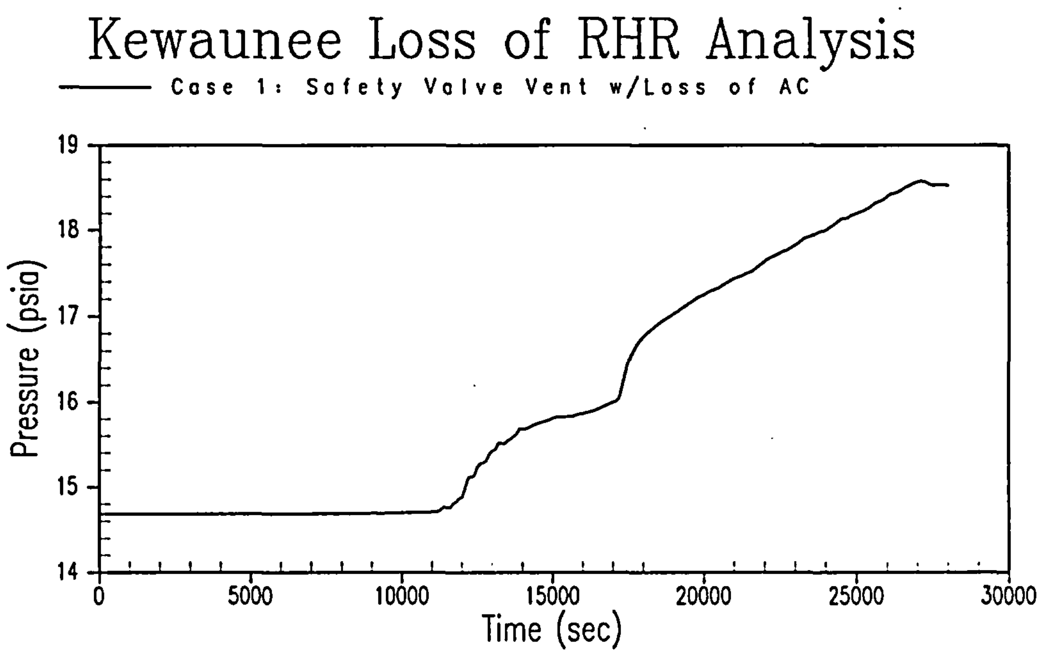

Figure 4.2-8 – Containment Pressure

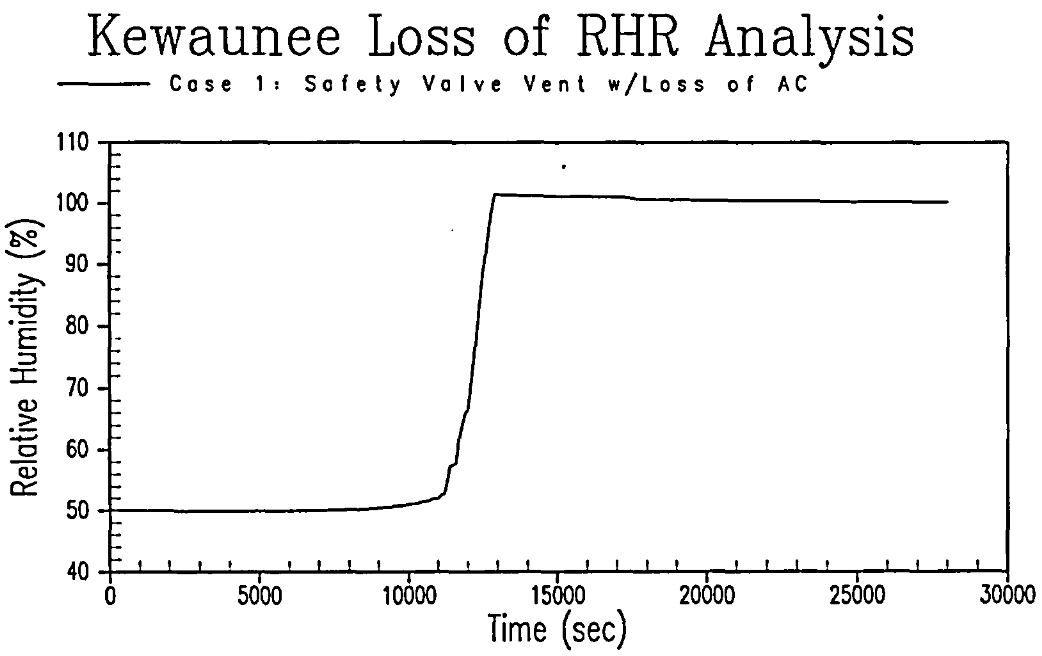

Figure 4.2-9 – Containment Humidity

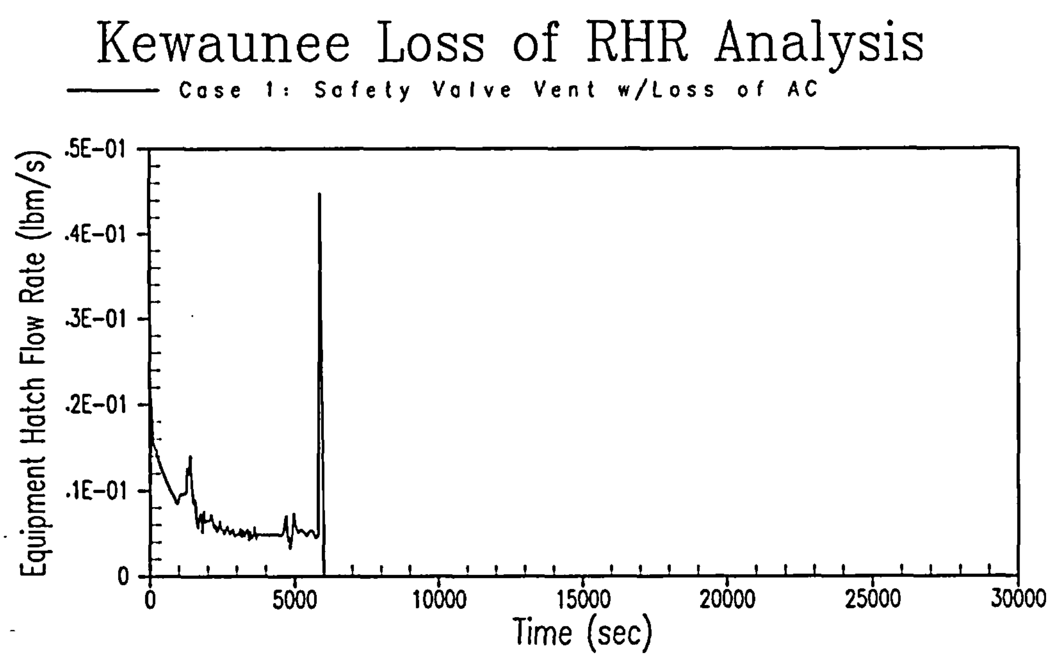

Figure 4.2-10 – Equipment Hatch Flow Rate

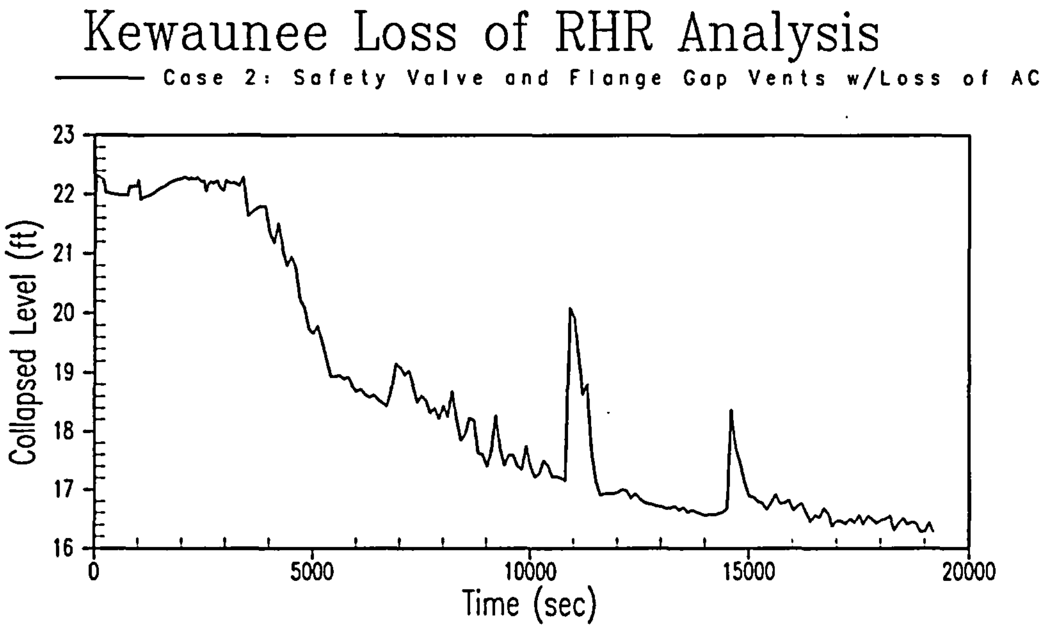

Figure 4.2-11 – Core Collapsed Level

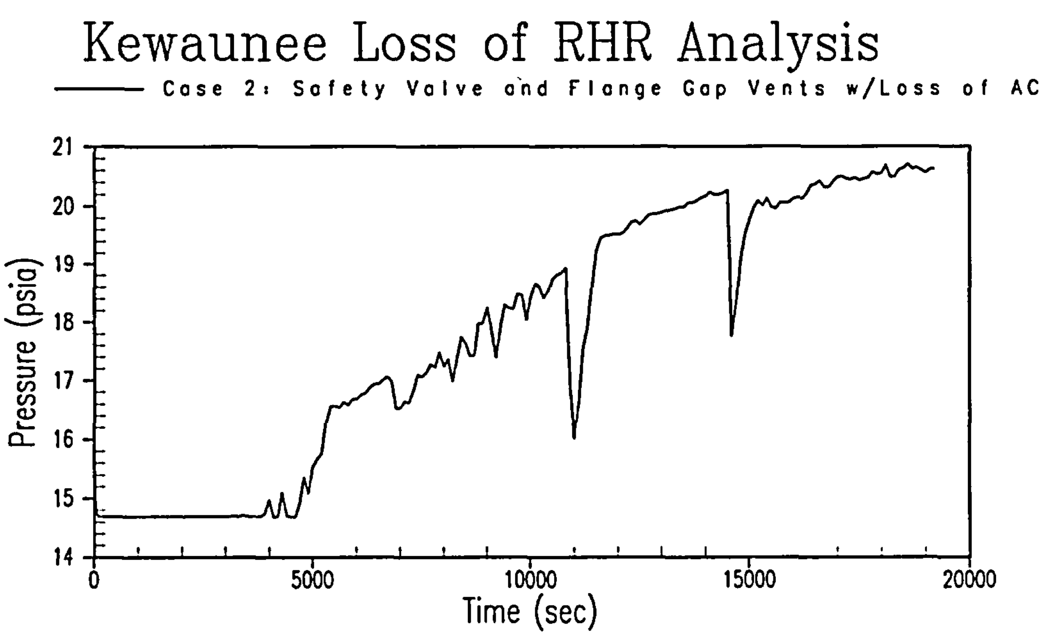

Figure 4.2-12 – Upper Head Pressure

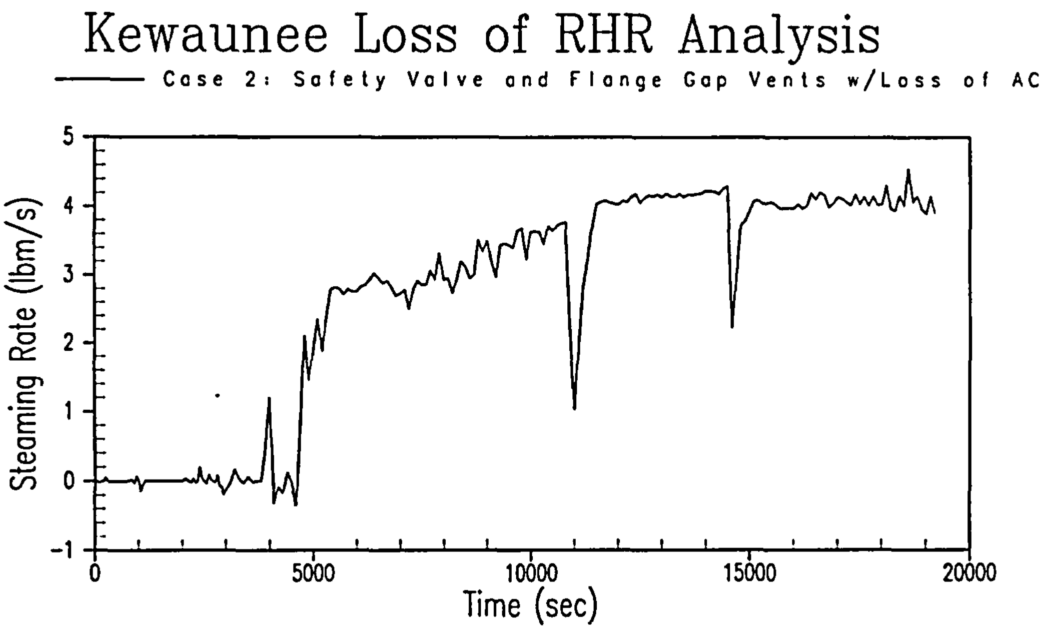

Figure 4.2-13 – Steaming Rate

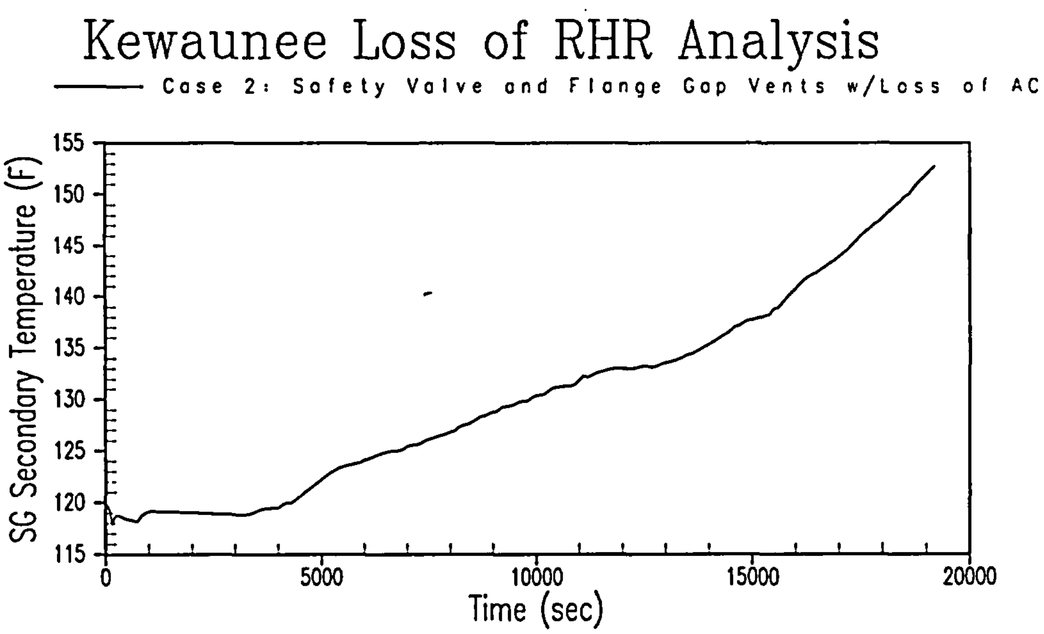

Figure 4.2-14 – SG Secondary Temperature

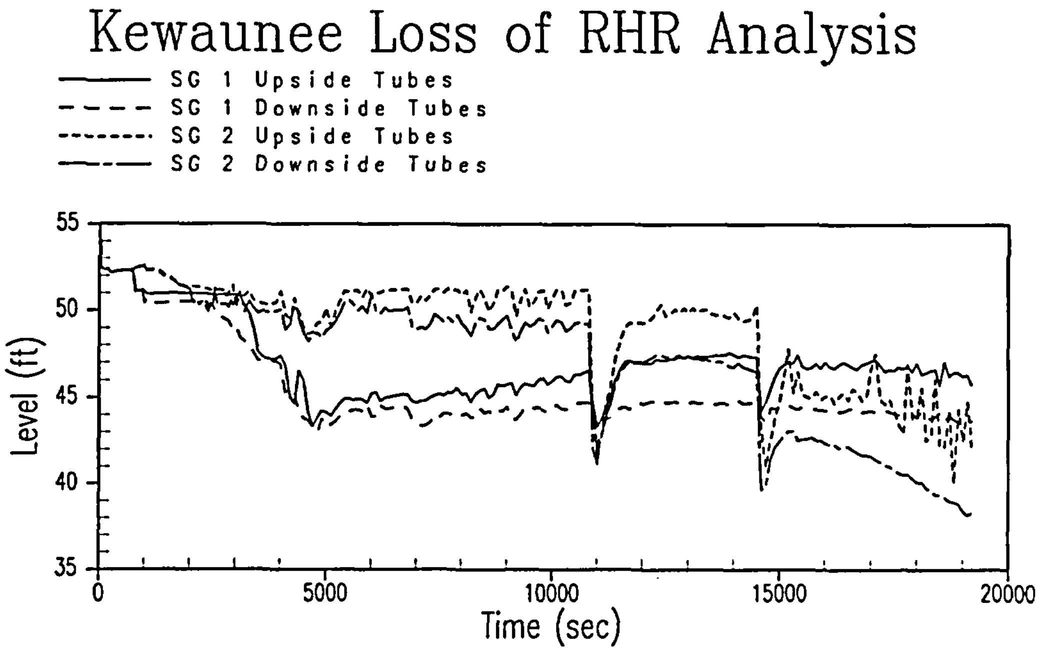

Figure 4.2-15 – SG Tube Levels

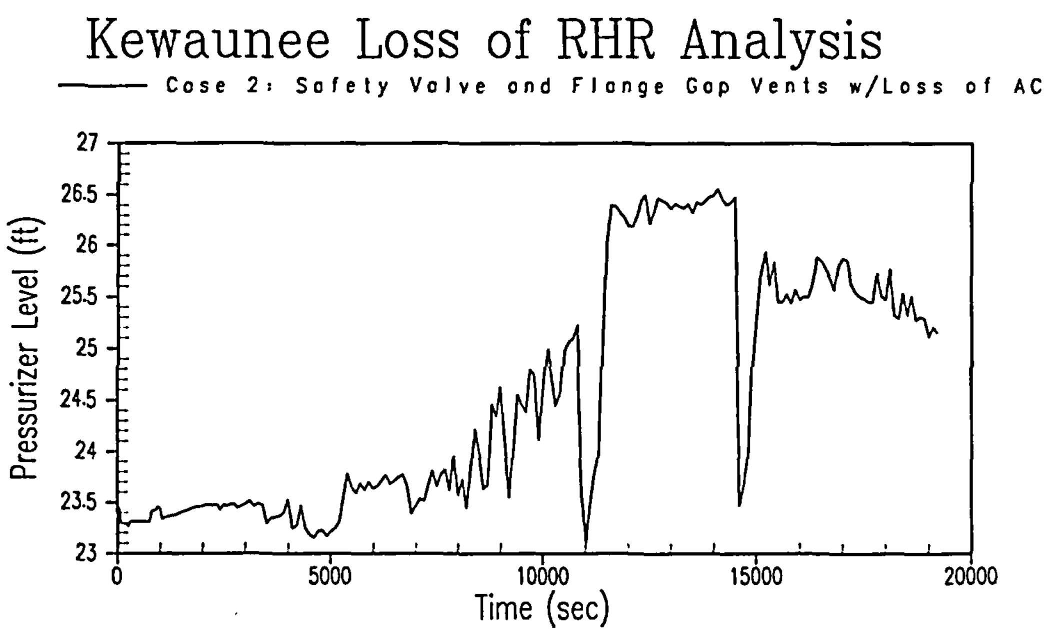

Figure 4.2-16 – Pressurizer Level

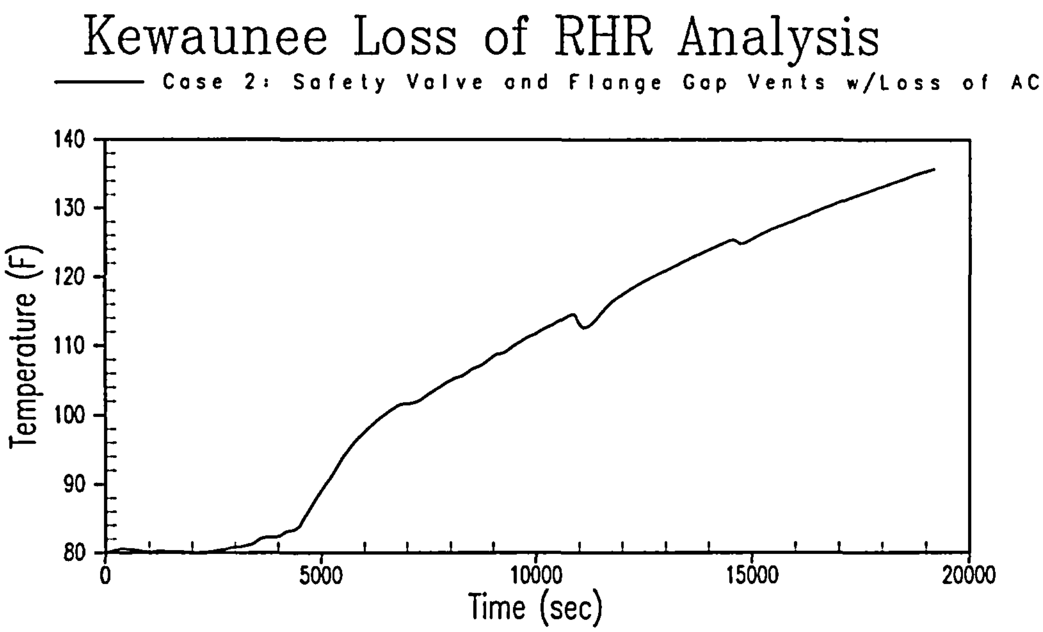

Figure 4.2-17 – Containment Temperature

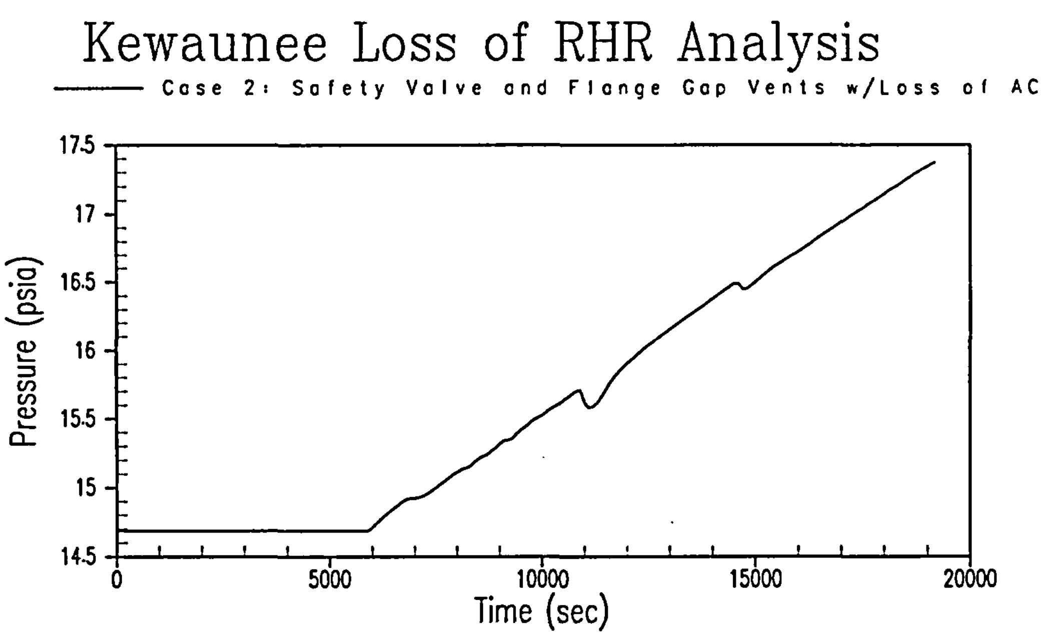

Figure 4.2-18 – Containment Pressure

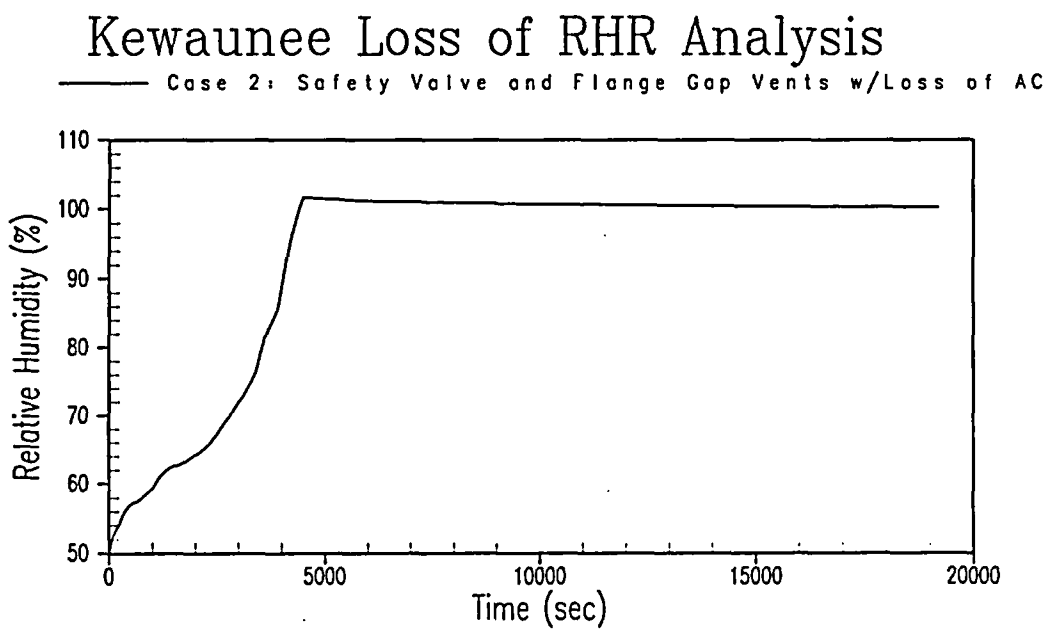

Figure 4.2-19 – Containment Humidity

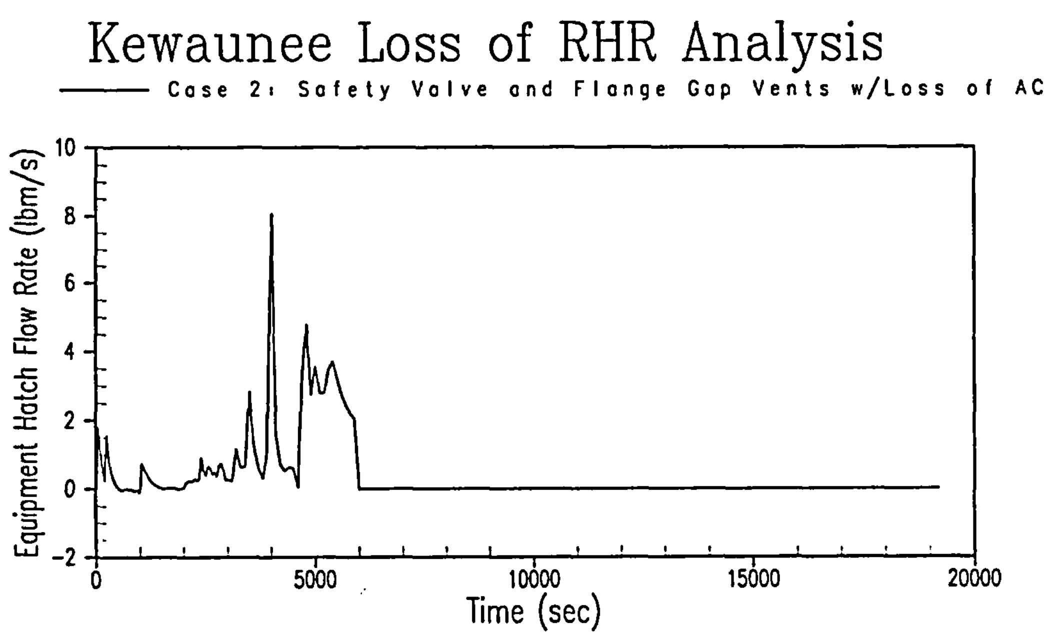

Figure 4.2-20 – Equipment Hatch Flow Rate

