FOR UNRESTRICTED DISTRIBUTION

DATE _____ WEC

Westinghouse Energy Systems

8907180454 890713
PDR ADOCK 05000247
P PNU

WCAP-12312

WESTINGHOUSE CLASS 3

SAFETY EVALUATION FOR AN ULTIMATE HEAT SINK TEMPERATURE INCREASE TO 95^{0}F AT INDIAN POINT UNIT 2

E. R. COLVIN
D. E. DURKOSH
J. M. GRIGSBY

JULY 1989

NUCLEAR AND ADVANCED TECHNOLOGY DIVISION
WESTINGHOUSE ELECTRIC CORPORATION

OTHER CONTRIBUTORS

M. Asztalos
M. Ball
R. Beck
G. Cefola
J. Conklin
J. Dudiak
R. Howard
J. Kolano
G. Konopka
K. Leonelli
W. Moore
L. Smith
J. Von Hollen
M. Watson
M. Wiatrowski

SAFETY EVALUATION FOR AN
ULTIMATE HEAT SINK TEMPERATURE INCREASE
TO 95°F AT INDIAN POINT UNIT 2

TABLE OF CONTENTS

	EXECUTIVE SUMMARY	vi
1.0	INTRODUCTION	1-1
1.1	1988 Justification For Continued Operation	1-1
1.2	1989 Program Scope	1-2
2.0	SYSTEM DESCRIPTION	2-1
2.1	Service Water System	2-1
2.1.1	Normal Plant Operations	2-2
2.1.2	Post-Accident Operations	2-2
2.2	Auxiliary Coolant System	2-3
2.2.1	Component Cooling Water System (CCWS)	2-3
2.2.2	Residual Heat Removal System (RHRS)	2-7
2.2.3	Spent Fuel Pit Cooling System (SFPCS)	2-8
3.0	AUXILIARY COOLANT SYSTEMS EVALUATIONS	3-1
3.1	Component Cooling Water System	3-1
3.1.1	Thermal/Hydraulic Model	3-1
3.1.1.1	PEGISYS Computer Code Description	3-1
3.1.1.2	Modeling Methodology	3-3
3.1.1.3	Thermal Analysis Assumptions	3-6
3.1.1.4	Calculated Performance Results	3-13
3.1.2	System Evaluation	3-19
3.1.2.1	Flow Requirements	3-20
3.1.2.2	System Design Temperature	3-20
3.1.2.3	CCW Pumps	3-22
3.1.2.4	CCWS Piping	3-25
3.1.2.5	Heatup During LOCA Injection Phase	3-26

TABLE OF CONTENTS (continued)

3.2 Residual Heat Removal System Performance 3-27

3.2.1 Plant Cooldown 3-27

3.2.1.1 Background 3-28
3.2.1.2 Methodology 3-29
3.2.1.3 Results 3-30

3.2.2 Post-LOCA Performance 3-33

3.3 Spent Fuel Pit System Performance 3-33

3.3.1 Power Operation 3-34
3.3.2 Refueling 3-35

4.0 COMPONENT EVALUATIONS 4-1

4.1 Accident Required Equipment Cooled By the SWS 4-2

4.1.1 Reactor Containment Fan Coolers (RCFCs) 4-2
4.1.2 RCFC Fan Motors 4-4
4.1.3 RCFC Service Water Discharge Radiation Monitors 4-6
4.1.4 Diesel Generators 4-9
4.1.5 Instrument Air System 4-13
4.1.6 Component Cooling Heat Exchangers 4-16

4.2 Equipment Cooled By CCWS 4-16

4.2.1 Mechanical Integrity Evaluation 4-17

4.2.2 Thermal Performance Evaluation 4-19

4.2.2.1 Recirculation Pump Motors 4-19
4.2.2.2 Safety Injection Pumps 4-20
4.2.2.3 RHR Pumps 4-22
4.2.2.4 Charging Pumps 4-23
4.2.2.5 Reactor Coolant Pumps 4-24
4.2.2.6 Reactor Vessel Support Cooling Blocks 4-25
4.2.2.7 Sample Heat Exchanger Cooling 4-26
4.2.2.8 Waste Gas Compressors 4-27
4.2.2.9 Non-Regenerative Heat Exchanger 4-29
4.2.2.10 Excess-Letdown Heat Exchanger 4-29
4.2.2.11 Seal Water Heat Exchanger 4-30

TABLE OF CONTENTS (continued)

5.0 LICENSING EVALUATION 5-1

5.1 Discussion 5-1

5.1.1 Normal Operations 5-3

5.1.1.1 Containment Cooling 5-3
5.1.1.2 Instrument Air Compressor Cooling 5-4
5.1.1.3 Main Feed Water Lube Oil Coolers 5-5
5.1.1.4 Turbine/Generator Cooling 5-6
5.1.1.5 CCW Heat Exchanger Cooling 5-8
5.1.1.6 Main Condenser Cooling via the CWS 5-17

5.1.2 Cooling Performance During Abnormal Conditions 5-18

5.1.2.1 Loss-of-Offsite Power 5-18
5.1.2.2 Safe Shutdown Following Postulated Plant Fires 5-18

5.1.3 Cooling Following Design Basis Accidents 5-21

5.1.3.1 Reactor Containment Fan Coolers 5-21
5.1.3.2 RCFC Motors 5-21
5.1.3.3 RCFC Service Water Return Radiation Monitors 5-23
5.1.3.4 Instrument Air Compressors 5-24
5.1.3.5 CCWS Cooling 5-24

5.2 Containment Integrity Analysis 5-32

6.0 CONCLUSIONS 6-1

6.1 Auxiliary Coolant System 6-1

6.2 Component Performance 6-2

6.2.1 SWS Components 6-2

6.2.1.1 RCFC Service Water Return Radiation Monitor 6-2
6.2.1.2 Diesel Generators 6-2

TABLE OF CONTENTS (continued)

6.2.2 CCWS Components 6-3

6.2.2.1 RCPs 6-3
6.2.2.2 Reactor Vessel Nozzle Blocks 6-3

APPENDIX A - CCWS PUMP MINIMUM/MAXIMUM PERFORMANCE DATA A-1

EXECUTIVE SUMMARY

This report describes the results of analyses used to support an increase in the design basis maximum temperature of the Indian Point 2 plant ultimate heat sink (Hudson River) to 95°F. The Service Water System (SWS) uses cooling water from the Hudson River to provide cooling to various plant equipment. SWS cooling is required to ensure equipment operability and adequate cooling performance to remove component and decay heat to support normal, safe plant operation, shutdown during abnormal conditions, and mitigation of postulated design basis accidents.

Normal, safe plant operation is defined for this evaluation to be the ability to cool equipment whose sudden failure could cause a design basis transient analyzed in FSAR Chapter 14 or whose operability is required to ensure that initial conditions assumed in the accident analyses are not exceeded. This includes cooling the containment atmosphere via the reactor containment fan coolers and various coolers required for turbine/generator operation. The SWS also provides cooling to the CCWS which in turn cools the following equipment needed for normal, safe plant operations: the spent fuel pit heat exchanger, the reactor coolant pumps, the charging pumps, various sample coolers, and the reactor vessel support cooling blocks. In addition, cooling water from the Hudson River is used to cool the main condenser via the circulating water system (CWS). Adequate cooling of the condenser is required to maintain vacuum and thus prevent turbine trip on low vacuum.

The SWS and the CCWS provide the required cooling to support plant shutdown under abnormal conditions. The safe shutdown condition is hot standby. Cooling required under normal operations bounds the hot standby requirements. Following postulated plant fires, cooldown to cold shutdown via the RHR heat exchangers is needed to meet 10 CFR 50 Appendix R requirements.

The SWS provides cooling to the emergency diesel generators if offsite power is lost.

The SWS provides cooling to safety-related equipment following postulated design basis accidents, including the Reactor Containment Fan Coolers, the Emergency Diesel Generators, and the CCWS. The CCWS in turn cools the SI pumps, the Recirculation Pumps, the RHR Pumps, and the RHR Heat Exchangers. The effects of increase SWS temperature on the containment integrity analysis is addressed in WCAP-12187, "Indian Point Unit 2, NSSS Stretch Rating - 3083.4 MWt, Engineering Report".

The safety evaluation in this report addresses the functions discussed above.

The following areas are being addressed by Con Ed in their assessment of the proposed Technical Specification change to increase the allowable Ultimate Heat Sink temperature:

a. The effects of possible increased ambient temperatures (including containment temperatures above 120°F), that may be associated with the meteorological conditions that result in high service water temperatures, on equipment operability or qualified life.

b. The ability of the service water system to provide the flow rates required to support safety functions with 95°F service water temperatures.

c. The ability of the plant to operate with 95°F service water and maintain CCWS cooled equipment, required for safe plant operation, within acceptable operating conditions, and still maintain CCW pump discharge header pressure above the required P(min) value.

d. Possible effects of increased SWS and CCWS temperatures, on piping stress analyses (e.g., increased thermal expansion due to higher process fluid temperatures).

e. The acceptability of increased SWS temperatures relative to environmental restrictions (releasing hotter water back to the Hudson River)

The results of an economic evaluation of nonsafety-related components that are ultimately serviced by the Hudson River water will be included in a separate report.

SWS cooling functions for safety-related equipment were evaluated and required SW flow rates were determined to support equipment cooling.

CCWS cooling functions and CCWS operability are included in this report. To support this effort, a thermal-hydraulic computer model of the CCWS was developed to determine process conditions during various modes of operation. Each component was evaluated to ensure that supplied flow was adequate to support safety functions with a UHS temperature of 95°F.

A licensing evaluation was then performed to ensure the current licensed safety limits, that are affected by UHS temperature, were met. It is concluded that all equipment required for safe plant operations, serviced by the SWS will operate acceptably with 95°F service water, current safety limits affected by SWS temperature will be met, and, within the scope of this evaluation, this change does not involve a significant hazards consideration.

1.0 INTRODUCTION

The Indian Point Unit 2 Service Water System (SWS) draws water from the Hudson River, and uses this water to cool various plant components. The warmed water is subsequently returned to the river. The design of the SWS is currently based on the inlet river water not exceeding 85°F. Because of the 1988 meteorological conditions, Westinghouse prepared Justifications for Continued Operation (JCO) for the Indian Point Unit 2 plant to operate the CCWS and the reactor containment fan coolers with SWS inlet temperatures up to 95°F. Con Ed has determined that the ultimate heat sink temperature may be challenged during future summers. To address this issue in a systematic manner, Con Ed contracted Westinghouse to perform necessary analyses to increase the design basis temperature of the ultimate heat sink to as high as 95°F.

1.1 1988 JCO for Increased Service Water System Temperature

In 1988, Westinghouse prepared two evalutions that supported emergency technical specification changes based upon maximum SWS inlet temperatures of 87°F and 90°F. These safety assessments addressed the ability of the Component Cooling Water System (CCWS) to perform its normal and post-accident safety functions given the higher service water temperatures. They also addressed the containment analysis and reactor containment fan cooler motors. It was noted that additional confirmatory design calculations would be required to permanently increase the design temperature of the SWS.

To maintain adequate cooling at the elevated temperatures, specific recommendations regarding component cooling water (CCW) pump operating requirements were provided in the safety assessments. The limiting requirements were based upon ensuring that the CCW heat exchanger outlet temperature remained below 156°F during post-accident conditions. Westinghouse recommended that interim emergency operating procedures be developed for implementation if CCW heat exchanger outlet temperature approached 150°F. The object was to maximize the CCW flow through the CCW heat

exchangers and to reduce the CCW flow to the Residual Heat Removal (RHR) heat exchangers, as necessary, to maintain the CCW heat exchanger outlet temperatures at or below established limits

1.2 1989 PROGRAM SCOPE

This report contains the results of analyses performed to evaluate increasing the maximum allowable service water temperature to 95°F. Adequate service water cooling must be provided to safety-related plant equipment to ensure equipment operability and adequate cooling performance to remove component and decay heat to support normal, safe plant operation, shutdown during abnormal conditions, and mitigation of postulated design basis accidents.

Normal Operations

Normal, safe plant operation is defined for this evaluation to be the ability to cool equipment whose sudden failure could cause a design basis transient analyzed in FSAR Chapter 14 or whose operability is required to ensure that initial conditions assumed in the accident analyses are not exceeded. This includes cooling the containment atmosphere via the reactor containment fan coolers, cooling the instrument air compressors, and cooling the main boiler feed pump lube oil coolers, and various coolers required for turbine/generator operation. The SWS also provides cooling to the CCWS which in turn cools the following equipment needed for normal, safe plant operations: the spent fuel pit heat exchanger, the reactor coolant pumps, the charging pumps, various sample coolers, and the reactor vessel support cooling blocks. In addition, cooling water from the Hudson River is used to cool the main condenser via the circulating water system (CWS). Condenser vacuum must be maintained to prevent turbine trips on low vacuum.

Abnormal Conditions

The SWS and the CCWS provide the required cooling to support plant cooldown via the RHR heat exchangers under abnormal conditions (i.e., following postulated plant fires).

The SWS provides cooling to the emergency diesel generators if offsite power is lost.

Postulated Accidents

The SWS and the CCWS provide cooling to safety-related equipment following postulated design basis accidents.

The safety evaluation described in this report addresses each of the above areas.

The results of an economic evaluation of nonsafety-related components that are ultimately serviced by the Hudson River water will be included in a separate report.

Section 2.0 contains a brief description of the SWS and the interfacing Auxiliary Coolant System (ACS). Sections 3.0 and 4.0 describe the analyses performed, including individual results and conclusions. Section 5.0 contains a summary of the containment integrity analysis performed using the higher SWS temperature, the results of the licensing evaluation that justifies a change in the ultimate heat sink design basis temperature to 95°F, and a brief discussion of the proposed Technical Specification changes required to allow operation of the plant with the higher ultimate heat sink temperature. Section 6.0 is a summary of conclusions and operating requirements associated with this design change. Appendix A defines the CCW pump minimum and maximum pump performance levels used to evaluate system performance.

2.0 SYSTEM DESCRIPTION

This section contains information on the current SWS and ACS. The system descriptions discuss aspects of the functions and operations that are affected by the SWS temperature change. They are not comprehensive descriptions of the systems. Modifications and recommendations required as a result of this evaluation are contained in subsequent sections.

2.1 SERVICE WATER SYSTEM

The SWS is designed to supply cooling water from the Hudson River to various heat loads in both the nuclear and balance of plant portions of the station. The SWS also provides water required for cleaning the traveling screens and trash trough, provides seal and lubricating water to the main circulating water pumps, and supplies raw makeup water.

The SWS consists of six pumps, each having a capacity of 6000 gpm at 195 feet total design head. Three service water pumps are aligned to supply service water to an essential header and the other three service water pumps are aligned to supply service water to a nonessential header. The system loads can be supplied from either header, interchangeably, but the system is maintained and operated as a split system.

The essential header supplies those safety-related loads that must have an immediate supply of cooling water in the event of a LOCA with a loss-of-offsite power (blackout). The nonessential header supplies the safety-related and nonsafety-related loads that do not require cooling immediately following an accident and are thus supplied with cooling water from the designated nonessential service water header by manually starting a nonessential service water pump, when required, following an accident.

2.1.1 Normal Plant Operations

During normal operations, one set of three pumps is aligned to provide service water flow to the essential loads, and the other set is aligned to provide service water flow to the nonessential loads. The technical specifications require that the reactor not be taken above 350°F with less than three operable pumps aligned to the essential header and two operating service water pumps aligned to the nonessential header (T.S. 3.3.F.1.A/B).

2.1.2 Post-Accident Operations

In the event of simultaneous loss-of-offsite power and an incident requiring safety injection, all SWS pumps are stripped from the electrical busses, but only the essential pumps are automatically restored. At the initiation of the recirculation phase following a postulated design basis accident, a nonessential pump, which supplies the safety-related CCW heat exchangers, is manually loaded onto the diesel generators

The cooling requirements for all five fan cooling units and the other essential loads can be supplied by any two of the three service water pumps on the designated header. Either of the two sets of three pumps can be placed on the diesel starting logic.

The CCW heat exchangers are not required during the injection phase, thus they are fed from the nonessential supply header. At the beginning of the recirculation phase, the CCW heat exchangers are placed in service by starting at least one of the service water pumps on the nonessential header. The SWS provides cooling water to the component cooling loop, which in turn cools the RHR heat exchangers, the recirculation pumps, and the SI pumps.

SWS Essential Header Loads

- Containment recirculation fan cooling coils
- Containment recirculation fan motor cooler coils
- Instrument air compressor closed cooling system
- Diesel Generator cooling services
- Service water pump strainer backwash
- Radiation Monitoring Sample Coolers

SWS Nonessential Header Loads

- Screen wash system
- Circulating water pump seal water
- Exciter air coolers
- Isolated phase bus coolers
- Generator hydrogen coolers and stator water coolers
- Conventional plant closed cooling heat exchangers
- Mechanical vacuum pumps
- Main boiler feed pump lube oil coolers
- Main Turbine oil coolers
- Generator seal oil coolers
- Component cooling heat exchangers

2.2 AUXILIARY COOLANT SYSTEMS

2.2.1 Component Cooling Water System

The CCWS serves as an intermediate system between the nuclear side systems and the SWS. This arrangement reduces the possibility of radioactive fluid leakage from the components being cooled to the environment via the SWS.

The CCWS is designed to remove residual and sensible heat from the RCS via the RHR loop during plant shutdown and post-accident conditions, and to provide cooling to specific plant components during power operation.

The CCWS consists of three component cooling pumps, two auxiliary CCW pumps, two CCW heat exchangers, a component cooling surge tank, and associated piping, valves, and instrumentation. The component cooling water flows from the CCW pumps, through the shell side of the CCW heat exchangers where heat is removed via the SWS, through the components being cooled, and is then returned to the pumps.

The surge tank, which is connected to the suction side of the CCW pumps, accommodate surges resulting from component coolant thermal expansion and contraction, accommodates water which may leak into the system from components that are being cooled, and maintains adequate available NPSH for pump operation. The surge tank also contain sufficient water to ensure a continuous component cooling water supply until a leaking cooling line can be isolated.

2.2.1.1 Normal Plant Operations

System operation depends upon the heat load. Two CCW pumps and two CCW heat exchangers are required to be operable by the technical specifications. The standby pump provides backup and starts automatically on low pump discharge header pressure.

2.2.1.2 Normal Plant Cooldown

Operation of three CCW pumps and both CCW heat exchangers are desired for removing residual and sensible heat during a normal plant cooldown. Failure of one of these components increases the time required for cooldown, but does not affect the safe operation of the plant.

The CCWS is designed to supply 120°F cooling water to the components being cooled when the RHR loop is first placed in operation during plant cooldown, this being the maximum permissible temperature of the cooling water supply to the reactor coolant pumps. During normal plant operation, the temperature of the cooling water supplied to the reactor coolant pumps is approximately 95°F (with a 95°F ultimate heat sink, the CCWS will supply approximately 105°F cooling water).

2.2.1.3 Post-Accident Operations

The CCW pumps are not required by the safeguards system immediately following a safety injection (SI) initiation signal. To reduce loading of the diesels during a blackout with SI, these pumps are not automatically started. However, for SI without blackout or blackout and unit trip without SI, the CCW pumps will be automatically started. If not running, the CCW pumps will be manually started during the recirculation phase of SI to provide cooling for the RHR heat exchangers, the recirculation pumps and the SI pumps.

During the injection phase of SI, the CCW pumps are not operating. To protect the recirculation pump motors from the containment atmosphere, the auxiliary CCW pumps are automatically started to circulate water to the recirculation pump motor coolers. In addition, a booster pump, driven by the SI pump motor shaft, supplies cooling water flow to each safety injection pump. During this injection period, the thermal capacity of the CCW loop is used as the heat sink, since service water is not being circulated to the CCW heat exchangers.

As a result of the SI signal, the CCW flow to the RHR heat exchangers is automatically aligned. This is done in anticipation of recirculation later in the event.

The phase A isolation signal, which occurs as a result of the SI, isolates all CCW flow into containment except the headers supplying the RCPs, the RHR heat exchangers, and the recirculation pumps. If a phase B isolation signal occurs, the RCP supply and return headers are also isolated.

For the recirculation phase of SI, the CCW system will provide cooling water to the RHR heat exchangers. One CCW pump provides the minimum required flow. If all three emergency busses are energized, a second CCW pump is manually started. This provides the maximum long-term cooling capacity.