4.2.1 Containment Model Noding Sensitivity Cases

It is important to know the local containment temperature and humidity near the equipment hatch location since the operators will be working to close the hatch. Because the steam sources are released as relatively low velocity plumes, the containment atmosphere will stratify. The volume above the steam source should fill with steam and get hot, but the volume below should remain relatively cool and air filled. Since the Kewaunee equipment hatch is located below the elevation of the reactor vessel flange, the operators should stay cool longer than if it were located at the operating deck elevation or higher.

The best way to model the stratification of the containment atmosphere is to use the 2D or 3D features in GOTHIC. This is computer time intensive and not really an option in the time frame available for this analysis.

If the containment were assumed to be perfectly mixed (single lumped parameter volume model), the temperature and humidity below the steam source would be over-estimated and the temperature and humidity above the steam source would be under-estimated. So using the results from the lumped parameter containment model should produce an earlier increase in temperature and humidity at the equipment hatch location than would actually occur and therefore produce a lower bound conservative estimate of the time available for the operator to install the equipment hatch.

Another way to model containment stratification is to use a stacked lumped parameter volume model. The containment volume is divided into several lumped parameter volumes and filled with steam from the top down; air is vented through the equipment hatch opening in the lower volume. This approach would over-estimate the temperature and humidity above the steam source and under-estimate the temperature and humidity below the steam source. This approach would produce an upper bound estimate of the time available for the operator to install the equipment hatch.

A stacked lumped parameter model was constructed for this sensitivity case. The containment volume was divided into 5 equal cells. The thermal conductor representing the containment dome was placed in the top cell (cell 5), the thermal conductor representing the containment shell was spanned across cells 2, 3, 4 and 5, and the remaining thermal conductors were placed in cell 1. The steam mass and energy releases from the flange gap and pressurizer safety valve pipe were put into the top cell of this containment model.

The initial containment temperature at Kewaunee was about 80 F. The temperature of all of the thermal conductors and cells were initialized to 80 F for this sensitivity case.

Per the NMC timeline provided via email (Appendix A), the containment equipment hatch was assumed to be closed 84 minutes after the loss of RHR cooling. A valve with a close trip time of 5940 seconds was added to the flow path representing the open equipment hatch to model the hatch closure.

The containment temperature and humidity results for the upper and lower cells of this model are compared with the results from a stand-alone single lumped parameter volume containment model with the same initial conditions and hatch closure time assumption. The comparison is shown in Figures 4.2-21 and 4.2-22. For the stacked lumped parameter volume containment model, the upper cell temperature and humidity increases rapidly soon after steaming begins while the lower cell (representing the area around the equipment hatch) remains cool for the entire transient. The single lumped parameter volume containment model temperature reaches 120 F about 2 hours after RHR cooling is lost.

The containment pressure transient is compared in Figure 4.2-23. Containment pressure remains at atmosphere condition until the hatch is closed. After this, the pressure in the stacked lumped parameter volume containment model increases faster than the single lumped parameter model since the average air temperature is higher.

The vapor flow rate through the equipment hatch opening is compared in Figure 4.2-24. Both models predict a similar transient flow rate until the hatch is closed. The vapor velocity through the actual equipment hatch would be roughly 0.1 fps.