Accident Required Loads

- Residual Heat Exchangers
- Residual Heat Removal Pumps
- Safety Injection Pumps
- Recirculation Pumps

Accident Non-required Loads

- RCP Thermal Barriers
- RCP Motor Coolers
- Non-Regenerative Heat Exchanger
- Excess Letdown Heat Exchanger
- Seal Water Heat Exchanger
- Sample Heat Exchangers
- Spent Fuel Pit Heat Exchanger
- Charging Pump Gyrol Coolers
- Charging Pumps Lube Oil Coolers
- Waste Gas Compressors
- Reactor Vessel Supports Blocks

2.2.2 Residual Heat Removal System

The primary function of the Residual Heat Removal System (RHRS) is to transfer heat energy from the core and RCS during the second phase of plant cooldown. It can also be used to transfer water between the refueling water storage tank (RWST) and the reactor cavity at the beginning and end of refueling operations. Additionally, the RHRS is used in conjunction with the SIS for emergency core cooling in the event of a loss-of-coolant accident (LOCA).

The RHR loop consists of two RHR heat exchangers, two motor-driven RHR pumps, piping, valves, and the instrumentation and control circuitry necessary for monitoring and operation.

The RHRS interfaces with the CCWS through the RHR heat exchanger and the RHR pumps. Cooling flow is provided to the RHR heat exchanger during cooldown operations, and during the recirculation phase of SI. Cooling is provided to the RHR pumps from the CCWS.

Normal Plant Cooldown

Two RHR pumps and two RHR heat exchangers perform the decay heat cooling functions for the reactor unit. After the RCS temperature and pressure have been reduced to approximately 350°F and 400 psig, RHRS operation is initiated by aligning the pumps to take suction from the hot leg of one reactor coolant loop and discharge through the RHR heat exchangers and back to the RCS cold legs. If only one RHR pump and one RHR heat exchanger are available, reduction of reactor coolant temperature is accomplished at a slower rate.

During plant shutdown, the cooldown rate of the reactor coolant, or the CCW maximum supply temperature, is controlled by regulating the RCS flow through the tube side of the RHR heat exchangers.

2.2.3 Spent Fuel Pit Cooling System (SFPCS)

The primary function of the spent fuel pit (SFP) cooling loop is to remove residual heat from spent fuel elements stored in the spent fuel pit. A secondary function of this system is to maintain water purity and clarity in the spent fuel pit and to purify the water of the RWST.

The cooling loop consists of two pumps, a heat exchanger, a filter, a demineralizer, piping and associated valves and instrumentation. One of the pumps draws water from the pit, circulates it through the heat exchanger and returns it to the pit. CCW cools the SFP heat exchanger.

The spent fuel pit accommodates and cools discharged nuclear fuel.

The loop is normally required to handle the heat load from one third of a core, freshly discharged from the reactor, but can safely handle the heat load from all of the assemblies for which there is storage space. The spent fuel pit, currently, allows for storage of four cores.

When 1/3 of a core is stored in the pit, the pump and SFP heat exchanger were designed to handle the heat load and maintain a SFP temperature less than 140°F. When a full core is stored, the pit is maintained below 173°F (Reference 2-1).

With no heat removal, the time for the spent fuel pit water to rise from 140°F to 212°F with one third of the core stored in the pit, is approximately 8.1 hours. With a full core in storage, this time is reduced to approximately 2.3 hours (Reference 2-2).

REFERENCES

2-1 Indian Point Unit 2 Updated FSAR Section 9.3.1.2.3, Revision 4

2-2 Indian Point Unit 2 Updated FSAR Section 9.3.3.2.3, Revision 4

3.0 AUXILIARY COOLANT SYSTEM EVALUATION

As discussed in Section 2.2, the ACS is comprised of the three subsystems: CCW, RHR, and SFPCS. The impact of a maximum river water temperature of 95°F on these subsystems is discussed in this section.

3.1 COMPONENT COOLING WATER SYSTEM

The CCWS was evaluated to determine the impact of higher river water temperatures on system performance. A discussion of this evaluation is discussed below.

3.1.1 Thermal/Hydraulic Model

To assist in the evaluation, a thermal/hydraulic model of the Indian Point Unit 2 CCWS was developed to predict system and component flows and temperatures during various system operating modes. An overview of the plant-specific model, analytical methodology, analysis assumptions, and results are provided below.

3.1.1.1 PEGISYS Computer Code Description

The Westinghouse Computer Code PEGISYS was used to develop and analyze the thermal and hydraulic performance of the Indian Point Unit 2 CCWS. The PEGISYS code is a menu driven, interactive, fluid systems design program which provides a fully integrated component and piping database together with thermal and hydraulic analysis capabilities. Verification of the computer code has been performed in accordance with Westinghouse Quality Assurance Manual (Reference 3-1).

The PEGISYS database developed for the Indian Point Unit 2 CCWS contains both component and system level data. In general, detailed piping takeoffs of the main header and component supply and return lines were input into the code. PEGISYS utilizes piping data (pipe size, lengths, elbows, tees, etc.) to determine flow path resistances based on calculated operating conditions.

Piping takeoffs of individual component branch lines containing throttle valves were not always performed since their resistances were to be determined by the system flow balance. For these component branch lines, PEGISYS calculates line resistances required to deliver a specific flowrate.

In addition to piping data, thermal and hydraulic design and operating data for the system heat exchangers supplied with CCW were also input into the database to allow for thermal and hydraulic analyses. To model small equipment coolers, a component heat load was input into the flow path which contained that particular component.

In the analysis mode, the program performs steady-state hydraulic (isothermal) or thermal/hydraulic (non-isothermal) analysis of flow networks. In the hydraulic calculation, PEGISYS determines the set of steady state continuity equations and Bernoulli loop equations which apply to the network. These equations are solved iteratively to yield a flow and pressure distribution in accordance with the principles of conservation of mass and momentum. In the thermal calculation, enthalpy distributions within the network are determined in accordance with the principle of conservation of energy. If the network is analyzed as a nonisothermal case, the code iterates between the hydraulic and thermal portions of the code. The output of the code is the calculated pressure, temperature and flow distribution for the entire network.

As noted previously, the PEGISYS code utilizes an interactive graphics feature which provides an interface between the User and the PEGISYS database and analysis features. The graphical model of the Indian Point Unit 2 CCWS has been constructed to be consistent with the CCW portion of the Auxiliary Coolant System flow diagram (Reference 3-2 and 3-3). All major system flow paths (excluding drains and vents) have been modeled except for the boric acid evaporator and distillate cooler, which have been retired from service with CCW physically isolated.

All system pumps and major water-to-water cooled heat exchangers are explicitly shown on the PEGISYS graphic model with conventional component symbols. Equipment provided with coolers are not shown on the graphic model since these components are modeled as a point heat load. Component branch lines are shown on the graphic model with at least one isolation valve. These valves allow a User to interactively isolate flow paths during the thermal/hydraulic analysis of the network. Check valves are also illustrated on the graphic model since they restrict backflow in their flow path. Although not illustrated on the graphic model, other system valves have been included in the hydraulic database. Provided in Figure 3-1 is the PEGISYS graphic model of the Indian Point Unit 2 CCWS.

3.1.1.2 Modeling Methodology

The original design basis of the CCWS was based on having all component throttle valves in a single position. This approach ensured that adequate cooling and pump runout protection was provided in the event of a design basis event. A drawback with this approach is that the system is required to support different operating modes and cooling flows were not always at optimum levels since flow requirements varied from mode to mode. To address this issue and to provide maximum system flexibility, Con Ed requested that the methodology used for this project allow for the adjustment of component throttle valves. This would allow system flow to be adjusted to users as necessary to satisfy component cooling requirements.

To allow for throttle valve adjustments, a limit on total CCWS flow is needed since only one CCW pump could be available with the loss of offsite power concurrent with a design basis event. In the post-LOCA alignment, a single CCW pump must be capable of delivering flow to both RHR heat exchangers as well as other system users.

Based on discussions with plant personnel, it was agreed that the system flow limit would be developed based on a minimum pump header pressure as measured on PIC-600. For this project, this pressure will be defined as P(min). Since the cooling water flow paths to the RHR heat exchangers are closed during power operation, P(min) would define the maximum total flow that can be sent to system users during Power Operation. This would establish the minimum system resistance of the network, and would ensure that a CCW pump would remain within its runout capacity with both RHR heat exchangers available.

To develop P(min), minimum and maximum allowable pump performance is required to be defined. For this evaluation, the CCW pump performance criteria used at the plant to determine pump operability in accordance with ASME Section XI recommendations (vendor certified head curve +3% /-7%) were used. Provided in Appendix A is the pump performance criteria used to develop P(min) and to evaluate system performance.

Provided below is an overview of the approach used to develop P(min):

1) Branch Line resistances were determined based on specified flows. The flow split was selected so that the weakest CCW pump operating at its minimum acceptable pump curve delivered at least 1275 gpm to one RHR heat exchanger. This value is the minimum flow assumption used in the Containment Integrity analysis.

2) Verification that with the strongest CCW pump operating at its maximum acceptable pump curve and with both RHR heat exchangers available, total system flow is less than 5400 gpm. This value is based on maximum pump runout.

3) Steps 1) and 2) were repeated until both requirements were satisfied.

4) The flow paths to the RHR heat exchangers were shut to simulate the Power Operation mode. With component resistances established, the strongest CCW pump operating at its maximum acceptable pump curve was modeled. The results of this case were then used to determine P(min) with one CCW pump operating.

5) A second CCW pump operating at its maximum acceptable pump curve was started. The results of this case were then used to determine P(min) with two CCW pumps operating.

Based on this approach, the one pump and two pump P(min) was calculated to be 74.5 psig and 111.5 psig, respectively. Due to the decreasing head versus flow characteristic of the pump and the fact an enhanced pump curve is used to determine P(min), pump degradation will reduce system flow margin. For example, operation with one CCW pump at its maximum allowable pump performance will allow approximately 4400 gpm total flow for system users. At minimum pump performance, approximately 3800 gpm is available.

Once P(min) was determined, thermal analysis was performed to calculate system temperatures for both Power Operation and Post-LOCA recirculation modes.

In order to ensure CCW pump runout protection post-LOCA, the required butterfly valve positions for RHR heat exchanger throttle valves 820 A&B were determined to be consistent with the analysis assumptions. The valve positions were calculated using both the PEGISYS model and valve performance data collected in support of this project. Provided below are the required valve positions at P(min) to prevent pump runout post-LOCA and to ensure adequate cooling to the RHR heat exchangers:

- RHR Heat Exchanger 21 (Valve 820A) - 27.5% open
- RHR Heat Exchanger 22 (Valve 820B) - 25.5% open

3.1.1.3 Thermal Analysis Assumptions

To perform thermal analysis, PEGISYS has the capability to explicitly model the performance of water-to-water heat exchangers. To model other nonconventional heat exchangers, a component heat load can be specified in the component flow path. A discussion of the assumptions and data used for the thermal analysis is provided in the following paragraphs.

3.1.1.3.1 Heat Exchangers

When a heat exchanger is explicitly modeled with the PEGISYS code, both design and operating data are required. In general, heat exchanger design data are based on information presented on the vendor specification sheet. Operating data (i.e., flows and temperatures) are based on information from design basis documents.

For this project, only the RHR and CCW heat exchangers were explicitly modeled as heat exchangers in the PEGISYS evaluation. The following design data is available for the RHR and CCW heat exchangers:

- RHR Heat Exchanger (two provided)

  - General Data
    Design Area - 3,579 ft^2
    Design U - 309 Btu/lb-ft^2-^oF
    Clean U - 410 Btu/lb-ft^2-^oF (calculated)
    Design Duty - 30.8E+06 Btu/hr
    Tube Fouling Factor - 0.0005 hr-ft^2-^oF/Btu
    Shell Fouling Factor - 0.0003 hr-ft^2-^oF/Btu

  - Tube-Side Conditions
    Design Flow - 1.44E+06 lb/hr
    Design Inlet Temperature - 135 F

  - Shell-Side Conditions (CCWS)
    Design Flow - 2.46E+06 lb/hr
    Design Inlet Temperature - 88.3 F

- CCW Heat Exchanger (two provided)

  - General Data
    Design Area - 6,729 ft^2
    Design U - 305 Btu/lb-ft^2-^oF
    Clean U - 674 Btu/lb-ft^2-^oF
    Design Duty - 31.4E+06 Btu/hr

  - Tube-Side Conditions
    Design Flow - 4.55E+06 lb/hr
    Design Inlet Temperature - 75 F

  - Shell-Side Conditions (CCWS)
    Design Flow - 2.66E+06 lb/hr
    Design Inlet Temperature - 100 F

A key assumption in the evaluation of thermal performance is the heat transfer capability of system heat exchangers. Generally, both fouled and clean heat transfer coefficients ("U") and design heat transfer area ("A") are provided on the vendor data sheet. The product of "U" and "A" defines the overall heat transfer coefficient ("UA") of the heat exchanger. The use of a "UA" lower than design results in degraded heat transfer capability. A "UA" greater than design results in enhanced heat transfer capability. For this project, the average of the fouled and clean "U" and zero tube plugging was selected to define a conservatively high heat transfer rate. To define a conservatively low heat transfer rate, the fouled "U" and a five percent uniform tube plugging was selected. Depending on the mode considered, either a degraded or enhanced "UA" is used to define a conservative heat exchanger heat transfer performance.

For the RHR heat exchangers, enhanced heat transfer is conservative during post-LOCA conditions since this maximizes both heat addition and CCW supply temperature. For this alignment, the heat transfer rate, tube area, and "UA" at design conditions were defined to be 360 Btu/lb-ft^2-^oF, 3579 ft^2 and 1.29E+06 Btu/hr-^oF, respectively. During plant cooldown, however, reduced heat transfer is conservative since this increases the cooldown transient. For this alignment, the heat transfer rate, tube area, and "UA" at design conditions were defined to be 309 Btu/lb-ft^2-^oF, 3400 ft^2 and 1.05E+06 Btu/hr-^oF, respectively.

For the CCW heat exchangers, minimum heat transfer capability is conservative for all modes considered since this maximizes CCWS supply temperature. The heat transfer rate, tube area, and UA at design conditions were defined to be 305 Btu/lb-ft^2-^{o}F, 6393 ft^2 and 1.95E+06 Btu/hr-^{o}F, respectively.

3.1.1.3.2 Heat Loads

As noted previously, the required input data for components not explicitly modeled as a heat exchanger is an expected heat load (Btu/hr). In general, the heat loads used in this project are based on design basis documents.

The total heat load for Power Operation and for post-LOCA recirculation modes are different and are dependant on the components in service. In the case of the non-regenerative and seal water heat exchangers (large heat loads), the design duty was increased by 5% to account for heat transfer greater than design. The specific component heat loads modeled for Power Operations were as follows:

- Ten (10) sample heat exchangers (10 * 0.2 = 2.0 mBtu/hr)
- RCPs (4 * 1.2 = 4.8 mBtu/hr)
- SFP - 30 days (8.79 mBtu/hr)
- Two (2) charging pumps (2 * 0.45 = 0.9 mBtu/hr)
- RV supports (0.2 mBtu/hr)
- Two (2) waste gas compressors (0.28 mBtu/hr)
- Non-Regenerative heat exchanger (design duty + 5%) (14.8 * 1.05 = 15.54 mBtu/hr)
- Seal water heat exchanger (design duty + 5%) (2.17 * 1.05 = 2.28 mBtu/hr).

The specific components modeled as point heat loads for post-LOCA recirculation were as follows:

- o One (1) sample heat exchanger (0.20 mBtu/hr)
- o SFP - 30 days (8.79 mBtu/hr)
- o One (1) charging pump (0.45 mBtu/hr)
- o Three (3) SI pumps (0.075 * 3 = 0.225 mBtu/hr)
- o Two (2) recirculation pumps (0.15 * 2 = 0.30 mBtu/hr).

In addition, the heat addition from the CCW pumps were considered when a pump was modeled on. This heat load was conservatively estimated at 0.29 mBtu/hr per pump.

3.1.1.3.3 RHR System Boundary Conditions

The RHR heat exchangers are a heat load on the CCWS during Plant Cooldown, Refueling, and Post LOCA recirculation modes. For Plant Cooldown, the heat rejection capability of the system is manually controlled to limit the rate of RCS cooldown and to limit CCW supply maximum temperature. Since decay heat is a function of time since plant shutdown, the capability of the ACS to cooldown the plant is specifically evaluated as part of the RHR System (See Section 3.2). Note, the CCWS computer model is used to predict system flows during a plant cooldown alignment.

In the Post-LOCA Mode, the heat transfer rate of the RHR heat exchangers are not manually controlled. As such, the capability of the CCWS to transfer the heat during the recirculation phase is specifically calculated with PEGISYS. Since the RHR heat exchangers are explicitly modeled, heat exchanger tube-side inlet temperature and flow are used. Presented below are the assumptions for RHR heat exchanger performance.

3.1.1.3.3.1 Containment Sump Temperature Post LOCA

During the recirculation mode of a LOCA, containment sump water is cooled by the ACS. Since the CCW system is used to cool ECCS pumps, the temperature of the sump water has a direct effect on the CCWS supply temperature.

To assist in the evaluation of CCWS post-LOCA performance, a containment sump temperature evaluation was performed to determine a conservative sump temperature at the time the ACS is placed in service during the switchover to cold leg recirculation. For this evaluation, several assumptions were made to conservatively envelope the sump temperature transient. The basic goal of these assumptions was to concentrate as much energy as possible in the containment sump so as to maximize sump temperature. (Note, containment response analyses are based on assumptions which maximize energy release to the containment atmosphere.)

Key assumptions used to maximize sump temperature are as follows:

- Decay heat is added to the reactor vessel water instead of causing boiloff directly
- Vessel thick metal energy is similarly added to the RCS water instead of causing boiloff directly
- All safety injection and recirculation water available is assumed to enter the vessel with no spill
- All water entering the Reactor Vessel is available for removing heat (maximizing spillage of hot water to the sump)

Of the preceding assumptions, the first two maximize heat available to the sump water and the last two maximize heat absorption of the sump. The result of these assumptions is a minimum steam phase heat inventory and a corresponding minimum heat removal by the fan coolers. The net result of these assumptions is a minimum containment pressure with a maximum sump water temperature.

To perform the subject evaluation, the Computer Code COCO (Reference 3-4) and the 1979 Westinghouse LOCA Mass and Energy Release Model (Reference 3-5) were used. The inputs for this evaluation are based on minimum safeguards assumptions and are consistent with the Stretch Rating analysis (Reference 3-6). The mass and energy release rates for the double-ended pump suction break with minimum safety injection, discussed in detail in Reference 3-6 and adjusted per the previously mentioned assumptions, were found to be limiting for sump temperature calculations.

The maximum sump temperature at the time of switchover to recirculation was found to be 250°F. Table 3-1 provides the calculated sump temperature time history following the design basis LOCA.

3.1.1.3.3.2 RHR Heat Exchanger Flows Post-LOCA

The RHR pumps are used as low-head SI pumps during the injection phase of a LOCA. During the switchover to recirculation, the RHR pumps are shut down and containment recirculation pumps are manually started. The use of recirculation pumps in lieu of the RHR pumps maintains radioactive sump fluid internal to the containment building.

The alignment of the low-head recirculation is performed manually per plant emergency procedures. For the initial alignment, two out of four cold leg injection lines measuring the lowest flow must exceed a total flow of 600 gpm. If the containment pressure is elevated (large-break LOCA), recirculation spray would be initiated. If recirculation spray is required, a minimum flow of 1300 gpm is required. As such, the minimum expected sump recirculation flow with recirculation spray is approximately 2500 gpm (>600 + >600 + >1300). To estimate maximum heat input into the CCWS, a pump flow of 3100 gpm is used. This value is based on the design flow plus approximately 3% for conservatism. Note, the pump is required to be limited to its design flow due to NPSH.

3.1.1.3.4 SWS Boundary Conditions

As discussed in Section 2.1.2, cooling water is provided to the tube-side of the CCW heat exchangers by way of the nonessential SWS header. Since these heat exchangers are explicitly modeled, heat exchanger performance data are needed. A discussion of the inlet temperature and flow assumptions is given below.

3.1.1.3.4.1 CCW Heat Exchanger Flows

The design flow to each CCW heat exchanger as specified on the vendor specification sheet is approximately 9200 gpm. With both heat exchangers available, the required flow would be approximately 18,400 gpm. Since the design and runout point for the pumps are 5000 gpm and 7000 gpm per pump, respectively, the design flow represents a case with all three nonessential pumps operating.

For evaluation of Power Operation and post-LOCA recirculation modes, the following SWS flows were assumed:

- One Nonessential SWS Pump - 2500 gpm to each CCW heat exchangers
- Two Nonessential SWS Pumps - 4500 gpm to each CCW heat exchangers

3.1.1.3.4.2 CCW Heat Exchanger Inlet Temperature

For this project, a maximum SWS inlet temperature of 95°F is used to determine system performance.

3.1.1.4 Calculated Performance Results

As described in Section 2.2, the CCWS is required to operate during all plant modes including:

- Startup
- Power Operation
- Blackout - Hot Standby
- Plant Cooldown
- Blackout - Cooldown
- Refueling
- Post-LOCA Injection
- Post-LOCA Recirculation

The Startup and Power Operation modes are identical from a performance basis since the excess letdown heat exchanger is not typically used. The Blackout - Hot Standby mode is also identical with respect to flow requirements since with the loss of offsite power (Blackout), automatic isolation of system flow paths does not occur. With a Blackout, however, system heat loads would be less since power to several components would not be available. As such, system performance during a Blackout with the plant in Hot Standby is bounded by the Startup/Power Operation modes. Component cooling water supply temperature for various alignments is calculated for use in the CCWS component evaluations performed in Chapter 4.0.

System performance for the Plant Cooldown with and without Blackout and Refueling modes are specifically addressed as part of the RHRS (Section 3.2) and SFPCS (Section 3.3) evaluations since these modes are transient in nature (decay heat varies with time since plant shutdown).

For the LOCA-Injection mode, flows to the SI recirculation pump motor coolers and to the SI pump coolers are calculated for use in the component evaluations performed in Section 4.0. Thermal performance of the system during this mode is addressed in Section 3.1.2.5.

Component cooling water supply temperatures for various alignments are calculated for use in the CCWS component evaluations performed in Chapter 4.0. Provided below are the calculated system results for the various modes analyzed.

3.1.1.4.1 Startup/Power Operation/Blackout

The primary difference between the Startup and the Power Operation modes is that the excess letdown heat exchanger may be in service to assist in removing reactor coolant during RCS heatup (expansion). As noted previously, the excess letdown heat exchanger is no longer used. As such, the Startup and Power Operation modes are identical from a flow and heat load basis.

In the event of a loss of offsite power (Blackout), all flow paths would remain opened since automatic isolation does not occur. With a Blackout, however, system heat loads would be less since power supplies would be lost to several system users. The Blackout mode at Hot Standby would therefore result in lower system heat loads and temperatures, and is bounded by the Startup/Power Operation Modes with respect to system temperatures.

Provided in Table 3-2 are the system cases analyzed to bound the Startup, Power Operation, and Blackout Modes. Specifically, operation with one and two CCW heat exchangers and one and two CCW pumps at the Minimum header pressure setpoint was considered. A 3% enhanced pump curve was considered since higher CCW flows to the CCW heat exchanger results in a higher CCW supply temperature with all other parameters held constant. For the subject cases, a SWS flow of 4500 gpm to each operating CCW heat exchanger was assumed. A requirement to verify the capability to supply this flow is provided in Section 6.0.

With a 95°F SWS inlet temperature and design fouling factors, the maximum CCW supply temperature is calculated to be approximately 105°F with both CCW heat exchangers in service.

Maximum CCWS supply temperatures were found to occur when one of the CCW heat exchangers is out-of service (OOS). Note, this is a Limiting Condition of Operation per plant technical specification 3.3.E. With one CCW heat exchanger OOS, and not taking credit for higher SWS flows, the maximum CCW supply temperature was calculated to be approximately 118°F. As SWS flow is increased, CCW supply temperature would decrease proportionally.

3.1.1.4.2 LOCA Injection

In the event of a Large-Break LOCA with Blackout, the CCW pumps would shut down since they are not automatically loaded onto the emergency diesels. A CCW pump would not be restarted until the switchover to cold-leg recirculation (Reference 3-7).

During the injection phase of the subject event, only the auxiliary component cooling (ACC) pumps and the SI circulating water pumps would be operational. With only these pumps operational, heat removal via the CCW heat exchangers is expected to be negligible due to low flow in the network and no SWS flow to the CCW heat exchangers (the nonessential pumps are not operating). Since several components are rejecting heat during this mode, CCWS temperature increases with time. The evaluation of this heatup transient is discussed in Section 3.1.2.

The ACC pumps were tested during the past plant outage to ensure that adequate cooling water flow is delivered. The test was performed with the CCW pumps not operating in order to simulate post-LOCA injection with Blackout conditions. The test ensured that both pumps delivered $\geq$ 80 gpm to the two SI pump recirculation motor coolers. To account for potential pump degradation, a minimum flow of 37 gpm to each cooler is expected. With both pumps operating, the maximum flow to each recirculation pump motor cooler would be less than 65 gpm.

The SI pumps each contain two mechanical seal coolers, two mechanical seal jacket coolers and a lube oil cooler which are serviced by CCW through a common header. The five flow paths are in parallel with the lube oil cooler at the end of the network. Attached to the shaft of the pump is a small centrifugal pump which is used to provide forced cooling to the SI pump coolers when the main SI pump is running. The shaft-driven pumps have a flow capacity of 40 gpm at approximately 100 feet. A check valve is provided at the discharge of each circulating water pump.

During the last refueling outage, a test was performed to demonstrate the operability of the circulating water pumps in accordance with ASME Section XI. The test was performed with CCW pumps in operation. The cooling water flow to one SI pump increased from approximately 15 gpm to 51 gpm when the circulating water pump was running.

During a design basis event with blackout, the CCW pumps would not be running and flow to the SI pump coolers would be less than that measured above since suction pressure would be less. For this alignment, the minimum circulating water pump flow is calculated to be approximately 30 gpm. This value is based on a 7% degraded vendor curve and minimum suction pressure. To evaluate component operability, a minimum flow of 4.5 gpm to the SI lube oil cooler is calculated. Since the SI pump coolers are in parallel, a minimum flow of 4.5 gpm to the other four coolers is a conservative estimate of minimum cooling water flow.

To evaluate maximum flow concerns, a total flow of 51 gpm (approximately 10 gpm to each cooler) should be used. This flow is based on measured data and is conservatively high since the CCW pumps would not be operating during the design basis event with Blackout.

3.1.1.4.3 LOCA Recirculation

As discussed previously, the CCW pumps are not started for a Large-Break LOCA with Blackout event until the switchover to sump recirculation. This event is considered limiting with respect to system operability since the heat transfer across the RHR heat exchangers is not manually controlled.

In review of the evaluations performed in support of the 1988 SWS temperature emergency technical specification change, two constraints were identified for the system. The first constraint is the outlet temperature on the RHR heat exchanger shell-side. Low RHR heat exchanger shell-side flows results in high shell-side outlet temperatures for a given heat exchanger duty. This temperature is limited by the structural integrity of the heat exchanger. The second constraint is high CCW supply temperature. This temperature is limited by the capability of equipment serviced by CCW to remain functional at elevated cooling water temperatures.

To determine the most limiting single failure which could result in either maximum sump heat into the CCWS or low CCW flow to the RHR heat exchangers, a qualitative evaluation was made. For a given low-head recirculation flow, RHR heat exchanger heat transfer increases when sump temperature is maximized. In general, sump temperature is maximized when containment heat removal equipment is minimized. As can be seen from Table 3-3, the failure of diesel generator 21 to operate results in both the minimum number of fan coolers (3/5) and containment spray pumps (1/2) which would tend to maximize sump temperature.

Assuming one CCW pump and one nonessential SWS pump can be OOS, the failure of diesel generator 21 to run would also result in only one of three CCW pumps and one of three nonessential SWS pumps available to supply cooling post-accident at the time of switchover to sump recirculation.

Consideration of other possible single active or passive failures is judged to be less limiting since both containment cooling and ACS heat removal capability would not be minimized.

To maximize CCW supply temperature, sump heat rejected to the CCWS was maximized. For this evaluation, both RHR heat exchangers are assumed to be available. Component cooling flow to the RHR heat exchangers is also maximized by use of a 3% enhanced vendor pump curve. Both one and two sets of recirculation/CCW/nonessential SWS pumps were considered to simulate recirculation switches two and five (Reference 3-7).

To maximize RHR heat exchanger outlet temperature, sump heat rejected to the CCWS was maximized as well as minimum cooling water flow to the RHR heat exchanger. For this evaluation, one RHR heat exchanger was considered. Sump flow from a recirculation pump was modeled through only the operable RHR heat exchanger. Component cooling flow to the RHR heat exchanger was minimized by use of a 7% degraded vendor pump curve. Operation of Switch 5 was not considered since this alignment would not minimize CCW flow to the RHR heat exchangers.

Provided in Table 3-4 are the calculated post-LOCA temperatures. A conservative estimate of the CCW supply temperature at the initial switchover to sump recirculation post-LOCA is approximately 134°F. A conservative estimate of the RHR heat exchanger shell-side outlet temperature is 202°F.

Also provided in Table 3-4 are the calculated temperatures post-LOCA at a sump temperature of 200°F. This temperature was selected lower than the long-term maximum sump temperature provided in Table 3-1 to allow for interpolation at various sump temperatures. At a sump temperature of 200 ^{o}F, a conservative estimate of the maximum CCW supply temperature is approximately 117°F. Using the conservative sump temperatures provided in Table 3-1 at approximately one day (225°F) and nine days (220°F) post-accident, a conservative estimate of the maximum CCW supply temperature is approximately 125.5^{o}F and 124°F, respectively.

The minimum flow to the SI recirculation pump motor coolers with one ACC pump was determined to be 37 gpm during the injection phase with no CCW pumps operating. With both a CCW and ACC pump operational, the flow would be greater since the ACC pump would receive suction boost from the CCW pump. To be conservative, the minimum injection mode flow of 37 gpm should be used to evaluate component operability for the recirculation phase.

The maximum flow to the SI recirculation pump motor cooler would occur when both ACC pumps and two CCW pumps would be operational. This flow has been calculated to be less than 100 gpm to each SI recirculation pump motor cooler.

For the SI circulating water pumps, the minimum flow of 4.5 gpm determined for the injection phase should be used to evaluate component performance during recirculation. This value is a conservative estimate of the flow during recirculation since a CCW pump would be providing "boost" to the operating circulating water pumps.

To evaluate maximum flow concerns, a total flow of 60 gpm to the SI pump coolers is conservatively calculated with two CCW pump operating. At this flow, approximately 12 gpm would be delivered to each cooler.

3.1.2 System Evaluation

The evaluation of the capability of the CCWS to operate at elevated river water temperatures is discussed in this section. CCWS component evaluations are discussed in Section 4.0

3.1.2.1 Flow Requirements

As discussed in Section 2.2, two CCW pumps were originally required to operate during the Power Operation modes since the flow requirements of the various system users exceeded the flow capability of a single pump. The design basis system flow requirement was approximately 6700 gpm. With the removal of the boric acid and waste evaporators and the flash evaporator, the flow requirement of the system was reduced to approximately 4600 gpm. Note, this reduced flow is still a conservatively high estimate of the system flow requirement since it based on 2000 gpm to the SFP heat exchanger and approximately 1000 gpm to the non-regenerative heat exchanger.

At the maximum allowable CCW pump performance criteria (3% enhanced), approximately 4400 gpm can be delivered at the minimum header pressure setpoint determined previously. At the lower limit (7% degraded), approximately 3800 gpm can be delivered at the minimum header pressure setpoint. Based on these ranges and nominal component flow requirements, a single CCW pump should be capable of meeting system flow requirements during Power Operation. At elevated CCW supply temperatures, two CCW pumps may be needed to meet normal system component cooling requirements.

3.1.2.2 System Design Temperature

The design temperature of the CCWS is 200°F, except for portions of the system located downstream of the cooling water piping to the RCP thermal barriers, which were designed based on the RCS design temperature of 650°F (References 3-2 and 3-8). In the evaluation of the impact of a 95°F SWS temperature on the design temperature limitation, post-LOCA recirculation temperatures were specifically reviewed due to the following concerns:

- Sump temperatures are relatively high at the initial switchover to recirculation
- Minimum pump capability could be available assuming a diesel generator failure

- o RHR tube side flows are not manually controlled to limit the heat transfer across the RHR heat exchangers (during plant cooldown, the cooldown rate and the CCWS supply temperature are limited)

As noted in Section 3.1.1.4.3, the highest CCWS temperature occurs at the outlet of the RHR heat exchanger and was calculated to be 202°F. This maximum temperature was based on the following conservative assumptions:

- o Maximum sump temperature at the start of switchover (250°F)
- o A recirculation pump operating at its maximum allowable flow (limited by NPSH available) plus approximately 3% (3100 gpm)
- o One RHR heat exchangers (shell and tube sides) with the design UA enhanced by 16%
- o The weakest CCW pump operating at its minimum acceptable flow versus head performance
- o Two CCW heat exchanger (shell and tube sides) with the design UA degraded by 5%
- o One nonessential SWS pump servicing both CCW heat exchangers at its minimum acceptable flow (5000 gpm)
- o A SFP heat load based on a 30 day decay of a 1/3 core discharge

It is clear from the above that 202°F represents a conservatively high estimate of the temperature at the outlet of the RHR heat exchangers post LOCA.

Although this maximum calculated temperature is higher than the design temperature of the RHR heat exchanger shell-side and the system, the temperature is evaluated to be acceptable based on the following conclusions:

1. The post-LOCA mode is considered a faulted condition, and as such, does not constitute a revision to the design temperature of the RHR heat exchangers. As such, the major concern is to ensure that component structural integrity is maintained. The applicable ASME Code is Section VIII, Division 1. For carbon steel, the allowable stress is unchanged at the expected temperatures and pressures. Therefore, the vessels are considered adequate for a maximum temperature of 230°F.

2 The system pressures at the outlet of the RHR heat exchangers is calculated to be greater than the corresponding saturation temperature. As such, the fluid leaving the RHR heat exchangers would remain subcooled and flashing would not occur. Downstream of the heat exchangers, CCW flow would mix with other flows which are at lower temperatures as CCW is returned to the pump suction. Since the mixed mean temperature at the pump suction is less than 165°F (See Table 3-4) and adequate pump NPSH is available, the system fluid would remained subcooled and flashing would not occur.

3 Although the design temperature of the CCWS is 200°F, the actual design temperature of the low pressure portion of the CCWS piping is 500°F at the system design pressure of 150 psig. Since the maximum calculated CCWS temperature is significantly lower than the maximum allowable design temperature, structural integrity of the piping is ensured.

4 The low pressure portion of the system are provided with 150# class system valves and flanges built to USAS B16.5 requirements. For a pressure of 225 psig, the maximum allowable temperature is 250°F. Since the maximum calculated CCWS temperature is lower than the allowable maximum temperature, structural integrity of these components is ensured.

5 Sump temperature will decrease with time into the event as decay heat levels drop and ACS cooling is established.

3.1.2.3 CCW Pumps

The design basis of the CCWS requires one CCW pump to be capable of operating in the post-LOCA mode with all system users available except for those automatically isolated on a design basis LOCA event. The excess letdown heat exchanger is automatically isolated on a Containment Phase A signal. The RCPs and reactor vessel nozzle blocks are automatically isolated on a Containment Phase B signal. For this design basis alignment, CCW flow to the RHR heat exchangers is required to be throttled to prevent total CCW system flow rate from exceeding the maximum flow capability (i.e., runout) of one CCW pump. The acceptability of operation at runout conditions for both the pump and motor is discussed below.

3.1.2.3.1 CCW Pump Capability

Operation at flow rates within the established pump operating range as defined in the vendor certified pump flow versus head performance curve is acceptable as long as adequate Net Positive Suction Head (NPSH) is available. NPSH required is defined on the vendor pump performance curve as a function of pump flow. NPSH available is calculated based on the plant piping and layout configuration and system operating temperatures.

The CCWS is provided with a surge tank which is physically located approximately 35 feet above the suction of the CCW pumps. With this configuration, the following equation can be used to calculate CCW pump NPSH available:

$NPSH_A$ = Surge Tank Pressure + Elevation Difference (Tank Water Level - Pump Impeller Centerline) - Piping Pressure Losses (Surge Line Connection to Pump Suction) - Vapor Pressure of Pumped Fluid

The most limiting NPSH conditions occur during the LOCA recirculation alignment when pump flow can be near runout and system temperatures are maximized. The original design basis NPSH calculation considered a pump flow of up to 6000 gpm. For a fluid temperature of 180°F, NPSH available was calculated to be approximately 46 feet with the surge tank water level at approximately 50% and the tank opened to atmospheric pressure. At this pump flow, NPSH required is approximately 36 feet.

The design basis NPSH calculation was revised during Indian Point Unit 2 CCWS preoperational testing to reflect expected maximum pump flows and system temperatures. With a CCWS temperature as high as 203°F, the NPSH available was recalculated to be approximately 36 feet. At a total pump flow of 5500 gpm, the NPSH required is approximately 29 feet.

In support of this project, CCW pump NPSH was reviewed based on the results of the thermal/hydraulic model. NPSH available was found to be dependent on which CCW pump is assumed to be operating due to layout effects. At a pump flow of 5500 gpm, pump suction temperatures as high as 185°F would be possible assuming a minimum 10% NPSH margin between actual and required. Based on the maximum calculated CCW return temperature of 163°F, adequate NPSH would be available during the most limiting LOCA recirculation conditions with SWS temperature at 95°F.

3.1.2.3.2 CCW Pump Motor Capability

The capability of the CCW pump motor to drive a CCW pump at pump runout conditions was evaluated. For this evaluation, the pump motor is considered adequate if pump required brake horsepower (bhp) as defined on the pump vendor performance curve is within the service factor rating of the pump motor.

The CCW pump motor nameplate output rating and service factor rating are 250 hp and 1.15, respectively. As such, the CCW pump motor is capable of driving the CCW pump up to loads of 287.5 hp. The maximum bhp as defined on the vendor certified pump performance curve occurs at pump runout condition and is approximately 285 hp.

Since the pump motor capability exceeds the pump runout requirement, it can be concluded that the CCW pump motor can adequately support pump operation over expected operating conditions. The design basis load study considered a runout power requirement of 285 hp.

3.1.2.4 CCWS Piping

To address higher system temperatures as a result of elevated SWS temperature, component flows will likely be increased in order to ensure adequate cooling. Provided in Section 4.0 are flow and temperature limits for CCWS components. As component flows are increased, the fluid velocity of the cooling water in the system piping will also increase. In general, the carbon steel CCWS piping was sized to maintain fluid velocities at or below 15 ft/sec. This velocity limit was selected to ensure that system piping would not be the limiting hydraulic resistance of the network. With this approach, component throttle valves could be used to established required system flows. The velocity limit combined with the material selection ensures adequate erosion protection.

A review of the piping design basis was performed to determine potential areas where fluid velocities could exceed 15 ft/sec. Provided in Table 3-5 is piping velocity data at nominal rated flows. Also included on the table are maximum flows which would yield a 15 ft/sec fluid velocity. Based on the data calculated in Table 3-5, three potential problem areas were identified. These are the following:

- The 8 inch supply and return piping to the SFP heat exchanger
- The 10 inch piping at the CCW pump discharge

Flows greater than 2342 gpm to the SFP heat exchanger could occur during refueling/core unload operations when maximum cooling is needed. Flows greater than 3691 gpm at the pump discharge piping could occur during Power Operation with one CCW pump in service and plant Cooldown when maximum cooling is needed. The potential concern of higher fluid velocity is pipe erosion.

3.1.2.5 Heatup During Injection Phase

During the Injection phase of a LOCA with Blackout, the CCWS acts as a heat sink. The design basis calculation estimated the time to heat the CCWS from 95°F to 200°F. The temperature of the CCWS at 4 hours into the event was also calculated. To perform this calculation, the following were considered:

1. A CCWS volume of 1237 cubic feet. This volume is conservative in that it does not include the surge tank and the supply and return lines for the RHR and SFP heat exchangers.