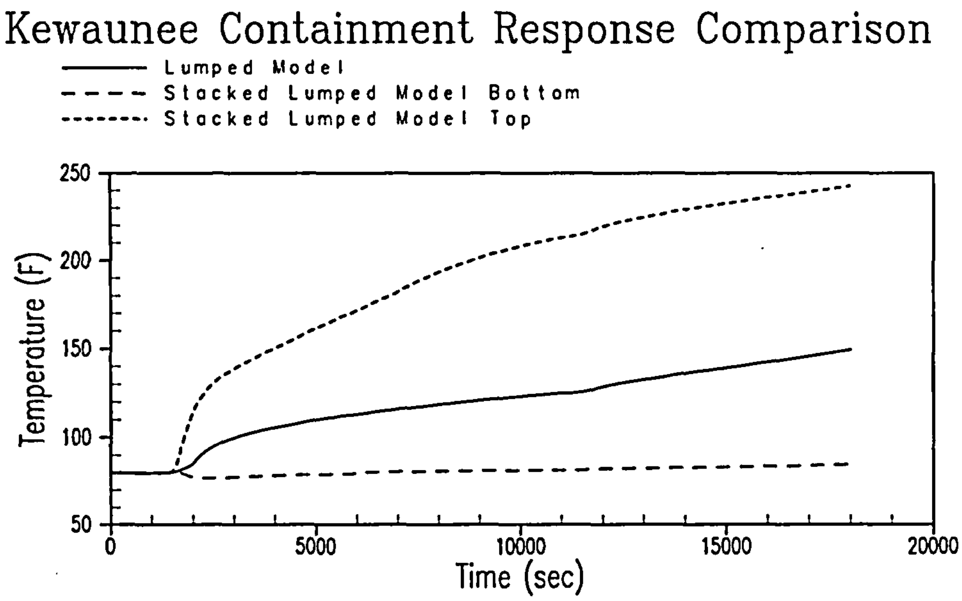

Figure 4.2-21 – Containment Temperature Comparison

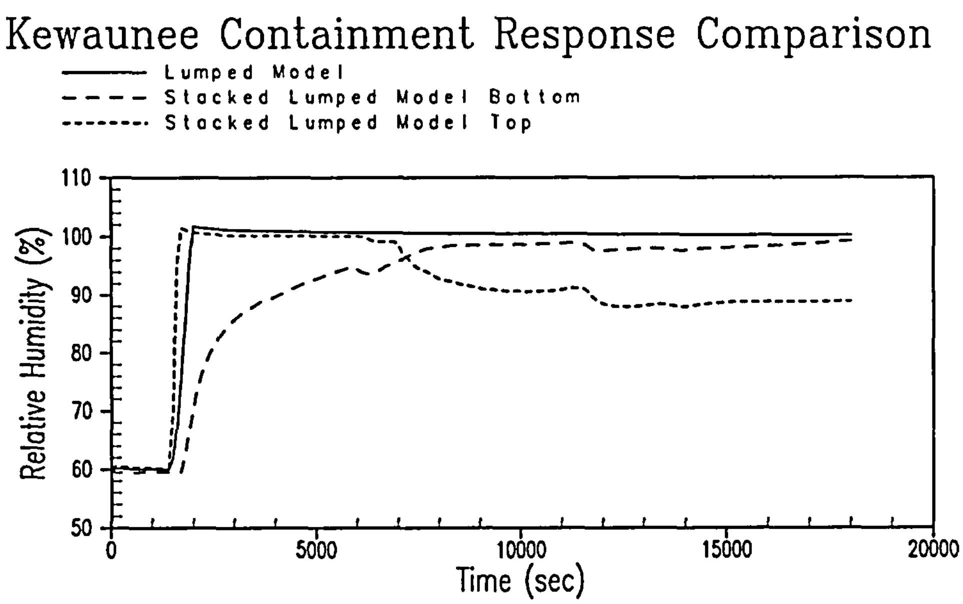

Figure 4.2-22 – Containment Humidity Comparison

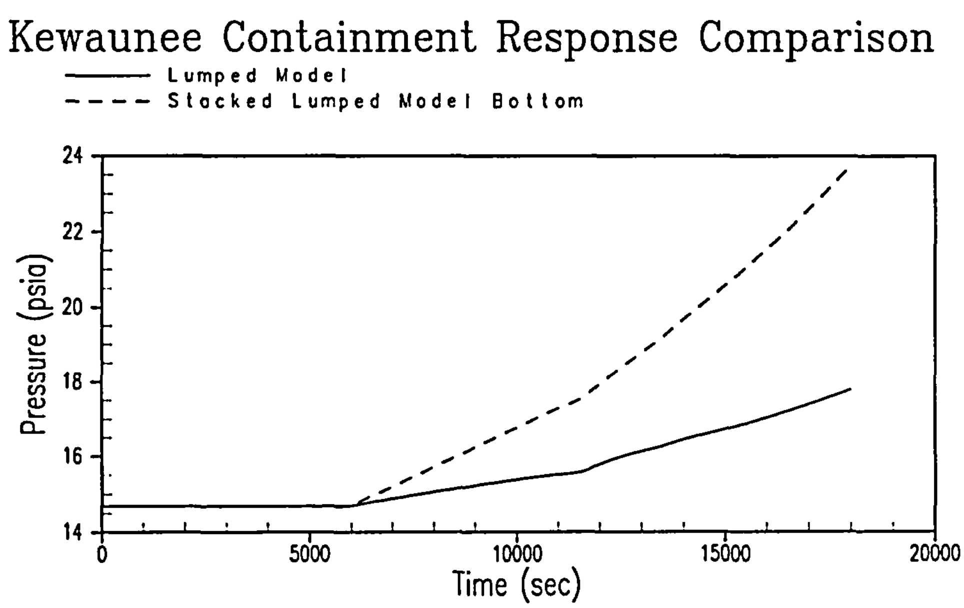

Figure 4.2-23 – Containment Pressure Comparison

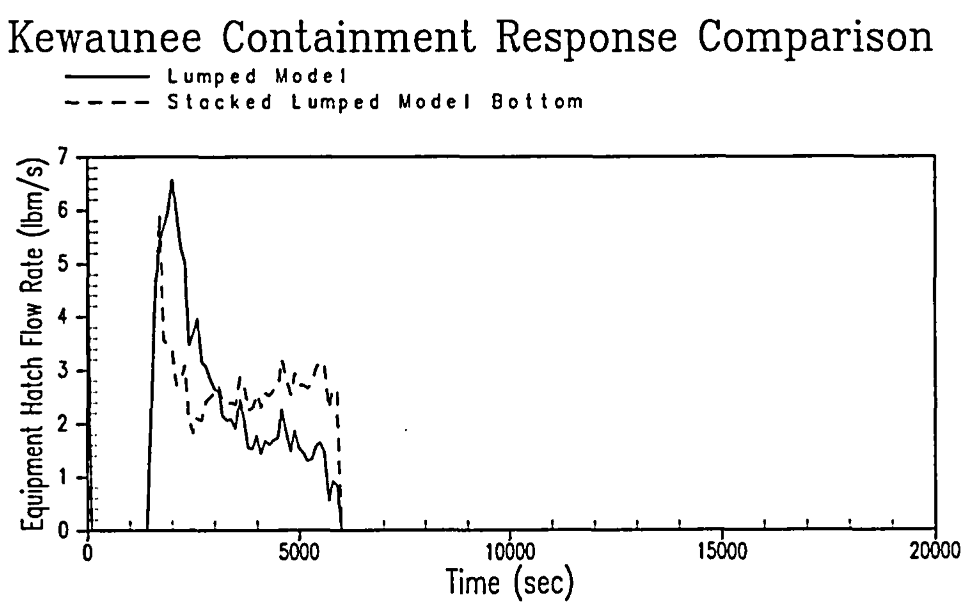

Figure 4.2-24 – Containment Equipment Hatch Vapor Flow Rate Comparison

5.0 Summary of Results and Conclusions

A generic 2-loop RCS model was used to calculate the time to boil and time for the collapsed fluid level to reach the top of the fuel after an assumed loss of AC power and subsequent loss of RHR. The results for the two cases presented in Section 4 are summarized below.

For Case 1 with the flange gap closed, the RCS pressure increased and water was forced into the pressurizer as the system began to boil. Some of the core decay heat was able to be removed by condensation in the steam generator tubes; steaming through the pressurizer vent was negligible until the steam generator secondary temperature had increased to the boiling point. The hold-up of water in the pressurizer due to surge line flooding and steaming through the pressurizer vent eventually resulted in core uncovery.

For Case 2 with the flange gap open (head de-tensioned), the RCS did not significantly re-pressurize after the system began to boil. About 4 lbm/s of steam was vented through the flange gap and a smaller amount of steam was condensed in the steam generator tubes than Case 1. The core would eventually uncover due to the slow loss of inventory through the flange gap. The core uncovery time for this case was conservatively estimated to be greater than 9 hours.

Case Summary of Generic 2-Loop RCS Model Results								
Case	Decay Heat	Przr Vent	Flange Gap	Initial Level	SG Tubes	Initial Temp	Time to Boil *	Time to Uncover Top of Fuel *
1	8 MW	Safety Valve Pipe	Closed	Flange -0.5 ft	Full	118 F	75 min	5.44 hours
2	6.82 MW	Safety Valve Pipe	Open	Flange -0.5 ft	Full	114 F	35 min	>9 hours

* These times to boiling and core uncovery are referenced following loss of all AC power and subsequent loss of pumped RHR flow. All analysis cases assume forced cooling is lost 900 seconds (or 15 minutes) into the transient.