2. 7.96 mBtu is required to heat the CCWS volume from 95°F to 200°F.

3. Total heat load on the system is 0.398 mBtu/hr. This value is based on heat from three SI pumps (10,000 Btu/hr each) and two recirculation pump motors (184,000 Btu/hr each). Note, a diesel generator failure was not taken.

The time required to reach 200°F was determined to be approximately 20 hours. The temperature of the CCWS at 4 hours was determined to be 116°F.

With elevated river water temperatures, the CCW supply temperature will increase. From Section 3.1.1.4.1, the highest normal CCW supply temperature is calculated to be approximately 105°F. With a conservative CCW supply temperature of 110°F (CCWS limit for RCP motor coolers - See Section 4.2.2.5) and the component heat loads used for this project (See Section 3.1.1.3.2), the time required to reach 200°F is calculated to be approximately 13 hours. The temperature of the CCW fluid at 4 hours is calculated to be approximately 138°F.

For a design basis large-break LOCA, the injection phase is relatively short (approximately 30 to 45 minutes). As such, system temperatures would be relatively low (<120°F) at the end of the injection phase. For smaller breaks, the time to switchover would increase.

The design basis calculation considered a four hour time interval. Within this time frame, it is reasonable to assume that operator action will be taken to implement forced cooling in the CCWS either via switchover to cold leg recirculation or by following post-LOCA cooldown procedures. Therefore, a 138°F CCWS temperature is a conservative estimate of the maximum CCWS temperature prior to the initiation of forced cooling. Following initiation of forced cooling, the CCWS supply temperature would drop to the calculated steady-state recirculation maximum temperature of 134°F within one hour. The CCWS supply temperature would then decrease with time as discussed in Section 3.1.1.4.3.

3.2 RESIDUAL HEAT REMOVAL SYSTEM

The primary function of the Residual Heat Removal System (RHRS) is to transfer heat energy from the core and RCS during the second phase of plant cooldown. The RHRS was evaluated to determine the impact of higher river water temperatures on the ability of the system to cooldown the plant. In addition, the RHRS is used to support the emergency core cooling system by providing cooling to the recirculated sump fluid. The RHR heat exchanger ability to subcool the sump fluid is also evaluated.

3.2.1 PLANT COOLDOWN

The cooldown analysis evaluates two separate plant cooldown scenarios. The first is a normal cooldown transient to both Cold Shutdown (RCS temperature $\leq$ 200°F) and Refueling (RCS temperature $\leq$ 140°F) with all cooling equipment available. The case of plant cooldown to a refueling mode is the case present in Table 9.3-3 of the Indian Point Unit 2 FSAR.

The second evaluation is Appendix R cooldown to Cold Shutdown. For this evaluation, only equipment capable of being powered by the Indian Point Unit 2 Auxiliary Safe Shutdown System are modeled.

3.2.1.1 Background

During the initial phase of plant cooldown from operating temperatures, auxiliary feedwater is supplied to the steam generators. The steam is relieved to the steam dump or via the main steam power-operated relief valves. As temperatures decrease, the ability to remove heat by steaming becomes ineffective, and the RHRS is aligned for operation at approximately 350°F. Decay heat and sensible heat from the RCS is transferred to the CCWS via the RHR heat exchangers. RHR heat exchanger heat loads as well as auxiliary heat loads serviced by the CCWS are transferred to the SWS by way of the CCW heat exchangers.

As SWS temperatures increase, the capability of the ACS to remove heat is decreased since the driving force (delta-T across the CCW heat exchangers) between the cooled and cooling fluids is smaller.

As part of the Stretch Rating program, RHRS cooldown capability was calculated based on the following assumptions:

1) Heat Exchanger Design Flows
2) 75°F SWS Temperature
3) 50°F per Hour Cooldown Limit
4) 120°F CCW Supply Limit
5) Two CCW and RHR Heat Exchangers with 3% Tube Plugging
6) Auxiliary Heat Loads of 16.2 and 9.5 mBtu/hr at 4 and 20 hours After Plant Cooldown as defined in Table 3-6
7) A 3083 MWt Core Power (conservative with respect to 3071.4 MWt stretch core power)

Based on the above assumptions, the time required to cool the plant to 140°F was calculated to be approximately 28 hours (4 hours on main steam and 24 hours on RHRS).

3.2.1.2 Methodology

To simulate the plant cooldown transient, the Westinghouse computer code RHRCOOL is used. The code simulates the heat transfer process of the RHR, CCW, and SWS systems. The code requires various design and operating parameters which are used to determine heat transfer capability. Examples include reactor thermal power, RCP heat input, heat exchanger design and operating data, and auxiliary CCWS heat loads. The code uses the Westinghouse Decay Heat Standard to establish decay heat levels as a function of time into plant shutdown. In the case where operating flows are less than design, the heat transfer coefficient of the RHR heat exchangers is reduced from its design value. Verification of the computer code has been performed in accordance with Westinghouse Quality Assurance Manual (Reference 3-1).

The code was established to evaluate a design basis cooldown. As such, CCWS auxiliary heat loads and SWS inlet temperature are required to be supplied at both 4 hours after plant shutdown (start of RHRS cooling) and 20 hours (end of the transient). Interim values are calculated using a linear progression from the initial to the final value.

An unique feature of the code is that RCS flow through the RHR tube-side heat exchangers will be "throttled" as necessary to ensure that one or both of the following limitations are satisfied:

- RCS cooldown rate
- Maximum CCW Supply Temperature

The limits for the above two parameters can be specified.

The output of the code consists of RHR and CCW heat exchanger temperature and flow data as a function of time into the cooldown transient.

With respect to thermal power, both the current licensed and Stretch Rating power were considered. Provided in the following section is a summary of the cooldown evaluation.

3.2.1.3 Results

Provided below are the calculated cooldown times for both a normal and Appendix R cooldown.

3.2.1.3.1 Normal Plant Cooldown

As part of this project, the current Stretch Rating analysis was reanalyzed based on a SWS inlet temperature of 95°F. Specifically, the following equipment were considered operational:

- Two RHR Pumps and Two RHR Heat Exchangers
- Three CCW Pumps and Two CCW Heat Exchangers
- Three Nonessential SWS Pumps

For this analysis, all of the original assumptions were used except for the following:

- Core Power Level = 3071.4 MWt versus 3083 MWt
- Tube Plugging = 5% versus 3%
- SWS Inlet Temperature = 95°F versus 75°F

The power level was reduced to be consistent with the maximum core licensed power at Stretch Rating conditions. The heat exchanger plugging level was increased to be consistent with the assumptions used to evaluate system performance as part of this project.

Provided in Table 3-6 are the auxiliary heat loads used in this analysis. The times required to reach the Cold Shutdown temperature of 200°F and the Refueling temperature of 140°F at various SWS temperatures at the two thermal ratings are presented in Table 3-7. As expected, cooldown times increase with higher SWS inlet temperatures.

Included in Table 3-7 are the time to initiate RHRS cooling. At river water temperatures greater than 90°F, the time at which RHRS cooling can be initiated had to be delayed since decay heat levels exceeded the heat rejection capability of the system (this prevented RCS heat up).

3.2.1.3.2 Appendix R Cooldown

To meet 10CFR50 Appendix R "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979" requirements, Indian Point Unit 2 has an Auxiliary Safe Shutdown System (ASSS) with which an alternate power supply can be provided to vital components. The power is supplied by gas turbine generators through the IP1 switchgear. The following equipment, within the scope of this analysis, can be supplied with power:

- RHR Pump 21
- CCW Pump 23
- Charging Pump 21 (requires CCW cooling)
- SWS Pumps 23 and 24 (one pump is aligned to the essential SWS header and one to the nonessential Header - the nonessential header supplies the CCW heat exchangers)

Based on this available equipment, both CCW heat exchangers can be used during the cooldown transient since the CCW pumps are headered together. Only one RHR heat exchanger can be utilized since the flows to both RHR heat exchangers are normally isolated and potential pump runout problems would be present unless other system users are manually isolated.

The CCW total flow and that fraction delivered to one RHR heat exchanger were varied until cooldown to Cold Shutdown could be obtained. The analysis considered one SWS pump delivering 2500 gpm to each CCW heat exchanger. The auxiliary heat loads on the CCWS for Appendix R Cooldown at RHR initial alignment and at 20 hours were based on those provided in Table 3-6 with a concurrent loss of offsite power.

Provided in Table 3-8 are the CCWS auxiliary heat loads used in the Appendix R analysis. From this table, note that the heat loads for the RCPs, waste gas compressors, and the gross failed fuel detector were eliminated due to the Blackout event.

The minimum CCW flow to the RHR heat exchanger along with the total system flow required to achieve a 72 hour plant cooldown to the Cold Shutdown temperature of 200°F with a SWS temperature of 95°F are provided below for the current core power rating of 2758 MWt. Also provided is the required time delay in placing the RHRS in service in order to ensure that decay heat levels are within the heat rejection capability of the system (this prevents RCS heat up).

- o Total CCWS Flow - $\geq$ 5000 gpm
- o RHR Heat Exchanger Flow - $\geq$ 2725 gpm
- o RHRS Cooling Initiated At 30 hours after Plant Shutdown

For the Stretch Power case, cooldown within 72 hours could not be achieved with the heat loads provided in Table 3-8. In addition, the RHR heat exchanger flow requirement was also significantly higher. In order to satisfy the minimum flow requirement, the flow path to the largest user (SFP heat exchanger) would have to be isolated. With the SFP heat load not considered at the time RHRS cooling is initiated, plant cooldown within 72 hours can be demonstrated. Provided below are the CCW flow requirements and the required time delay in placing the RHRS in service in order to ensure that decay heat levels are within the heat rejection capability of the system (this prevents RCS heat up):

- Total CCWS Flow - 5000 gpm
- RHR Heat Exchanger Flow - 4025 gpm
- RHRS Cooling Initiated At 42 hours after Plant Shutdown

Since in both cases, the required CCWS flows are within the flow capacity of a single CCW pump (5400 gpm), the ACS is capable of satisfying the Appendix R cooldown requirement as long as the CCWS throttle valves (820 A&B) are repositioned to increase CCWS flows to the values defined above.

3.2.2 Post-LOCA Performance

The RHR heat exchangers are used during the recirculation phase of a LOCA to provide cooling to the recirculated sump fluid. In order to provide adequate cooling, the recirculated sump fluid must be subcooled to prevent flashing in the reactor vessel.

To minimize RHR heat transfer, the design data described in Section 3.1.1.3.1 was used as a basis except that the fouled "U" and a five percent area reduction was considered. The transfer rate, tube area, and overall heat transfer coefficient ("UA") at design flows were defined as 309 Btu/hr-ft^2-F, 3400 ft^2, and 1.05 mBtu/hr-F, respectively.

The maximum RHR heat exchanger tube-side outlet temperature is calculated to be approximately 225°F at the initial switchover to sump recirculation. Since the pressure and inside the reactor vessel is greater than or equal to containment pressure, at least 25 degrees of subcooling is available to the recirculated sump fluid.

3.3 SPENT FUEL PIT COOLING SYSTEM

Component cooling is provided to the shell-side of the SFP heat exchanger in order to remove decay heat generated by spent fuel assemblies in storage. Typically, approximately one third of the fuel assemblies contained in the reactor vessel are added to the SFP each refueling. The SFP heat exchanger tube-side inlet temperature is a key parameter in that it represents the bulk temperature of the SFP.

Provided in this section is the calculated SFP bulk temperatures for both Power Operation and Refueling conditions. For both of these modes, the following design data is available for the SFP heat exchanger:

- General Data
  Design Area - 2,000 ft^2
  Design U - 310 Btu/lb-ft^2-^{o}F
  Clean U - 468 Btu/lb-ft^2-^{o}F
  Design Duty - 7.96E+06 Btu/hr
  Tube Fouling Factor - 0.0005 hr-ft^2-^{o}F/Btu
  Shell Fouling Factor - 0.0005 hr-ft^2-^{o}F/Btu

- Tube-Side Conditions
  Design Flow - 1.1E+06 lb/hr
  Design Inlet Temperature - 120°F

- Shell-Side Conditions (CCWS)
  Design Flow - 1.4E+06 lb/hr
  Design Inlet Temperature - 100°F

To minimize heat transfer capability, the fouled "U" and a 5% reduction in the design surface area was considered. For this project, the heat exchanger transfer rate, tube area, and overall heat transfer coefficient ("UA") at design flows were defined as 310 Btu/hr-ft^2-F, 1900 ft^2, and 0.589 mBtu/hr-F, respectively.

Provided below are the calculated SFP temperatures for both Power Operation and Refueling conditions.

3.3.1 Power Operation

During Power Operation, the SFP contains spent fuel assemblies from the recent one-third core discharge along with previous one-third core discharges. The SFP temperature is dependent on the CCW flow to the SFP heat exchanger, the heat rejection capability of the system, and the amount of heat generated by the various spent fuel assemblies. With time, the SFP decay heat load decreases due to radioactive decay.

To evaluate heat exchanger performance, a parametric study was performed. Provided below is the range of parameters varied for this evaluation:

- o CCW Flow - 1.4, 1.0, and 0.6 mlb/hr
- o CCW Inlet Temperature - 70°F and 120°F
- o SFP Heat Load - 10, 5, and 2 mBtu/hr

The above ranges were selected in an effort to bound expected operating conditions during Power Operation. Provided in Table 3-9 is the results of this analysis. From Table 3-9, the SFP temperature is capable of being maintained below 150°F even at the most limiting conditions analyzed (120°F CCW inlet temperature and a 10 mBtu/hr heat load).

The results provided in Table 3-9 can be used to define CCWS flow requirements within the analyzed ranges.

3.3.2 Refueling

The highest SFP temperatures occur during the initial discharge of spent fuel to the SFP during plant refueling. Provided in the FSAR is the evaluation of a one-third and full core discharge to the SFP at 131 hours after plant shutdown. The maximum SFP temperature with a one-third and full core discharge is calculated to be 140°F and 155°F, respectively (Reference 3-8). The FSAR analysis considered a CCWS flow rate of 1.1 mlb/hr (approximately 2200 gpm) and an inlet temperature of 91.3^{o}F.

At a 95°F SWS inlet temperature, the CCW supply temperature is calculated to be approximately 100°F. This temperature considers both CCW heat exchangers to be in service at design flows. To compensate for the higher CCW supply temperature, CCW flow to the SFP heat exchanger must be increased. If SFP heat exchanger design flows are considered, the one-third and full core discharge SFP temperature are calculated to be 148°F and 164°F, respectively. Since the revised SFP temperatures with 95°F SWS inlet temperature are higher than the present basis, an update to the FSAR is required.

To increase CCW flow to the SFP heat exchanger, flow to system users which are not operating could be isolated and/or the CCWS throttle valve to the SFP heat exchanger (valve 803) can be manually repositioned.

In support of the Stretch Program, SFP temperatures were recalculated following both a one-third and full core discharge. The analysis considered both a core unload time of 131 hours after plant shutdown and SFP heat exchanger design performance. The calculated one-third and full core discharge SFP temperature were 140°F and 199°F, respectively.

At a 95°F SWS inlet temperature, the CCW supply temperature is greater than the design CCWS inlet temperature (100°F). This would cause the SFP temperature following a full core discharge temperature to exceed the design temperature of the SFP heat exchanger (200°F).

As a result of the evaluation of the fuel handling accident at Stretch power, the minimum core discharge time was required to be increased from 131 hours to 174 hours after plant shutdown (Reference 3-6). At the revised longer core unload time, the SFP temperatures were calculated to be lower than the existing Stretch analysis. As such, the Stretch Rating SFP thermal/hydraulic analysis is conservative with respect to a 95°F SWS inlet temperature when the minimum core unload time is 174 hours after plant shutdown.

REFERENCES

3-1 "NATD Quality Assurance Program", Westinghouse Electric Corporation, WCAP-9565.

3-2 "Flow Diagram Auxiliary Coolant System", Con Edison Drawing No. 9321-F-2720-49.

3-3 "Flow Diagram Auxiliary Coolant System", Con Edison Drawing No. A227781-15.

3-4 "Containment Pressure Analysis Code (COCO)", Westinghouse Electric Corporation, WCAP-8326, July 1974.

3-5 "Westinghouse LOCA Mass And Energy Release Model for Containment Design - March 1979 Version", WCAP-10325-A, May 1983.

3-6 "Consolidated Edison Company of New York, Inc., Indian Point Unit 2, NSSS Stretch Rating - 3083.4 MWt, Engineering Report," Westinghouse Electric Corporation, WCAP-12187, March 1989.

3-7 Indian Point Unit 2 Updated Final Safety Analysis Report, Chapter 6.

3-8 Indian Point Unit 2 Updated Final Safety Analysis Report, Chapter 9.

TABLE 3-1
SUMP TEMPERATURE TIME HISTORY FOR THE LOCA EVENT

Time (Sec)	Temperature (F)	Time (Sec)	Temperature (F)
0	130.0	2900	249.5
5	227.0	3000	249.3
20	249.5	3999	246.8
40	252.0	4999	244.2
60	252.8	5999	242.0
80	253.6	6999	240.2
100	254.3	7999	238.6
150	255.8	8999	237.2
199	256.9	9999	236.1
399	259.7	19999	229.7
599	261.2	29999	225.5
799	262.1	49999	225.3
999	262.5	69999	224.7
1199	262.2	89999	224.6
1499	260.9	99999	223.9
1999	257.8	299999	223.4
2500	252.6	399999	223.4
2600	251.6	599999	221.8
2700	250.7	799999	219.6
2800	249.7		
2811*	249.6		
2815	249.6		
2850	249.6		

*Approximate time of switchover

TABLE 3-2
CCWS PERFORMANCE FOR STARTUP/POWER OPERATION/BLACKOUT MODES

Component	Cases Considered 1	2	3	4
CCWS EQUIPMENT IN SERVICE				
CCW Pumps On	1	1	2	2
CCW HXs In Service	2	1	2	1
SWS BOUNDARY CONDITIONS				
SWS Pumps On	2	2	2	2
SWS Temperature - ^{o}F	95	95	95	95
Total SWS Flow to CCW HXs - gpm	9000	4500	9000	4500
CCWS PERFORMANCE				
Total CCW Flow - gpm	4400	4400	5382	5382
CCW HX Inlet Temp. - ^{o}F	120.5	132.7	118.2	130.4
CCW HX Outlet Temp. - ^{o}F	104.9	117.2	105.4	117.9

TABLE 3-3
480 V BUS ESSENTIAL LOADING SUMMARY

Description	Bus 5A DG #21	Bus 2A/3A DG #22	Bus 6A DG #23
SI Pumps	21	22	23
Cont. Spray Pumps	21		22
RHR Pumps		21	22
Aux. FW Pumps		21	23
Cont. Fans	21/22	23/24	25
Recirc. Pumps	21		22
Service Water Pumps	21/24	22/25	23/26
CCW Pumps	21	22/23	
MCCs	26A/AA		26B/BB

[1]Con Ed Drawing A208088-08

TABLE 3-4
CCWS ALIGNMENT FOR LOCA RECIRCULATION MODE

Component	Cases Considered 1	2	3	4	5	6
CCWS EQUIPMENT IN SERVICE						
CCW Pumps On	1	1	2	2	1	1
CCW HXs In Service	2	2	2	2	2	2
SWS BOUNDARY CONDITIONS						
SWS Pumps On	1	1	2	2	1	1
SWS Temperature - ^{o}F	95	95	95	95	95	95
SWS Flow Per CCW HX - gpm	2500	2500	4500	4500	2500	2500
RHR SYSTEM BOUNDARY CONDITIONS						
Sump Temperature - ^{o}F	250	200	250	200	250	200
RHR/Recirc. Pumps On	1	1	2	2	1	1
RHR HXs In Service	2	2	2	2	1	1
Sump Flow Per RHR HX - gpm	1550	1550	3100	3100	3100	3100
CCWS PERFORMANCE						
Total CCW Flow - gpm	5480	5480	7900	7900	4950	4850
RHR HX Outlet Temp. - ^{o}F	196.3	164.5	199.2	166.1	201.9	168.1
CCW HX Inlet Temp. - ^{o}F	163.2	132.7	162.9	142.6	148.2	133.6
CCW HX Outlet Temp. - ^{o}F	133.6	117.2	132.9	121.6	123.6	115.8

TABLE 3-5
CCWS PIPING EVALUATION

Component	Nominal Flow (gpm)	Piping Dia. (in)	Velocity (ft/sec)	Vel. Limited[1] Flow (gpm)
RCPs				
- Thermal Barrier	25	1.5	3.9/5.7[2]	95/65[2]
- Upper Bearing	150	3	6.5	346
- Lower Bearing	5	1	1.9	40
RHR Heat Exchangers	5000	12	14.2	5294
Non-Regenerative Heat Exchanger	1000	6	11.0	1352
Excess Letdown Heat Exchanger	230	3	10.0	346
Seal Water Heat Exchanger	200	3	8.7	346
Sample Heat Exchangers	14	1	5.2	40
SFP Heat Exchanger	2000	8	12.8	2342
RHR Pumps	15	1	5.6	40
SI Pumps	15	1	5.6	40
SI Recirculation Pumps	40	2	3.8	157
Charging Pumps				
- Speed Controller	85	2	8.1	157
- Lube Oil Cooler	5	1	1.9	40
Waste Gas Compressors	25	2	2.4	157
Reactor Vessel Nozzle Blocks	12.5	0.75	7.5	25
CCW Pumps				
- Suction	3600[3]	12	10.2	5294
- Discharge	3600[3]	10	14.6	3691
CCW Heat Exchangers	3600[3]	14	8.4	6454

1 Flow rate that yields a 15 feet per second velocity.
2 High pressure portion of piping (schedule 160).
3 Value based on pump design flow.

TABLE 3-6
CCWS AUXILIARY HEAT LOADS FOR NORMAL PLANT COOLDOWN

Component	Heat Loads (mBtu/hr) 4 hours	20 hours
Spent Fuel Pit Heat Exchanger *	7.5	7.5
Seal Water Heat Exchanger	0.4	----
Non-Regenerative Heat Exchanger (approx. 40 gpm)	4.8	0.93
Sample Heat Exchanger	0.3	----
Reactor Coolant Pump (1)	1.8	----
RHR Pump Coolers (2)	0.15	0.15
SI Pump Coolers (0)	----	----
Charging Pump Coolers (1)	0.45	0.45
Recirculation Pump Motor Coolers (0)	----	----
Waste Gas Compressors (1) **	0.27	0.27
Excess Letdown Heat Exchanger	----	----
Reactor Vessel Supports	0.23	----
CCW Pump Heat Input (0)	----	----
Gross Failed Fuel Detector ***	0.3	----
TOTAL AUXILIARY HEAT LOAD	16.2	9.5

* Heat load based on a one-third core unload at 45 days after plant shutdown.

** This component is not in service below 350°F.

*** This component is no longer in service.

TABLE 3-7
COOLDOWN TIMES FOR NORMAL PLANT COOLDOWN

Service Water Temperature	Reactor Core Power	Time To RHR Alignment	Total Time To Cold Shut. At 200°F	Total Time To Refueling At 140°F
32 F	2758 MWt	4 hrs	7.2 hrs	10.0 hrs
50 F	2758 MWt	4 hrs	7.5 hrs	11.9 hrs
65 F	2758 MWt	4 hrs	8.0 hrs	15.8 hrs
75 F	2758 MWt	4 hrs	8.8 hrs	22.0 hrs
85 F	2758 MWt	4 hrs	11.4 hrs	34.5 hrs
90 F	2758 MWt	4 hrs	14.9 hrs	45.1 hrs
95 F	2758 MWt	7 hrs	24.2 hrs	61.3 hrs
32 F	3071.4 MWt	4 hrs	7.4 hrs	10.7 hrs
50 F	3071.4 MWt	4 hrs	7.8 hrs	13.6 hrs
65 F	3071.4 MWt	4 hrs	8.4 hrs	19.9 hrs
75 F	3071.4 MWt	4 hrs	9.5 hrs	29.0 hrs
85 F	3071.4 MWt	4 hrs	12.8 hrs	46.3 hrs
90 F	3071.4 MWt	4 hrs	17.5 hrs	60.9 hrs
95 F	3071.4 MWt	10 hrs	29.4 hrs	82.6 hrs

Key Assumptions

(1) All heat exchanger equipment operating with design flows.
(2) RHRS cooling initiated at a RCS temperature of 350°F.
(3) One RCP operates until 160°F RCS temperature is reached.
(4) RHR start time 4 hours after reactor trip, except for those cases were RCS heat up occurs (SW temp. > 90°F).
(5) RHR tube-side flow throttled to limit RCS cooldown to 50°F per hour and a 120°F CCW supply temperature.
(6) Cooldown time includes both main steam and RHR cooling.

TABLE 3-8
CCWS AUXILIARY HEAT LOADS - APPENDIX R COOLDOWN

Component	Heat Loads (mBtu/hr) 4 hours	20 hours
Spent Fuel Pit Heat Exchanger *	7.5	7.5
Seal Water Heat Exchanger	0.4	----
Non-Regenerative Heat Exchanger (approx. 40 gpm)	4.8	0.93
Sample Heat Exchanger	0.3	----
Reactor Coolant Pump (0)	----	----
RHR Pump Coolers (1)	0.075	0.075
SI Pump Coolers (0)	----	----
Charging Pump Coolers (1)	0.45	0.45
Recirculation Pump Motor Coolers (0)	----	----
Waste Gas Compressors (1)	----	----
Excess Letdown Heat Exchanger	----	----
Reactor Vessel Supports	0.23	----
CCW Pump Heat Input (0)	----	----
Gross Failed Fuel Detector	----	----
TOTAL AUXILIARY HEAT LOAD	13.8	9.0

* Heat load based on a one-third core unload at 45 days after plant shutdown.

TABLE 3-9
SPENT FUEL PIT HEAT EXCHANGER CAPABILITY

CCW Flow (Mlb/hr)	CCW Temperature (°F)	SFP Heat Load (mBtu/hr)	SFP Temperature (°F)
1.4	70	10	95.8
		5	83.0
		2	75.2
	120	10	145.8
		5	132.9
		2	125.2
1.0	70	10	98.7
		5	84.4
		2	75.8
	120	10	148.7
		5	134.4
		2	125.8
0.6	70	10	105.4
		5	87.7
		2	77.1
	120	10	155.4
		5	137.7
		2	127.1

NOTES:
1 - Five percent area reduction considered.
2 - Tube-side design flow used (1.1 mlb/hr).

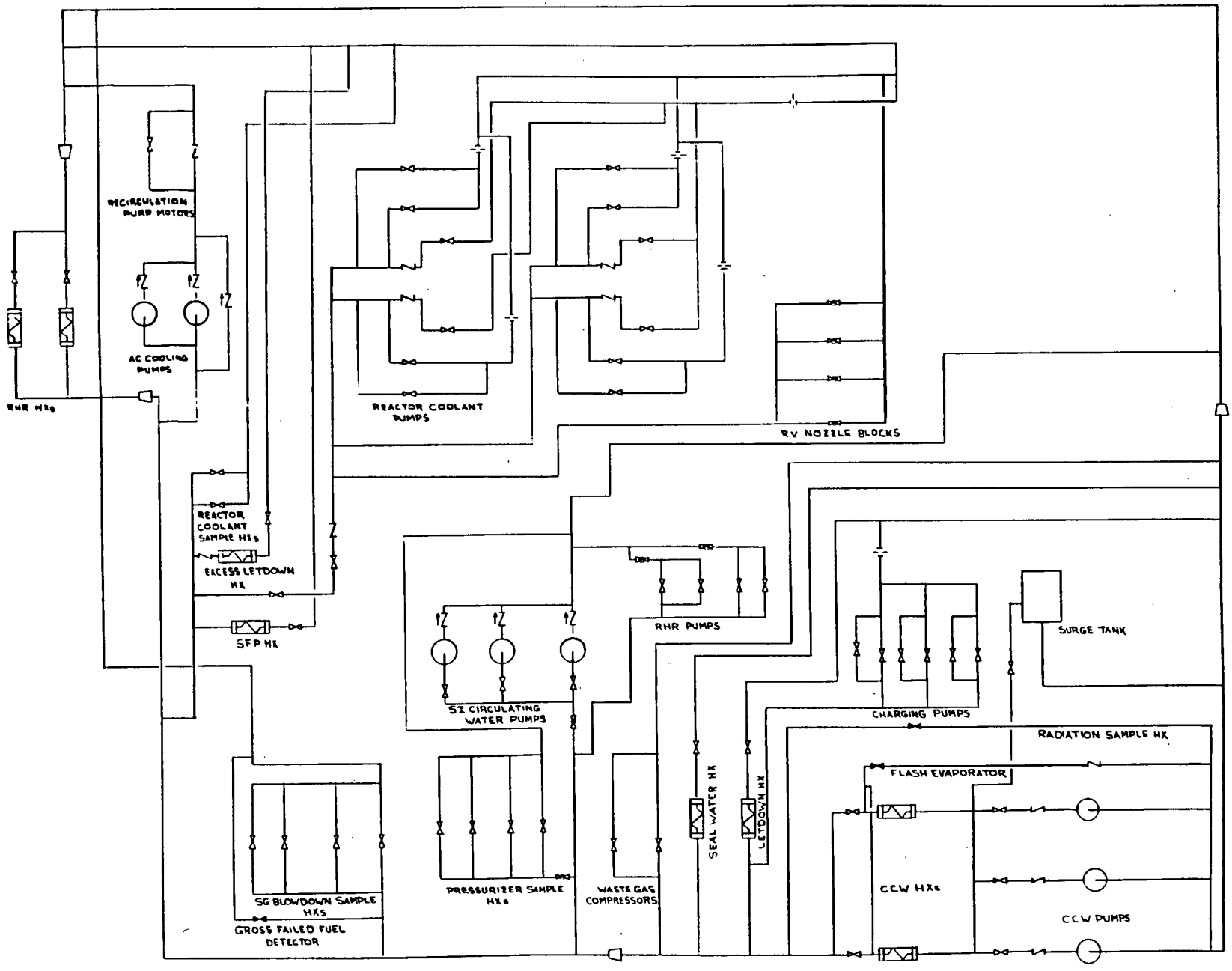


FIGURE 3-1. SCHEMATIC OF THE INDIAN POINT CCWS THERMAL/HYDRAULIC MODEL

4.0 COMPONENT EVALUATIONS

Table 4-1 lists the safety-related components serviced by the SWS. An evaluation of the increased service water temperature from 85°F to 95°F was conducted for each of the components listed in this table. The component studies consisted of analyses and/or engineering evaluations sufficient to determine that the SWS process conditions are acceptable, subject in some cases to corresponding flow or operating limits.

The SWS also cools the CCWS. The CCWS in turn, cools the equipment listed in Table 4-2. This equipment was also evaluated to determine that adequate cooling is provided to support safe plant operation.

All engineering analyses required for safety-related component evaluations have been performed by Westinghouse in accordance with the applicable requirements of the Westinghouse Quality Assurance Program (Reference 4-14). Analyses obtained from the original component manufacturers have been utilized as reference information only; therefore, qualification of these suppliers' QA programs was not performed for purposes of these evaluations. The evaluations do not provide certification or environmental qualifications for the components.

Various aspects of the unit were included in the evaluation with regard to the function of the component in the system. The evaluation considered both the mechanical aspects of maximum cooling flow rates for tube vibration and erosion, as well as the thermal aspects of sufficient cooling. Where an absolute determination that design limits could be met was not possible, one or more of the following considerations was discussed:

- Impact on equipment performance
- Required service water flow at evaluated temperatures (i.e., flow at 95°F versus flow at 85°F)
- Valve position for process flow to achieve desired temperature

This section includes a summary of the evaluations performed for each component. Each item is covered on an individual basis with a portion of that section devoted to concluding the impact of service water temperature changes. The result is the impact of the temperature effects and determination that the SWS process conditions are acceptable as a permanent design basis. Included in each section is a description of the component function as well as the evaluation assumptions and results.

4.1 ACCIDENT REQUIRED EQUIPMENT COOLED BY THE SWS

4.1.1 Reactor Containment Fan Coolers

4.1.1.1 Description/Function

The Reactor Containment Fan Cooler (RCFC) Units provide for cooling and filtering recirculated containment building air in order to:

1) Maintain containment building temperatures during normal plant operation.

2) Reduce containment building temperatures and remove radioactive iodine and methyl iodide from the steam-air mixture during incident conditions.

The RCFC unit is an engineered safeguard system. There are five RCFC units in the containment building. Each unit consists of a series of filters for removal of entrained moisture, particles, and radioactive iodine and methyl iodide; two banks of cooling coils; a fan assembly; a motor assembly including an enclosed heat exchanger; and an enclosure assembly. During normal operation, air is drawn from the containment building through a roughing filter, the cooling coil banks, a demister, and an absolute (HEPA) filter by the fan and into a distribution header. During post-accident operation, the air is diverted to charcoal beds for removal of fission products prior to entering the distribution header.

The two banks of cooling coils in each unit include ten continuous water tube Marlo cooling coils manufactured by Nuclear Cooling, Inc. The coils are stacked 5 high to a bank. Each coil consists of plate copper fins spaced 8-1/2 fins per inch of tube length and 5/8" OD AL6X-SB676 tubes. The coils have six rows of tubes through their depth with two pass flow circulation Cooling water is provided by the service water system.

4.1.1.2 Method of Analysis

The performance of the cooling coils using 95°F inlet service water was determined for the normal condition in this section. The coil performance for the post-accident condition is provided in the containment integrity analysis (Reference 4-16). Table 4-3 provides the data used in the evaluation. All of the data provided in this table was taken from Reference 4-1, except as noted below.

1) Per the IP2 Updated FSAR, Section 6.4.2.2.9, all five RCFC units now have the Marlo coils described in Table 4-3.

2) The coils were evaluated for an inlet service water temperature of 95°F and flow rates ranging from 500 gpm to 2000 gpm, which should envelop normal operating flow rates.

3) The fan cooler performance was evaluated for containment temperatures of 120°F and 130°F.

4) An assumed tube pluggage value of 5% was used in order to be consistent with the original performance evaluation for these coils by Nuclear Cooling, Inc. (Reference 4-2).

The evaluation of the performance of the cooling coils conservatively assumes no heat removal via condensation. The heat removal rates (Q) were determined from the following relationship:

$$Q = (U)\ (A)\ (LMTD)$$

where U is the overall heat transfer coefficient for a plate fin coil of this type, A is the face area of the coils, and LMTD is the logarithmic mean temperature difference. Heat removal rates for containment temperatures of 120°F and 130°F are plotted in Figure 4-1. Outlet water temperatures are provided in Table 4-4.

4.1.1.3 Impact and Conclusion

Although measured heat load data for the Indian Point Unit 2 containment building was not available for this evaluation, Reference 4-1 provides a design heat removal capacity of 2.198×10^6 Btu/hr for the Marlo Coils, at a containment temperature of 120^oF. With 95^oF SWS supply temperature, this design heat removal rate can be achieved by the RCFC units at a containment temperature of 130^oF (see Figure 4-1). The conclusion can thus be drawn that the RCFC performance with 95^oF SWS temperature is adequate to maintain containment temperature below 130^oF. However, the RCFC units are probably not adequate to maintain containment temperature below the design limit of 120^oF.

4.1.2 RCFC Fan Motor Heat Exchanger

4.1.2.1 Description/Function

The RCFC fan motor heat exchanger is a component of the motor/motor base assembly which is designed to absorb heat due to motor heat losses and external effects under all operating conditions and limit the maximum thermal environment consistent with the motor design. The motor/motor base assembly serve as an enclosure to isolate the major functional elements of the motor from the containment environment which would exist in the post accident condition. Air exiting the motor passes through the heat exchanger and is directed by the ductwork in the enclosure back through the motor. A relief valve mounted on the enclosure allows the pressure inside the enclosure to equalize with the pressure outside in the post accident condition. In this case, moisture is condensed from the air by the heat exchanger to protect the motor.

The motor heat exchanger is a Marlo continuous water tube cooling coil manufactured by Nuclear Cooling, Inc. The coil is a plate cooper fin coil with 5/8" OD AL6X-SB676 tubes. Cooling water is provided by the service water system.

4.1.2.2 Method of Analysis

A motor life expectancy calculation was completed which evaluates the performance of the cooling coil against conservatively calculated heat loads for the normal and post accident conditions. Table 4-5 provides data used in the evaluation of the coils. The sources of this data are summarized below:

1) The specific coil data for the Marlo coil (i.e., coil type, fin material, fins/inch, etc.) was taken from Marlo Coil data sheets (Reference 4-1).

2) The heat exchanger was initially evaluated at a SWS flow rate of 50 gpm which was taken from the Westinghouse Instruction and Operating Manual for the Indian Point 2 RCFC units.

3) The containment atmosphere pressures were taken from the Updated IP2 FSAR, Section 6.4.1.

The heat exchanger was evaluated by determining the maximum motor winding temperatures permitted to provide an expected motor life of 40 years of normal operation plus one year of post-accident operation. The heat exchanger was then evaluated to determine if it could remove the calculated heat load to maintain these temperatures. The following conservative assumptions made were:

1) For the normal condition, the conservative assumption of 85°F service water for nine months and 95°F service water for three months of each of 40 years of normal operation was made. No credit was taken for actual operation data to date.

2) For the accident condition, the conservative assumption of 95°F service water year round was made. The heat load was assumed constant for the entire year where in reality it would be reduced significantly shortly after the accident.

The maximum permitted motor winding temperatures were established from the relationship of motor winding life to insulation temperature, per References 4-3 and 4-4.

The heat removal capacity of the heat exchanger was then calculated for the normal and post-accident conditions from the following relationship:

$$Q = (U)\ (A)\ (LMTD)$$

where U is the overall heat transfer coefficient for a plate fin coil of this type, A is the face area of the coil, and LMTD is the logarithmic mean temperature difference. These resulting heat removal rates were compared to the heat loads for the normal and post-accident conditions to verify the adequacy of the heat exchanger performance. An iteration was then performed using this same methodology to determine the minimum service water flow rate required to remove the calculated heat loads. This flow was determined to be 17 gpm.

4.1.2.3 Impact and Conclusion

It was concluded from the calculations described above that the heat exchanger performance is adequate, with a minimum service water flow rate of 17 gpm, to maintain motor winding temperatures below a level which will provide for the required motor life. Therefore, an increase in the service water temperature to a maximum of 95°F for three months and 85°F for nine months of each year will not impact the life expectancy of the RCFC motors of 40 years of normal operation plus one year of post-accident operation.

4.1.3 RCFC Service Water Return Radiation Monitor

4.1.3.1 Description/Function

RCFC Service Water Return Radiation Monitors (R-46 and R-53) serve to detect radiation leakage from the containment into the service water return lines from the containment fan coolers and motor coolers.

Sample flow from the SWS return lines is induced via a motor driven pump through the sample heat exchanger associated with each of the radiation monitors. Temperature switch TS100 (Reference 4-17) monitors sample temperature coming out of the heat exchanger, and opens cooling water solenoid valve ECV17 when sample temperature exceeds 120°F, which allows additional cooling water to flow through the heat exchanger. The rate of sample flow through the skid assembly, indicated by flowmeter FI102, can be regulated between one and five gpm (Reference 4-17, Figure 2-1). The function of temperature switch TS101 is to shut down the pump motor when sample temperature exceeds the appropriate setpoint. The maximum permissible sample temperature into the radiation monitor is 160°F.

4.1.3.2 Method of Analysis

The relatively low temperatures (approximately 100°F) of the return service water during the normal condition are well below the 130°F setpoint of TS101. Therefore, no further evaluation of the radiation monitors for normal plant operation is required.

For post-LOCA operation, a heat balance calculation was performed for the sample heat exchanger using data from the heat exchanger design specification sheet (Reference 4-17). As in the original design, a maximum cooling water (SWS) flow rate of 10 gpm and a maximum sample flow rate of 5 gpm were used in this evaluation. The 5 gpm sample flow rate is limiting since it results in the maximum heat load on the heat exchanger. The cooling water (SWS) inlet temperature was increased to a maximum of 95°F. As directed by Con Ed, the maximum sample water inlet temperature was assumed to be $\leq$ 185°F. This is conservative since the applicable piping design specification (Reference 4-18) classifies this piping with a design temperature of 160°F. To account for the effects of potential future tube plugging, a calculation was also performed assuming that about 10% of the tubes (5 tubes) were plugged.