The lumped parameter Kewaunee containment model was used to estimate the containment pressure and temperature response to this event. The average containment temperature increased most rapidly in the cases where the flange gap was open. Closing the equipment hatch caused the containment pressure to slowly increase when steam was being released through either the flange gap or safety valve pipe.

6.0 References

1. WCAP-14988, "Use of the GOTHIC Computer Code for Analyses to Support Shutdown Operations", R. Ofstun, et. al., April 1998
2. WCAP-15145, "Development and Testing of Generic Plant Models with the GOTHIC Computer Code for Analyses to Support Shutdown Operations", R. Ofstun, et. al., February 1999.
3. EPRI/ORAM Report NSAC-176L, Safety Assessment of PWR Risk During Shutdown Operations, August, 1992.

Appendix A: Supporting Documentation

This section contains the design interface agreement and design information transmittal for the analysis of a potential loss of RHR cooling at reduced inventory conditions for Kewaunee.

QF-0545 (FP-E-MOD-11) Rev. 0

NMC
Committed to Nuclear Excellence
Fleet Modification Process

Design Interface Agreement (DIA)

Date: 1-05-04

Mod or Tracking Number: CEQH Revision: 0

Plant: Kewaunee Quality Classification: Safety related

Title: Containment Equipment Hatch Closure GOTHIC Analysis

Initiating Organization: NMC Kewaunee

Identify Applicable Positions:	Name/Contact Info:
X Project Manager:	Tom Breene
Engineering Supervisor:	
X Responsible Engineer:	John Holly

External Organization: Westinghouse Electric Company

Identify Applicable Positions:	Name/Contact Info:
☐ Engineering Supervisor:	
X Responsible Engineer:	Rick Ofstun
☐ Other: ______	

Scope of Interface Agreement:
Perform GOTHIC analyses to support Kewaunee Containment Equipment Hatch Closure Issue and associated PRA analyses.

Applicable QA Program and/or Procedures:
Westinghouse Quality Management System (QMS)

Tasks/Deliverables: Attach additional information as required. Identify if the item is to be Prepared, Design Verified or Technical Review, Approved and/or PE Stamped and if PE what state.

Task	Deliverable	Due Date	Level of Completion: Prep	DV	APP	PE
Perform and Document GOTHIC NSSS and Containment analyses for selected plant conditions and configurations	Calculation Prepared and Technically Reviewed and Approved	January 15 2005	X	X	X	☐
					☐	☐
						☐

Note: Identify if item is to be Prepared, Design Verified or Technical Review, Approved and/or PE Stamped

CF-0548 (FP-E-MOD-11) Rev. 0

NMC Committed to Nuclear Excellence Fleet Modification Process	Design Interface Agreement (DIA)

Reference Documents:

Budget and Charge Number(s):

Prepared by:	John Holly	Date:	01-06-05
Initiating Organization:	NMC Kewaunee	Date:	01-06-05
External Organization:	Westinghouse Electric Company	Date:	01-06-05

QF-0545 (FP-E-MOD-11) Rev. 0

NMC Committed to Nuclear Excellence Fleet Modification Process	Design Information Transmittal (DIT)

From:	John Holly, NMC				
To:	Rick Ofstun, WEC				
Mod or Tracking Number:	Containment Equipment Hatch Closure GOTHIC Analysis	Date:	01-06-05	DIT No:	CECH 05 001
Mod Title:	Containment Equipment Hatch Closure GOTHIC Analysis				
Plant:	Kewaunee	Unit 1 ☒ Unit 2 ☐ Common ☐		Quality Classification:	Safety Related

SUBJECT:Containment Equipment Hatch Closure GOTHIC Analysis

Check if applicable:

☐ **This DIT confirms information previously transmitted orally on ______ by ______________.**

☐ **This information is preliminary. See explanation below.**

SOURCE OF INFORMATION (Source documents should be uniquely identified)

Kewaunee Nuclear Power Plant (KNPP) Design Drawings:

M-940-1, Rev C - Reactor Coolant From Pressurizer to Pressurizer Relief Tank

M-940-2, Rev C - Reactor Coolant From Pressurizer to Pressurizer Relief Tank

S-210, Rev E - Reactor Bldg. Containment & Shield Wall Blockouts & Embedded

S-212, Rev C - Reactor Bldg. Cont & Shield Wall - Plans of Blockouts

A-203, Rev BK - General Arrangement, Reactor & Auxiliary Bldg-Oper Floor

KNPP Containment Equipment Hatch Closure Issue Documentation a) KNPP plant configuration information and operating data during the 2004 refueling outage (10-08-04 through 10-15-04) derived from operating logs b) KNPP Containment Equipment Hatch Closure Time Line developed by the PRA group

DESCRIPTION OF INFORMATION (Write the information being transmitted or list each document being transmitted)

See Attachment 1

Page 1 of 2

QF-0545 (FP-E-MOD-11) Rev. 0

NMC Committed to Nuclear Excellence Fleet Modification Process	**Design Information Transmittal (DIT)**

DISTRIBUTION (Recipients should receive all attachments unless otherwise indicated. All attachments are uncontrolled unless otherwise indicated)

One copy to Rick Ofstun of Westinghouse Electric Corp

PREPARED BY (The Preparer and Approver may be the same person.)

John Holly	RE		
Preparer Name	Position	Signature	Date

APPROVED BY (The cognizant Engineering Supervisor has release authority. Consult the Design Interface Agreement or local procedures to determine who else has release authority.)

Tom Breene	Plant Systems Engineering Mgr		
Approver Name	Position	Signature	Date

A copy of the DIT (along with any attachments not on file) should be sent to the modification fille

Attachment 1
KNPP Containment Equipment Hatch Closure GOTHIC Analysis Design Information Transmittal

1.0 Decay Heat

Perform the GOTHIC RCS analysis assuming core decay heat at 3 days after shutdown based on the following actual times:

10-09-04 0055 reactor shutdown
10-12-04 0127 Diesel generator (DG) A out of service

Actual time line for KNPP containment equipment hatch closure analysis is presented below:

Date	Time	Activity
10/9/04	0055	Reactor is shutdown
	0154	Enter Intermediate Shutdown mode
	0302	Enter Intermediate Shutdown
	0600	Boron 1324 ppm; RCS1920 psig, 518°F
	1800	Boron 1406 ppm: RCS417 psig, 344°F
	2302	Aligned RHR Per N-RHR-34
10/10/04	0600	Boron –1533 ppm: RCS at 250°F, 356 psig
	0814	Reactor in Cold Shutdown Mode – Containment Integrity no longer required
	1245	RCS is in Solid Operation
	1515	Equipment Hatch Opened
	1800	Boron –1679 ppm: RCS at 147°F, 308 psig
10/11/04	0230	Entered Refueling Shutdown
	0236	Stopped RXCP B
	0600	Boron –2516 ppm: RCS at 130, 84sig
	1245	Start of track installation
	1327	D/G A OOS – SP-33-110
	1430	Pressurizer Safety removed
	1510	D G A RTS
	1604	D G B OOS for maintenance
	1606	Track installation complete in equipment door
	1800	Boron –2516 ppm: RCS at 117°F
	1947	D/G B RTS
	2148	D/G B OOS – SP-33-110
	2239	D G B RTS
10/12/04	0032	Started RCS Drain Down to 20.6%
	0127	D/G A OOS for BRA-104 work
	0502	Drain down complete – RCS level 20.6%

	0600	Boron –2516 ppm: RCS at 117°F
	1617	S/G A in wet layup
	1800	Boron –2516 ppm: RCS at 115.5°F, RCS at ATM press
	2340	S/G in wet layup
10/13/04	0600	Boron –2504 ppm: RCS at 114°F, RCS at ATM press
	1045	Rx stud hoists on
	1215	No power to stud hoists. Called control room to check breaker. OCC informed. Electricians investigating. Ops called back breaker is on.
	1645	Had problems with a stud hoist
	1800	Boron –2504 ppm: RCS at 113.8°F
	2325	Tension devices removed from the lower level.
10/14/04	0300	Started removal of Rx Studs from Containment
	0600	Boron –2504 ppm; RCS at 112°F
	1230	Discovered equipment door could not close
	1800	Boron –2647 ppm: RCS at 111.3°F
	1800 – 1855	Removing part of the rail system so that the hatch door could be closed.
	1910	Start of equipment door closure
	2030	Equipment door closed
10/15/04	0600	Boron –2647 ppm: RCS at 110.8°F
	0700	Started Filling Refueling Cavity

2.0 Pressurizer Safety Valve Area

The Pressurizer Safety is mounted on 6" ANSI Class 1500 Flange so the area of the opening left when we take off the safety would be 28.27 sq. inches. (Reference drawing M-940)

3.0 RV flange elevation relative to containment equipment hatch elevation

The very bottom of the equipment hatch is at elevation 609' per drawing S-213
The bottom of the refueling cavity is at elevation 623' 7" per drawing A-208

4.0 Equipment Hatch Closure Time

To maximize containment temperature in the equipment hatch region, in the GOTHIC containment model close the containment equipment hatch at 84 minutes (the "early" time that the equipment hatch was positioned over the opening) based on the containment equipment hatch closure time line shown below:

Early Elapsed	Action	Justification/Comments

0	Station Blackout – Containment Equipment Door open, Reactor Head de-tensioned. 6 inches below vessel flange	Initiating event
0.8	Operators enter ECA-0.0	Based on average operator action time. ECA-0.0 would be entered due to the operator training. Basic training is to enter this procedure when Control Room lights go out and this is an acceptable entry condition
1.3	ECA-0.0 steps 1 and 2 completed concurrently	Operator interview 9/24/02
2.3	ECA-0.0 step 3 – RCS Isolation checked	The PRZR Safeties have been removed so isolation is not possible. Containment closure may be directed at this point and entry into A-RHR-34 may be directed.
2.55	ECA-0.0 step 4 – Verify AFW	AFW is not available due to S/G being depressurized and no electric power. Note that the S/G are in wet lay-up and would have a substantial mass.
3	ECA-0.0 step 5 – Restore power to Bus 5 or 6.	Diesel Generator A is disassembled for maintenance. Diesel Generator B failed.
9	ECA-0.0 step 5.a.1 RNO.1 Operator try to start D/G B from Control Room using A-DGM-10B	This is assumed a failure. The NAO is directed to locally start the D/G while Control Room Operators continue in ECA-0.0.
10	ECA-0.0 step 5 – step is completed	Operator interview 9/24/02
10.8	ECA-0.0 step 6 – Direct placing equipment in pullout including RHR.	It is assumed that placing RHR pump to pullout would cause the operator to enter A-RHR-34. Loss of RHR pumps is an entry condition for A-RHR-34, which is typically out during RHR operations. This would be performed in parallel with ECA-0.0 due to available personnel from "super crew" concept during outages.
11	Operators enter A-RHR-34	Based on the identification of a loss of RHR on Step 6 of ECA-0.0.
11.8	Operators progress to Step 4.2 of A-RHR-34 due to conditions	Step 4.2 deals with the loss of RHR Cooling, which includes flow.
19	Local start of D/G B completed	This is assumed to fail.
24.5	Operators reach step 4.2.6.b.1 of A-RHR-34 to initiate containment closure. Containment operator and Containment Coordinator are contacted by the Control Room Operators.	Time based on Operator interview 1/21/03. If the operators fail to enter A-RHR-34, Step 29 of ECA-0.0 directs isolation of Containment, which would add 10 minutes to timeline
29.5	Crew mobilized to remove exterior rail and begin work	Bigge/Westinghouse via ACE2824
32.5	ECA-0.0 steps to start TSC D/G and energize Bus 52 are complete.	Time based on Operator interview 9/24/02
36.5	ECA-0.0 steps to initiate Charging complete.	Time based on Operator interview 9/24/02

arly Elapsed Time (minutes)	Action	Justification Comments
44.5	Exterior Rail is removed and personnel to close Containment Equipment Door are positioned and mobilized.	Bigge/Westinghouse via ACE2824. It issued personnel required to close Containment Equipment Door would be assembled and positioned during time required to remove exterior rail.
72	Obstacle removed for Containment Equipment Door	Based on half the 55 minutes to remove obstructio by cutting rail instead of rigging and repositioning rail to allow closure.
84	Containment Equipment Door positioned for bolting (early)	Final Containment Equipment Door Closing 11/20/04 using A-RHR-34 procedure path
94	Containment Equipment Door positioned for bolting (late)	Final Containment Equipment Door Closing 11/20/04 and going to step 29 of ECA-0.0
104	Containment Equipment Door closure (early)	Final Containment Equipment Door Closing 11/20/04 using A-RHR-34 procedure path
114	Containment Equipment Door closure (late)	Final Containment Equipment Door Closing 11/20/04 and going to step 29 of ECA-0.0

5.0 Analysis Assumptions for GOTHIC Analysis cases 5 and 6

Note: GOTHIC cases 5 and 6 are cases that have revised some of the conservative inputs from the GOTHIC model and replaced them with KNPP specific inputs consistent with actual configuration and conditions.

In both case 5 and case 6, model the Reactor Vessel water inventory at 6 inches below the RV flange. The model should include SG tubes filled with water. This water level corresponds to a KNPP RCS level of 20.6%.

In case 5, the pressurizer safety valve removed case:
RCS initial temperature= 117 degree F
Reactor decay heat is 3 days after shutdown

In case 6, the prz safety valve removed plus RV flange vent gap case:
RCS initial temperature is 114 degree F
Reactor decay heat is 4 days 9 hrs and 50 minutes (105.8 hrs) after shutdown