Based upon the calculations performed, the following temperatures are predicted.

Case	Cooling Water Exit Temperature	Sample Water Exit Temperature
No Tubes Plugged	119°F	137°F
5 Tubes Plugged	118°F	140°F

The above results indicate that the sample water temperatures for both cases evaluated are likely to exceed the current setpoints for control valve ECV17 (120°F), and temperature switch TS101 (130°F). Above 120°F, ECV17 is fully opened, and will allow at least 10 gpm cooling water flow to the heat exchanger. Since TS101 is currently set to trip the sample pump motor at 130°F, the setpoint will have to be revised in order to maintain sample monitoring capability post-LOCA.

4.1.3.3 Impact and Conclusions

Due to the relatively low temperatures (approximately 100°F) of the return service water during the normal condition there is no impact to the radiation monitors of raising the inlet service water temperature to 95°F.

For the post-LOCA condition, the evaluation has shown that the possibility exists for the sample water temperature to exceed the current temperature setpoint (130°F) at which TS101 will isolate the sample flow to the radiation monitor. Therefore, in order to maintain radiation monitoring capability post-LOCA, the setpoint of TS101 must be revised upward to a level high enough to ensure that the radiation monitor will not be isolated for sample temperatures as predicted above in Section 4.1.3.2. The revised setpoint must also be limited to below 160°F, which is the maximum inlet temperature allowed to the radiation monitor.

4.1.4 Diesel Generators

4.1.4.1 Description/Function

The function of the emergency diesel generators (EDGs) is to provide a reliable source of backup power to the essential equipment receiving power from the 480 volt buses. This includes equipment required for a safe shutdown of the reactor following a loss of the normal power supply and the safeguards equipment specifically required to limit the consequences of a LOCA.

Three EDGs are installed to provide a high degree of reliability and independence from outside power to the engineered safeguards system components requiring electrical power. The three units are identified as DG #21, DG #22 and DG #23. Two of the three EDGs can supply sufficient power to meet the minimum safeguard requirements.

This evaluation addresses the three EDGs installed at Indian Point Unit 2. These specific units are Alco Power 2450 HP sixteen cylinder turbo-supercharged engines of the four-stroke cycle type, designed with open combustion chambers and a solid-state fuel injection system. The evaluation covers those items of the EDGs which receive cooling from service water (considered to be 95°F for this evaluation). These include the diesel engine jacket water cooler and the lube oil cooler.

The jacket water system removes the unused heat of combustion imparted to the cylinder's walls and thereby keeps the engine metal within design temperature conditions (Refer to Figure 4-2, Engine Jacket Water System). Heat removed from the engine jacket is subsequently transferred to the service water through the jacket water cooler.

The oil used in the engine lubricates and cools bearings and friction parts of the engine. The oil must also be maintained within a specified temperature range, otherwise it could break down and lose its lubricating qualities. The heat of the oil is transferred to the service water through the lube oil cooler. (Refer to Figure 4-3, Diesel Engine Lube Oil System).

4.1.4.2 Method of Analysis

An evaluation of the performance of the diesel engine jacket water and lube oil coolers at 95°F service water was done for Indian Point Unit 3 by United Engineers and Constructors (UE&C). Per Reference 4-5, three identical 2450 HP turbo-supercharged engines were originally supplied to each Indian Point plant by Alco Power, under Alco Shop Order DE-35211. On the basis that the EDGs at Indian Point Unit 2 are identical to those for Indian Point Unit 3, it is appropriate to apply the evaluation results obtained for Indian Point Unit 3 to Unit 2.

The results of the evaluation for Indian Point Unit 3 are included in Reference 4-6, which is on file at NYPA (Reference 4-7). The results of this work are included as justification for the equipment evaluation.

Results of the UE&C evaluation provide justification for operation of the EDGs. The summaries provided by UE&C for the two cases analyzed are included below.

Case 1: Diesel generator cooler performance during the post LOCA recirculation phase concurrent with a rupture of the 10 inch SWS supply line from the essential header line supplying the coolers, a river temperature of 95°F and lube oil cooler tube plugging (up to 20 tubes). Note, although this case is not part of the licensing basis for Indian Point Unit 2, the results presented provide valid and useful information.

Case 2: Diesel generator cooler operation at its maximum two (2) hour rating of 1950 KW, a river temperature of 95°F, and twelve (12) lube oil cooler tubes plugged.

For each of the two cases, the increase in both lube oil and jacket water temperatures were predicted and compared to the normal and maximum recommended temperatures provided by the manufacturer.

The diesel manufacturer, Alco Engines, has provided the following as guidelines for jacket water and lube oil temperatures:

	Jacket Water	Lube Oil
Maximum Recommended Operating Temperature (^oF)	190	210
Normal Operating Temp (^oF)	170	180 - 195

Also, the evaluation of each of the two cases assumed that both the jacket water (JW) and lube oil (LO) coolers are not fouled beyond their design fouling values. The results and conclusions for each of the cases are as follows.

Case 1

The rupture of the 10 inch essential header SW line supplying the DG coolers results in a service water flow of 1020 gpm through DG #31 and reverse service water flow of 260 gpm through each of the other DG coolers (#32 and 33). These flows were taken from the results of the SW hydraulic computer model using the replacement Ingersoll Rand pumps. This case was evaluated at diesel generator loadings of 2047 HP each (which is the maximum loading of any diesel during recirculation) and 2450 HP (which is the rated loading for the diesels).

Case 1 considered only the performance of DG #32 and 33 coolers since service water flow is minimized and the service water temperature entering the coolers is maximized due to the pickup of heat through DG cooler #31.

The results of the analysis for each of the diesel loadings are shown below:

A. 2047 HP Loading

No. of Plugged LO Cooler Tubes	0	4	8	12	16	20
JW Temp. (^oF)	176.0	176.0	176.0	176.0	176.0	176.0
LO Temp. (^oF)	189.8	190.9	191.9	193.0	194.2	195.5

B. 2450 HP Loading

No. of Plugged LO Cooler Tubes	0	12	20
JW Temp. (^{o}F)	181.0	181.0	181.0
LO Temp. (^{o}F)	195.5	199.9	201.3

At a diesel loading of 2047 HP, the limited service water flow through the coolers resulting from a rupture of the 10 in. SW line can adequately cool DG #32 and 33 jacket water and lube oil. However, increases in jacket water and lube oil temperatures above normal would occur. Jacket water temperatures would increase to 176°F, or a six (6) degree increase above the normal operating temperature of 170°F. With more than 16 tubes plugged, the lube oil temperature increases beyond the normal operating temperature range recommended by the manufacturer (180°F - 195°F) but remains within the maximum recommended operating temperature of 210°F.

At the higher diesel loading of 2450 HP, the jacket water temperature will increase beyond the normal operating temperature to 181°F. Once again, this value is within the maximum recommended operating jacket water temperature and, therefore, the cooling provided will be adequate.

The lube oil temperature will increase to 196°F with zero tubes plugged and to 200°F with 12 tubes plugged. Although beyond the normal operating temperature range set by the manufacturer, these values are within the maximum operating temperature of 210°F.

Case 2

In this case, a service water flow of 400 gpm at 95°F is provided to the DG coolers with the diesels operating at their maximum two (2) hour rating of 2730 HP (1950 KW) and with 12 lube oil cooler tubes plugged. The results of the analysis are shown below.

No. of Plugged LO Cooler Tubes	12
JW Temp. (^{o}F)	180.0
LO Temp. (^{o}F)	180.0

In this case, both jacket water and lube oil coolers have been found to provide adequate cooling. The JW temperature will increase approximately $10^{o}F$ beyond the normal range but will still be within the maximum recommended operating temperature.

4.1.4.3 Impact and Conclusions

The emergency diesel generator jacket water and lube oil coolers are capable of providing the necessary cooling with service water temperatures up to $95^{o}F$. This cooling will not be detrimental to the diesel generator and resulting lube oil and jacket water temperatures will be within safe limits, as provided by the equipment vendor, Alco Power.

4.1.5 Instrument Air Compressors

4.1.5.1 Description/Function

The primary function of the Instrument Air System is to provide clean, oil and moisture free compressed air to the instruments, controls and other required services in the nuclear plant.

Ambient air is supplied to two motor driven 225 SCFM single stage horizontal compressors. The compressed air exits to an aftercooler (heat exchanger) and then to a series of moisture separators, dryers, filters, etc. After the desiccant dryers, the header splits, supplying compressed air to the conventional plant building instrument air system. A restriction orifice designed to pass 225 SCFM (the capacity of one compressor) is contained in this line. In the event of a line rupture in the secondary plant, one compressor will supply the primary plant while the second compressor will supply the line break until isolation can be accomplished. Included in each line between the compressor and aftercooler are individual temperature controllers TC-1104S and TC-1105S. Each controller will trip its associated compressor on high discharge air temperature.

The aftercooler and compressor cylinder jackets are cooled by the Instrument Air closed cooling water system (Reference 4-11). This system consists of two 20 gpm pumps, two heat exchangers, expansion/replenishment tank and a chemical feed system. Normally, one pump is in service while the other is in standby in case of problems with the first. From the pump, flow proceeds to the closed cooling heat exchanger.

The water exitting the heat exchanger is maintained at a constant temperature by TC-1113 modulating service water valve TCV-1113. After leaving the heat exchanger, flow proceeds to the aftercooler and then to the compressor jacket. Before entering the compressor jacket, the flow is split, with one line continuing to the compressor jacket, and the other line bypassing the compressor.

A manual valve in the bypass line allows regulation of the temperature of the cooling water as it exits the compressor and returns to the circulating pump. On the discharge from each compressor is a temperature controller (TC-1106S, No. 21 and TC-1107S, No. 22) which will trip its respective compressor on high cooling water temperature.

4.1.5.2 Evaluation

A heat balance calculation was performed on the closed cooling heat exchangers using the heat exchanger design specification sheet (Reference 4-8) and heat exchanger performance curves from TEMA (Reference 4-10). This heat balance calculation assumed the same closed cooling water flow rate (18.4 gpm) and heat transfer rate (180,000 BTU/Hr) as on the specification sheet. For conservatism, the service water inlet flow rate was reduced from 72 gpm at 85°F (design basis), to 65 gpm at 95°F. Assuming that heat exchanger performance would not change significantly for this small flow rate change, revised closed cooling water inlet and outlet temperatures and service water outlet temperature were calculated.

A comparison of design basis and revised results follows.

Case	Parameter	Closed Cooling Water	Service Water
Service Water Temp. = 85°F (Design Basis)	Flow Rate	18.4 gpm	72 gpm
	Temp In	114.6°F	85°F
	Temp Out	95°F	90°F
Service Water Temp. = 95°F	Flow Rate	18.4 gpm	65 gpm
	Temp In	125°F	95°F
	Temp Out	105°F	101°F

Based upon the calculations performed, the revised compressor cooling water outlet temperature is predicted to increase about 10°F above the design basis temperature, to approximately 125°F. This is well below the maximum allowable outlet water temperature of 160°F defined by the vendor in Reference 4-9, and is therefore acceptable.

Based on the prediction of a 10°F increase in cooling water temperature, it is reasonable to also predict a similar increase in compressor discharge air temperature. Due to a lack of operating data, it is not possible to explicitly evaluate the impact of increased discharge air temperature. However, as stated previously, the discharge air temperature from each compressor is monitored by individual temperature controllers TC-1104S and TC-1105S. These controllers will trip the associated compressor on high discharge air temperature, thus protecting the compressors and other air handling components from damage due to high discharge air temperature.

4.1.5.3 Impact and Conclusions

Based upon the results of the reviews and evaluations documented above, it can be concluded that the instrument air system will function as designed when operated with a SWS temperature of 95°F.

4.1.6 Component Cooling Heat Exchangers

The primary function of the CCW heat exchangers is to transfer waste heat from components serviced by component cooling during all modes of plant operation. The heat exchangers are a shell and tube counter flow design with SWS flow supplied on the tube-side. The design SWS flow was selected based on an ACS optimization study of heat removal loads, raw water inlet temperature, and equipment costs. This flow corresponds to 4,550,000 lb/hr (approximately 9100 gpm). The design temperature and pressure of the CCW heat exchanger tube-side are 200°F and 150 psig, respectively.

The highest SWS temperatures would occur during the post-LOCA conditions when CCW temperatures are maximized. As calculated in Section 3.1, the highest CCW return temperature is approximately 163°F.

Since the heat exchanger tube-side outlet temperature would be lower than this value, it can be concluded that the design temperature (200°F) of the heat exchanger would not be exceeded, and structural integrity will be maintained. In addition, as long as CCW flow to the heat exchanger is maintained below the design value in Table 4-6, excess tube vibration will not be a concern.

The thermal performance of the heat exchanger has been shown to be adequate at 95°F (*see* Section 3.1).

4.2 EQUIPMENT COOLED BY THE CCWS

As a result of the CCWS evaluations which are discussed in Section 3.1, calculated maximum CCW supply temperatures were calculated for both Power Operation and post-LOCA recirculation. As discussed in Section 3.1, Con Ed will adjust component flows as necessary to ensure sufficient cooling to system users. Provided in this section are component limits for both flow and temperature.

4.2.1 Mechanical Integrity Evaluation

The mechanical integrity of the various coolers and heat exchangers must be assured to prevent cooler failure and subsequent leakage from the CCWS. This structural integrity is based on, (1) maximum flow rates through the coolers and heat exchangers remaining below acceptable limits that are based on tube vibration and tube erosion criteria, and (2) CCW temperatures remaining below design temperature limits that are based on stress criteria.

4.2.1.1 Maximum Flow Limits

Most of the coolers and heat exchangers are of the shell and tube design. Typically, tube side flow is limited by erosion of the tubes, which is a function of the flow velocity and tube material.

Maximum shell side flow is typically limited by flow induced tube vibration limits. The pump and heat exchanger vendors were contacted and provided the information necessary to calculate the maximum allowable tube side flow rates for the coolers where design limits were not already available.

In the case of the SI and RHR pumps, the mechanical seal jacket coolers are not heat exchangers in the traditional sense but are simply cavities in the pump casing which to some extent surround the stuffing box area. Since there are no erosion or vibration concerns with this design, specified maximum flow limits were not defined for these coolers.

In the case of the excess letdown heat exchanger, shell-side flows greater than design were evaluated in support of the Indian Point Unit 3 Ultimate Heat Sink Temperature Revision project. The results from this evaluation are applicable to Indian Point Unit 2 since the equipment is identical. The acceptability of a higher design flow was determined based on a review of the heat exchanger internal geometry to obtain the flow velocities associated with the maximum flow rates.

These velocities were used with tube outside diameter and tube natural frequency to calculate the minimum value of the dimensionless quantity fd/V, which was then compared to allowable limits. Based on the results, neither heat exchanger should be subject to excessive tube vibration when exposed to the maximum analyzed flow.

Provided in Table 4-6 are the maximum allowable design flow limits for CCWS users. In any shell and tube heat exchanger, excessive shell side flow can lead to high tube vibrations and eventual failure. In order to ensure the structural integrity of the various heat exchanger and coolers, flows should be kept at or below the maximum flows as defined in Table 4-6.

4.2.1.2 Maximum Temperature Limits

The maximum CCW supply temperatures for normal and post-LOCA operation were determined in Section 3.0. These maximum temperatures were then compared to the maximum allowable design temperatures for the various equipment.

The comparison of maximum versus design temperatures is given in Table 4-7. As the table shows, with the exception of the RHR heat exchanger, none of the maximum temperatures evaluated herein exceed the design temperatures of the tabulated equipment. The acceptability of temperatures greater than design is addressed in Section 3.1.2.2.

In conclusion, the equipment listed in Tables 4-6 and 4-7 have been shown to be adequate, in terms of mechanical integrity, for normal and post-LOCA modes of plant operation.

4.2.2 Thermal Performance Evaluation

The CCWS provides cooling to interfacing ACS heat exchangers, process coolers, and to various mechanical equipment coolers. As such, acceptable CCWS thermal performance is based on (1) supporting RHR and SFPCS functions, (2) supporting process cooling functions, and (3) supporting mechanical equipment operability. This section defines minimum thermal performance requirements for the equipment cooled by the CCWS. Note, thermal performance of the ACS has been evaluated in Section 3.0.

4.2.2.1 SI Recirculation Pump Motors

The SI Recirculation pumps need to operate only during LOCAs. As such, the thermal evaluation only covers CCW cooling capability during the post-LOCA injection and recirculation phases.

The SI recirculation pump motors are totally enclosed water to air cooled motors. The motor exhaust air is cooled by heat exchangers and recirculated to the motor air intakes in an enclosed system.

The increased CCW supply temperature will result in increased stator winding and bearing temperatures. These motors were originally qualified by Reference 4-12 for a containment ambient temperature of 324°F. This qualification demonstrated that the stator winding and bearing temperatures were well within acceptable limits with the ambient temperature of 324°F and various component cooling water temperatures. Maximum predicted containment temperature for Indian Point Unit 2 is 271°F (Reference 4-19), which is less than 324°F and is therefore acceptable for this component.

Based on the results from Reference 4-12, with cooling water temperatures of 134°F peak and 124°F steady state, at a flow rate of 40 gpm, the stator winding temperatures are expected to remain within the maximum allowable temperature limit for Class F insulation systems. Thus no abnormal insulation degradation is expected to occur and there will be no reduction of the motor qualified life. The motor bearing temperatures are predominantly dependent upon the ambient temperature and not the component cooling water temperature.

The test results for the ambient temperature of 324°F are bounding for the actual ambient temperature in conjunction with the increased component cooling water temperature. Therefore, the recirculation pump motors will remain operable for the component cooling water temperatures experienced during the post-LOCA recirculation phase.

4.2.2.2 Safety Injection Pumps

The SI pumps operate during the injection and recirculation phases following a LOCA. During the injection phase the SI pumps take suction from the RWST and inject this coolant into the RCS cold legs. With a Blackout event, the CCW pumps are not running, but auxiliary component cooling pumps, driven off the SI pump shafts, circulate CCW through the SI pump coolers. Since the SI pumped fluid during injection is cool water from the RWST, the cooling requirements during injection are not as severe as during the recirculation phase.

As discussed in Sections 3.1.1.4.2 and 3.1.1.4.3, at least 4.5 gpm of CCW flow is provided to each of the SI pump coolers post-LOCA. The CCW temperature slowly increases during the injection phase as no CCW heat is rejected to the SWS during this mode (the CCW and SWS nonessential pumps are not operating). If required during the ECCS recirculation phase, the containment recirculation pumps deliver flow to the suction nozzles of the SI pumps, which assures that the NPSH requirements of the SI pumps are met. The recirculation pumps draw recirculated core coolant from the containment sump.

The SI pumps each contain two mechanical seal coolers, two mechanical seal jacket coolers and a lube oil cooler which are serviced by component cooling water through a common header. The mechanical seal coolers are intended to maintain temperatures in the mechanical seal chambers within limits that will prevent abnormal seal wear. The lube oil cooler is required to maintain the oil temperature at a level which will provide adequate lubrication to the bearings and prevent accelerated viscosity breakdown.

The SI pumps were originally provided with John Crane mechanical seals, which are qualified for operation at temperatures of up to 300°F. The mechanical seals are cooled by component cooling water which flows through the pump seal coolers. Seal chamber fluid is pumped by a pumping ring through the mechanical seal coolers and returned to the seal chambers. Mechanical seals are installed on both ends of the pump shaft and each seal has its own mechanical seal cooler.

The seal chamber temperature is influenced by the pump suction temperature due to migration of the pumped fluid into the seal chamber. The maximum pump suction temperature will correspond to the containment sump temperature, which is 250°F at the beginning of the recirculation phase (Table 3-1), reducing with time. The effect of elevated temperatures on the seal would be an increase in seal wear and a reduction in seal life.

Tests performed by the seal manufacturer (John Crane) with 300°F seal cavity temperatures and no seal cooling resulted in only minor wear to the seals. The seal temperature conditions posed here are much less severe, especially since there will be cooling of the seal cavity from the seal coolers. Consequently, it was determined that the post-LOCA recirculation conditions will have little effect in reducing seal life expectancy, compared to operation with 85°F SWS temperature. Lastly, both of these seals are furnished with a safety bushing which, in the event of catastrophic failure to the primary seal, will limit leakage from the seal to maintain the operability of the HHSI pump. Replacement seals provided by vendors other than John Crane may be used for this application provided that the seals are properly qualified for the applicable design conditions.

The safety injection pumps utilize a pressurized lubrication system which provides oil to the two shaft journal bearings and a thrust bearing. The hot oil leaving the bearings is drained to a 3 gallon reservoir. This reservoir is the source of oil for the lube oil pump which supplies oil through the lube oil cooler to the pump bearings. The oil recommended by the vendor for use in these pumps has a nominal viscosity rating of 150 SSU at 100°F. Increased component cooling water temperature will result in increased oil temperatures at both the inlet and outlet of the pump bearings.

From Section 3.1.2.5, the CCW supply temperature to the SI pump coolers during post-LOCA injection will increase from 110°F to 138°F in four hours. Following initiation of forced cooling, the CCW supply temperature would drop to the steady-state recirculation maximum temperature of 134°F within one hour. As discussed in Section 3.1.1.4.3, the CCW supply temperature would then decrease to 125.5°F after 24 hr and to 124°F after 216 hr (9 days). The flow rate to each of the coolers will be at least 4.5 gpm for this mode of operation. Based upon the results of a thermal evaluation of the lube oil system, it has been determined that the SI pumps will operate satisfactorily under these conditions.

4.2.2.3 Residual Heat Removal Pumps

The RHR pumps operate during the second phase of plant cooldown and during LOCA injection phase. In addition, the RHR pumps provide a backup to the recirculation pumps during post-LOCA ECCS resurrection.

The RHR pump is equipped with a shell and tube mechanical seal cooler as well as a jacket cooler, similar to that used on the HHSI pump, which are serviced by CCW. The mechanical seal coolers are intended to maintain temperature in the mechanical seal chamber within limits that will prevent abnormal seal wear.

The mechanical seals originally specified for use in the RHR pumps are manufactured by John Crane and are very similar in design to the HHSI pump mechanical seals. The RHR pump mechanical seals will be subjected to a peak post-LOCA pump suction temperature of 250°F, reducing with time, and a peak CCW temperature of 134°F, also reducing with time. Thus the test performed by John Crane which qualified the seal for 300°F seal chamber temperatures with no seal cooling bounds the RHR pump mechanical seal operating conditions, post-LOCA. Replacement seals provided by vendors other than John Crane may be used for this application provided that the seals are properly qualified for the applicable design conditions.

For Appendix R cooldown operation, the CCW temperature can go as high as 125°F, which is 5°F higher than for normal cooldown. Also, during

Appendix R cooldown, the pump suction temperature remains above 300°F (mechanical seal design temperature) for less than a day longer than during normal cooldown. These conditions are not considered to be severe enough to cause significant degradation of the mechanical seals, compared to the original design basis.

Therefore, it is concluded that the CCW cooling water temperatures during post-LOCA recirculation and Appendix R cooldown will have an insignificant effect on the mechanical seal life, compared to design basis operation.

4.2.2.4 Charging Pumps

The charging pumps provide RCS makeup and RCP seal injection during non-accident operations. In addition, the charging pumps provide RCP seal injection during plant cooldown following postulated plant fires.

The charging pumps use CCW for both the Gyrol drive oil cooler and the pump lube oil cooler. An adequate cooling water supply is needed to prevent the oil temperatures in the Gyrol drive and pump power frame from increasing to the point of oil breakdown and subsequent bearing failure.

CCW flow to both the Gyrol drive and lube oil coolers is through the tube side of each cooler. Consequently, the maximum allowable flow to each cooler is determined by tube erosion limits. These flow limits, which are tabulated in Table 4-6, must not be exceeded.

In order to ensure adequate cooling of the Gyrol oil, the vendor recommended cooling water flow is 85 gpm at 125°F. From Section 3.2, the maximum CCW temperature for normal operation is 118°F, which is therefore acceptable as long as approximately 85 gpm is provided to the Gyrol cooler. Since the CCW temperature is allowed to increase to 125°F during Appendix R cooldown, at least 85 gpm of CCW flow must be insured during this mode of operation. The vendor recommended cooling water flow to the lube oil cooler is 4.0 gpm at 125°F. As long as this limit is met, the power frame lube oil will be adequately cooled during pump operation.

4.2.2.5 Reactor Coolant Pumps

Cooling water is provided to three separate component coolers. These are the pump thermal barrier and the motor upper and lower bearing cooler. As part of this project, cooling requirements and recommendations were obtained from the pump vendor. In the case of the motor bearing coolers, the cooler vendor was contacted to obtain cooling data. Provided below is a discussion of the cooling requirements for each of the three RCP coolers.

4.2.2.5.1 Thermal Barrier Cooler

Thermal barrier cooling provides a redundant backup to seal injection. In the event of a loss of seal cooling, thermal barrier cooling provides cooling to RCS fluid which would leak through the No. 1 seal.

The design basis cooling water requirement as a function of CCW supply temperature was obtained from the pump vendor. Provided below are the minimum cooling water flow as a function of CCW supply temperature:

CCW Supply Temp. (F)	Minimum Flow (gpm)
70	13
80	16
90	19
100	23
110	29
120	45

To ensure adequate cooling, flows greater than or equal to the above limits are required.

4.2.2.5.2 Motor Lower Bearing Cooler

Cooling water to the RCP motor lower bearing cooler is provided to maintain the lower bearing temperature within design limits. Oil is used to transfer heat from the bearing to the CCW fluid. For CCW supply temperatures between 70°F and 105°F, the recommended flow range is 5 gpm to 8 gpm. For supply temperatures higher than 105°F, but less than 120°F, the recommended flow range is 7 gpm to 8 gpm. CCW supply temperatures greater than 120°F are not recommended.

4.2.2.5.3 Motor Upper Bearing Cooler

Cooling water to the RCP motor upper bearing is provided via a cooler to maintain the upper bearing temperature within design limits. Oil is used to transfer heat from the bearing to the CCW fluid. For CCW supply temperatures between 70° and 105°F, the recommended flow range is 150 gpm to 219 gpm.

For supply temperatures higher than 105°F, but less than 110°F, the recommended flow range is 200 gpm to 219 gpm. CCW supply temperatures greater than 110°F are not recommended for continuous service. Fouling on the oil side of the cooler may occur at temperatures greater than 110°F. A RCP upper bearing alarm is provided in the central control room to alert of inadequate cooling to the upper bearing.

4.2.2.6 Reactor Vessel Support Cooling Blocks

The reactor vessel has supports located at alternate nozzles. The nozzle blocks are cooled by CCW to prevent the supporting concrete from overheating.

The design basis calculation determined the required CCW flow to each support which would ensure that the concrete temperature (underneath the support block) will stay at or below 150°F. This calculation considered a CCW supply temperature of 91°F and a RCS hot leg temperature of 596°F. Based on the results, three gpm was determined to be the required cooling water flow rate.

In support of this project, the design basis calculation was revised to determine the minimum CCW flow required with a maximum CCW supply temperature of 120°F and maximum Stretch Rating RCS hot leg temperature of 611.7^{o}F (Reference 4-13). At these conditions, approximately five gpm is required.

For Power Operationm, cooling water flow to each nozzle block has been calculated to be in the range of 5 to 7 gpm. As such, adequate cooling should be provided to the nozzle block coolers if the throttle valves are left in a "wide open" position. Excessive flow concerns are not an issue with the valves in a "wide-open" position due to the high resistance of the cooler design.

4.2.2.7 Sample Heat Exchangers

The CCWS provides cooling to the following sample heat exchangers:

- Pressurizer Liquid and Vapor
- Reactor Coolant
- Steam Generator Blowdown

The heat exchangers process high-pressure, high-temperature samples that are cooled to minimize the generation of radioactive aerosols. Process flow are cooled as they pass through the tube side of the coolers while CCW flows through the shell side.

Sampling capability is required during normal and post-accident operations. Sampling during post-LOCA operation, however, will be performed from the ECCS recirculation flow path, which does not require cooling. Therefore, CCWS sample cooling is only required during normal and abnormal modes of operation.

The design process conditions were specified as a shell-side flow of 14 gpm at inlet and outlet temperatures of 95°F and 125°F, respectively. Tube-side conditions are based on approximately 0.5 gpm sample flow and inlet and outlet temperatures of 653°F and 127°F, respectively (Reference 4-15). The tube-side inlet temperature is based on the saturation temperature of the pressurizer fluid at a pressure of 2250 psia. The tube-side outlet temperature is based on the normal operating temperature of the volume control tank (VCT) and coolant discharge to the Waste Disposal System.

In general, higher CCW supply temperatures will result in higher sample outlet temperatures with all other parameters held constant. At CCW supply temperatures greater than 95°F, additional cooling may be needed to maintain sample temperatures to present values. Sample outlet temperatures 10°F to 20°F higher returned to the VCT during power operation are evaluated to be acceptable since sample flow rates are very small (< 1 gpm) compared to the normal flow through the VCT with a charging pump in service (87 gpm).

4.2.2.8 Waste Gas Compressors

The waste gas compressor does not perform any safety-related functions post-accident. Its operability only during normal operations is therefore evaluated.

The waste gas compressor uses CCW to cool seal water which provides cooling of the mechanical seal and acts as a liquid compressant in the compressor. The waste gas compressor, by design, requires a nominal cooling water flow of 25 gpm at 105°F. For Indian Point 2, the maximum CCW temperature during normal operation is 110°F, which is limited by RCP operation. The maximum sustained CCW temperature is 105°F.

The mechanical seal is a John Crane Type 9 seal which can operate with normal temperatures as high as 175°F. The normal operating temperature range of the compressor seal water is 70° - 130°F. Since the maximum CCW temperature will exceed the design basis temperature by only 5°F, and for limited periods of time, it is clear that the normal operating temperature of the seal will not be exceeded. Therefore, the higher CCW temperature will have no effect on the mechanical seal operation or life expectancy.

The seal water which is injected into the compressor acts as the liquid compressant which forces the waste gas through the compressor discharge nozzle. The seal water at higher temperatures becomes more compressible and, therefore, is less capable of forcing the waste gas out of the compressor.

This will result in decreased performance of the compressor. However, the increased seal water temperature will have no detrimental mechanical effect on the compressor unit.

Thus, the waste gas compressors will operate satisfactorily, with slightly reduced performance, when supplied with 110°F CCW. The reduction in compressor performance due to the increased cooling water temperature would actually be offset to some extent by any increase in cooling water flow rate above the design flow.

4.2.2.9 Non-Regenerative Heat Exchanger

The CVCS non-regenerative heat exchanger is used to cool reactor coolant to approximately 130°F prior to purification through the CVCS demineralizers. Following purification, the reactor coolant is normally returned to the VCT where it is pumped back to the RCS via a charging pump. Process fluid flows through the tube-side and CCW flows through the shell-side. The design shell and tube flows of the non-regenerative heat exchanger are 494,000 lb/hr (approximately 987 gpm) and 59,280 lb/hr, respectively. The tube flow represents a "maximum" letdown flow of approximately 120 gpm. The design CCW inlet temperature is 105°F and the design CVCS outlet temperature is 127°F.

Cooling water flow to the non-regenerative heat exchanger is automatically controlled via TCV-130 to maintain the tube outlet temperature to approximately 127°F. A local indicator (TI-149) is available to monitor heat exchanger process outlet temperature. Automatic isolation of the letdown flow is also provided (TIC-149) to prevent high-temperature fluid from being delivered to the CVCS demineralizers.

With CCW supply temperatures greater than 105°F or reduced heat exchanger performance (fouling, tube plugging, etc.), process temperature will increase. At elevated CCW supply temperatures, letdown flow could be manually reduced to reduce cooling requirements of the CCWS. Reduction in process flow will result in reduced CCWS supply temperature and would allow for CCW flow to be diverted to other system users, as needed.

4.2.2.10 Excess Letdown Heat Exchanger

The CVCS excess letdown heat exchanger is provided as a backup letdown flowpath in the event the normal letdown flowpath (via the regenerative and non-regenerative heat exchangers) is not available. The heat exchanger can also be used during plant startup to remove RCS fluid due to thermal expansion. Tube-side flow is directed to the VCT via the seal water heat exchanger. The CVCS process fluid flows through the tube-side of the heat exchanger and CCW flows through the shell-side.

The design shell and tube flows of the excess letdown heat exchanger are 119,000 lb/hr (approximately 238 gpm) and 12,400 lb/hr (approximately 25 gpm), respectively. The design CCW inlet temperature is 95°F; the design CVCS inlet and outlet temperatures are 555°F and 195°F, respectively. A control room alarm is provided (TIA-122) to alert of high excess letdown heat exchanger outlet temperature. With the heat exchanger in service, reactor coolant flow through the excess letdown heat exchanger could be manually reduced, as required, to limit tube-side outlet temperature to below the alarm setpoint.

4.2.2.11 Seal Water Heat Exchanger

The CVCS charging pumps delivers seal water injection to each RCP at a rate of approximately 8 gpm per pump. Of the 8 gpm, approximately 5 gpm are normally injected into the RCS. The remaining 3 gpm flows past the pump radial bearing and the #1 seal and out the #1 seal leakoff line. RCP seal leakoffs are directed to the VCT via the seal water heat exchanger. Note, the excess letdown heat exchanger process flow is also directed through the seal water heat exchanger.

The design shell and tube flows of the seal water heat exchanger are 108,541 lb/hr (approximately 217 gpm) and 126,756 lb/hr (approximately 270 gpm), respectively. The design CCW inlet temperature is 105°F; the design CVCS inlet and outlet temperatures are 144°F and 127°F, respectively. A local indicator (TI-120) is available to monitor heat exchanger process outlet temperature. A control room high temperature alarm is also available (TIA-140) to alert of high fluid temperature in the VCT.

The design tube-side flow is based on the excess letdown heat exchanger design flow plus the maximum design leakage from all four RCP shaft seals. Since the design tube-side flow is very conservative for normal plant operation, the CCW flow to the seal water heat exchanger can be reduced. The process outlet temperature should be maintained at approximately 127°F. Reduction of CCW flow to the seal water heat exchanger allows for flow to be diverted to other system users, as needed.

REFERENCES

4-1 Marlo Coil, Nuclear Cooling Inc., Quote No. U-199-3-85-AH, 3/22/85.

4-2 Nuclear Cooling, Inc., Report No. ER-85-7182.

4-3 "Steady State Performance of Fan Motor Cooling Systems Following a Reactor Incident," Westinghouse Research Report 69-1E9-TABLD-R1, 12/22/69.

4-4 "Temperature Rise and Insulation," Machine Design - Electric Motors Reference Issue, 3/19/64.

4-5 Alco Power Emergency Diesel Generator Instruction Manual TPI-899.

4-6 UE&C Calculation Set 6604.003-8-SW-097, Rev. 0.

4-7 UE&C Letter File: A-5.003, A-4.2, "New York Power Authority, Indian Point 3 Nuclear Power Plant, Authority Work Authorization WAS-1, Replacement Service Water Pump - Diesel Generator Jacket Water/Lube Oil Cooler Performances with Tube Plugging" dated May 12, 1989.

4-8 UE&C Heat Exchanger Specification Sheet for the Instrument Air Compressor Cooling Water System, Job No. 9321-01, Inquiry No. 525-2, Rev. 1, 12/20/67.

4-9 Vendor Manual (Con Ed Index No. 2319 1.1), Instructions for Operation and Maintenance of Worthington Type HBB Instrument Air Compressor, Manual No. 3610-E1-0 including Manual 3612-E1-V1.

4-10 Standards of Tubular Exchanger Manufacturers Association, Sixth Edition, 1978.

4-11 Con Ed Dwg. 9321-F-2722-49, 11/29/88, "Flow Diagram - Service Water System, Nuclear Steam Supply Plant," Sheet 1 of 2.

4-12 Westinghouse Topical Report, WCAP-7829.

4-13 "Consolidated Edison Company of New York, Inc., Indian Point Unit 2, NSSS Stretch Rating - 3083.4 MWt, Engineering Report," Westinghouse Electric Corporation, WCAP-12187, March 1989.

4-14 "NATD Quality Assurance Program", Westinghouse Electric Corporation, WCAP-9565.

4-15 Indian Point Unit 2 Updated Final Safety Analysis Report, Chapter 9.4

4-16 Westinghouse Topical Report WCAP-12237 (Draft), "Containment Integrity Analysis for Indian Point Unit 2."

4-17 Victoreen, Inc., Instruction Manual 4, "Installation, Operation, Maintenance & Calibration of the Digital Radiation Monitoring System."

TABLE 4-1

ACCIDENT-REQUIRED EQUIPMENT COOLED BY THE SERVICE WATER SYSTEM

- Reactor Containment Fan Cooler Units (RCFCs)
- RCFC Fan Motor Coolers
- RCFC Service Water Return Radiation Monitor
- Instrument Air Compressor Closed Cooling System
- Emergency Diesel Generator Cooling Services
- Component Cooling Water Heat Exchangers

TABLE 4-2

EQUIPMENT COOLED BY THE COMPONENT COOLING WATER SYSTEM

Accident-Required Loads

- Residual Heat Exchangers
- Residual Heat Removal Pumps
- Safety Injection Pumps
- Recirculation Pumps

Accident Non-Required Loads

- RCP Thermal Barriers
- RCP Cooler Header
- Letdown Heat Exchanger
- Excess Letdown Heat Exchanger
- Seal Water Heat Exchanger
- Sample Heat Exchangers
- Spent Fuel Pit Heat Exchanger
- Charging Pump Gyrol Coolers
- Charging Pump Lube Oil Coolers
- Waste Gas Compressors
- Reactor Vessel Support Blocks

TABLE 4-3

REACTOR CONTAINMENT FAN COOLER COOLING COIL DATA

Coil Data

Number of Coil Assemblies		5
Number of Banks/Assembly		2
Number of Coils/Bank		5
Coil Types		Marlo Coil
	(4 of 5 coils/bank)	6Q24-105-5608.5T
	(1 of 5 coils/bank)	6Q20-105-5608.5T
Fin Material		Copper
Tube Material		AL6X-SB676
Fins Per Inch of Tube Length		5.8
Tube Rows/Coil		6
Number of Passes		2
Tube Wall Thickness (in)		0.035
Tube Nominal OD (in)		5/8
Tube Length (in)		105
Fin Thickness (in)		0.008
Fouling Factor (ft^2-hr-^oF/Btu)		0.001
Percent Tubes Plugged (Assumed Margin)		5

Conditions (Normal Operation)

Service Water Flow Rate (gpm)	500 to 2000
Service Water Temperature (^oF)	95
Containment Atmosphere Temperature (^oF)	120/130
Containment Atmosphere Pressure (psig)	0
Containment Atmosphere Density (lb/ft^3)	0.069
Fan Capacity (CFM)	70,000

TABLE 4-4

REACTOR CONTAINMENT FAN COOLER OUTLET WATER TEMPERATURE

(Normal Operation @ 95°F Inlet Water Temperature)

Flow Rate (gpm)	Outlet Water Temp Cntmnt Temp = 120°F (°F)	Outlet Water Temp Cntmnt Temp = 130°F (°F)
500	101.2	103.7
750	99.3	101.0
1000	98.3	99.6
1250	97.7	98.7
1500	97.2	98.1
1750	96.9	97.7
2000	96.7	97.4

TABLE 4-5

REACTOR CONTAINMENT FAN MOTOR COOLER DATA

Coil Data

Number of Motor Cooler Assemblies	5
Number of Coils/Assembly	1
Coil Type	Marlo Coil 8Q16-27-5608.5T
Fin Material	Copper
Tube Material	AL6X
Fins Per Inch of Tube Length	8.5
Tube Rows/Coil	8
Number of Passes	4
Tube Wall Thickness (in)	0.035
Fin Thickness (in)	0.008
Tube Nominal OD (in)	5/8
Tube Length (in)	27
Fouling Factor (ft^2-hr-^oF/Btu)	0.001
Percent Tubes Plugged	0

Conditions

	Normal	Accident
Service Water Flow Rate (gpm)	50	50
Service Water Temperature (^oF)	85/95	95
Containment Atmosphere Pressure (psig)	0	47

TABLE 4-6

CCWS EQUIPMENT MAXIMUM ALLOWABLE FLOW LIMITS

EQUIPMENT NAME	DESIGN FLOW (gpm)
RHR Heat Exchanger	4920
CCW Heat Exchanger	5313
Spent Fuel Pit Heat Exchanger	2796
Seal Water Heat Exchanger	217
Letdown Heat Exchanger	987
Excess Letdown Heat Exchanger	238/289 (1)
Sample Heat Exchanger	40
RV Support Cooling Blocks	14
Reactor Coolant Pump	
Thermal Barrier	75
Lower Bearing Cooler	8
Upper bearing Cooler	219
Charging Pump	
Gyrol Drive Cooler	209
Lube Oil Cooler	39
Safety Injection Pump	
Lube Oil Cooler	13
Seal Cooler	20
Jacket Cooler	N/A
Recirculation Pump	
Motor Cooler	102
RHR Pump	
Seal Cooler	10
Jacket Cooler	N/A
WG Compressor Seal Cooler	95

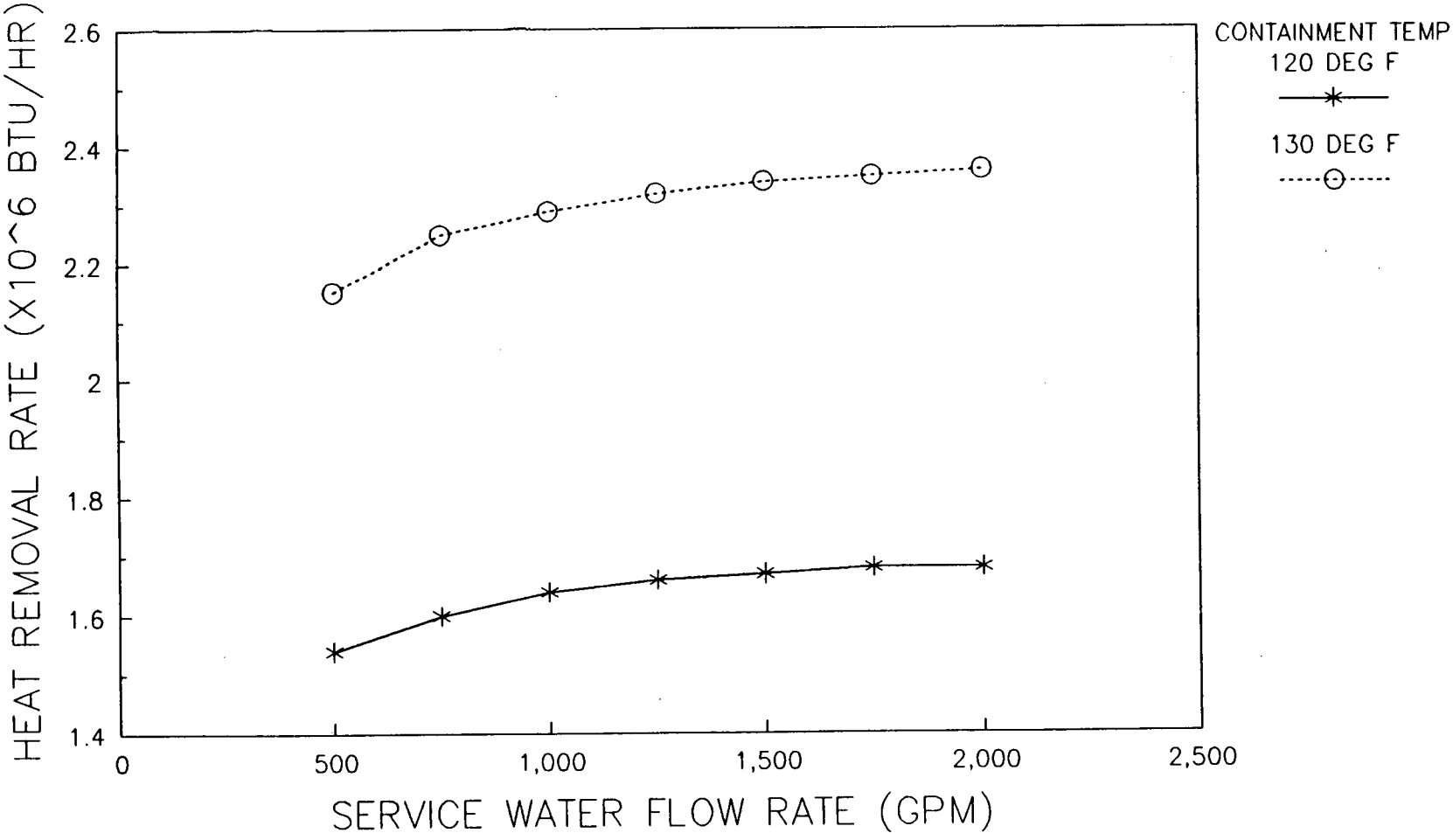
(1) The first value is the original design basis flow rate; the second value is allowable based on detailed component evaluation.

TABLE 4-7

CCWS EQUIPMENT MAXIMUM TEMPERATURE VERSUS DESIGN TEMPERATURE

EQUIPMENT NAME	MAX TEMP (°F)	DESIGN TEMP (°F)
RHR Heat Exchanger	202	200
CCW Heat Exchanger	163	200
Spent Fuel Pit Heat Exchanger	<200	200
Seal Water Heat Exchanger	<200	250
Letdown Heat Exchanger	<200	250
Excess Letdown Heat Exchanger	<200	250
Sample Heat Exchanger	<200	350
RV Support Cooling Blocks	<200	200
Reactor Coolant Pump		
Thermal Barrier	<200	200
Lower Bearing Cooler	<200	200
Upper bearing Cooler	<200	200
Charging Pump		
Gyrol Drive Cooler	<200	300
Lube Oil Cooler	<200	300
Safety Injection Pump		
Lube Oil Cooler	<200	300
Seal Cooler	<200	550
Jacket Cooler	<200	350
Recirculation Pump		
Motor Cooler	<200	200
RHR Pump		
Seal Cooler	<200	350
Jacket Cooler	<200	400
WG Compressor Seal Cooler	<200	300

FIGURE 4-1
INDIAN POINT 2 - RCFC
HEAT REMOVAL RATE FOR NORMAL OPERATION

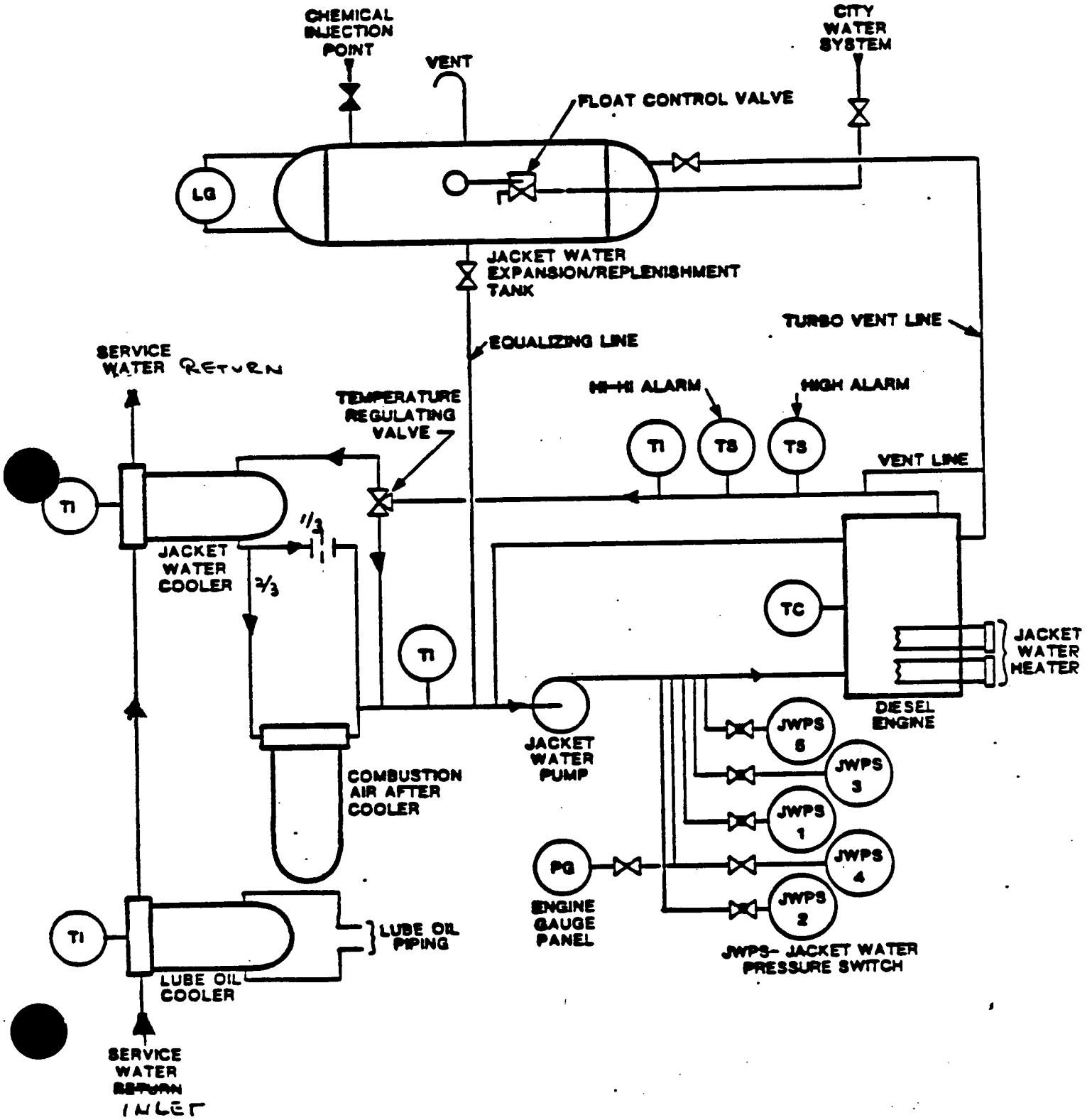


SERVICE WATER INLET
TEMPERATURE = 95 DEG F

TUBE PLUGGING = 5.0%
FOULING FACTOR = .001

FIGURE 4-2

DIESEL ENGINE JACKET WATER SYSTEM



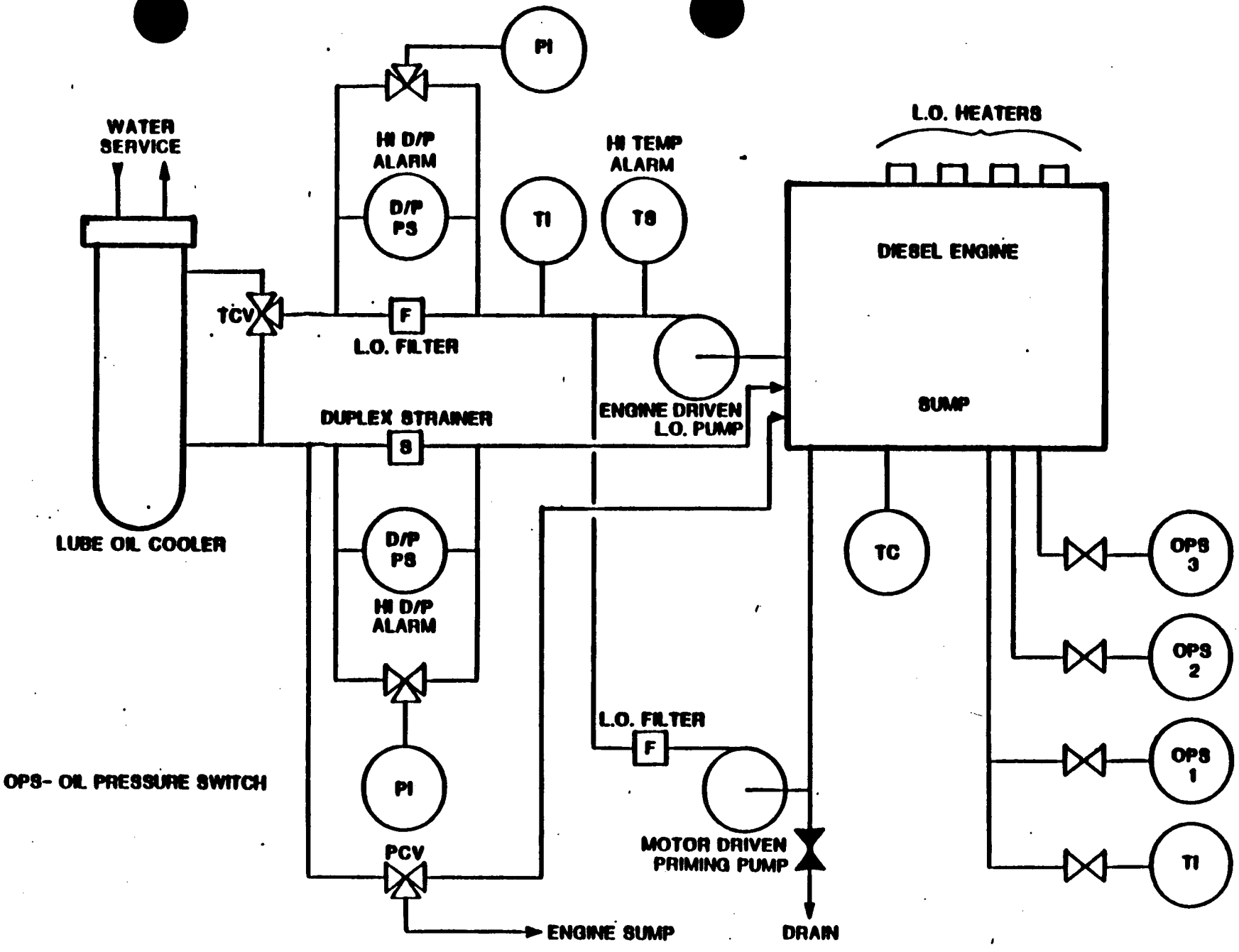


FIGURE 4-3. DIESEL ENGINE LUBE OIL SYSTEM

5.0 LICENSING EVALUATION

5.1 DISCUSSION

The SWS is designed to supply cooling water from the Ultimate Heat Sink (Hudson River) to various heat loads in both the nuclear and balance of plant portions of the station. Provision is made to ensure a continuous flow of cooling water to those systems and components necessary for plant safety during normal operation, or under abnormal and accident conditions.

Adequate service water cooling must be provided to safety-related plant equipment to ensure equipment operability and adequate cooling performance to remove component and decay heat to support safe plant operation, shutdown, and mitigation of postulated design basis accidents.

Normal Operations

Normal, safe plant operation is defined for this evaluation to be the ability to cool equipment whose sudden failure could cause a design basis transient analyzed in FSAR Chapter 14 or whose operability is required to ensure that initial conditions assumed in the accident analyses are not exceeded. This includes cooling the containment atmosphere via the reactor containment fan coolers, cooling the instrument air compressors, and cooling the main boiler feed pump lube oil coolers, and various coolers required for turbine/generator operation. The SWS also provides cooling to the CCWS which in turn cools the following equipment needed for normal, safe plant operations: the spent fuel pit heat exchanger, the reactor coolant pumps, the charging pumps, various sample coolers, and the reactor vessel support cooling blocks. In addition, cooling water from the Hudson River is used to cool the main condenser via the circulating water system (CWS). Condenser vacuum must be maintained to prevent turbine trips on low vacuum.

Abnormal Operations

The SWS and the CCWS provide the required cooling to support plant cooldown via the RHR heat exchangers under abnormal conditions.

The SWS provides cooling to the emergency diesel generators if offsite power is lost.

Postulated Accidents

The SWS and the CCWS provide cooling to safety-related equipment following postulated design basis accidents.

This report addresses the functions described above.

This report does not address the following areas, that are being addressed by Con Ed in their assessment of the proposed technical specification change to increase the allowable Ultimate Heat Sink temperature:

a. The effects of possible increased ambient temperatures (including containment temperatures above 120°F), that may be associated with the meteorological conditions that result in high service water temperatures, on equipment operability or qualified life.

b. The ability of the service water system to provide the flow rates required to support safety functions with 95°F service water temperatures.

c. The ability of the plant to operate with 95°F service water and maintain CCWS cooled equipment, required for safe plant operation, within acceptable operating conditions, and still maintain CCW pump discharge header pressure above the required P(min) value.

d. Possible effects of increased SWS and CCWS temperatures, on piping stress analyses (e.g., increased thermal expansion due to higher process fluid temperatures).

e. The acceptability of increased SWS temperatures relative to environmental restrictions (releasing hotter water back to the Hudson River)

5.1.1 Normal Operations

The cooling functions required during power operation to support safe plant operations are discussed below.

Safe plant operation is defined, for this evaluation, as maintaining the plant in a condition that is consistent with the assumptions for the accident analyses (i.e., containment temperature below limits and the probability of a failure of equipment that could initiate a transient evaluated in FSAR Chapter 14 is not increased).

Cooling required to support normal, safe plant operations is discussed below.

5.1.1.1 Containment Cooling

The SWS provides cooling for the reactor containment fan cooling units which provide cooling to maintain the containment temperature during normal operations. They also provide cooling during post-LOCA conditions. There are five RCFC units in the containment building. Each unit consists of a series of filters for removal of entrained moisture, particles, and radioactive iodine and methyl iodide, two banks of cooling coils, a fan assembly, a motor assembly including an enclosed heat exchanger, an enclosure assembly, and four dampers. During normal operation, air is drawn from the containment building through the normal flow inlet dampers, through the cooling coils, and discharged by the fan into a common distribution header.

As discussed in Section 4.1.1, a conservative evaluation of the containment heat loads verses the heat removal capability of the fan coolers, supplied with 95°F service water, indicates that it may not be possible to maintain the containment temperature below the current limit of 120°F or possibly not even below 130°F. It is expected, however, that significant conservatism in determining the heat removal capability and the heat loads will result in the plant being able to maintain the containment temperature below 130°F. Containment temperature during normal operations is an important initial condition assumed in the containment integrity and post-accident EQ profile analyses. In addition, normal containment temperature is an important consideration in equipment operability and qualified life for equipment located inside containment. Therefore, based on the above evaluation, it is recommended that containment temperature be monitored and appropriate action taken to maintain temperature below licensed limits.

As containment temperature will be monitored and adjusted to remain within limits, increasing the service water temperature to 95°F, will not impact plant safety in this area.

5.1.1.2 Instrument Air Compressor Cooling

The Instrument Air System is designed such that the instrument air shall be available under all operating conditions; all essential systems requiring air during or after an accident shall be self supporting; all controls shall fail to a safe position on loss of power; and, after an accident, the air system shall be re-established.

The primary function of the Instrument Air System is to provide clean, oil and moisture free compressed air to the instruments, controls and other required services in the nuclear plant.

Ambient air is supplied to two motor driven 225 SCFM single stage horizontal compressors. The compressed air exits to an aftercooler (heat

exchanger) and then to a series of moisture separators, dryers, filters, etc. After the desiccant dryers, the header splits, supplying compressed air to the conventional plant building instrument air system. Included in each line between the compressor and aftercooler are individual temperature controllers TC-1104S and TC-1105S. Each controller will trip its associated compressor on high discharge air temperature of 375°F.

The aftercooler and compressor cylinder jackets are cooled by the Instrument Air closed cooling water system. Normally, one pump is in service while the other is in standby in case of problems with the first. From the pump, flow proceeds to the heat exchanger at a temperature of about 120°F.

On the discharge from each compressor is a temperature controller (TC-1106S, No. 21 and TC-1107S, No. 22) which measures cooling water return temperature and at 150°F will shutdown its respective compressor.

The above discussion of the instrument air closed cooling system shows that there is a margin of about 30°F between the normal operating temperature of the compressor cooling water (120°) and the high temperature trip setpoint (150°). Considering this margin, it is clear that a 10° inrease in service water temperature will not cause a 30° increase in closed cooling water temperature. Based upon the calculations performed, the revised compressor cooling water temperature is predicted to be approximately 125°F, which is well within the previously stated limits.

Based upon the information provided by Con Ed and the evaluations performed by Westinghouse, it is expected that the instrument air system will function as designed when operated with a SWS temperature of 95°F.

5.1.1.3 Main Boiler Feed Water Pump Lube Oil Coolers

Two half-size steam-driven main feedwater pumps are provided to increase the pressure of the condensate for delivery through the final stage of

feedwater heating and then through the feedwater regulating valves to the steam generators.

Bearing lubrication for the pumps and their turbine drives is provided by an integral lubricating oil system. Cooling of this lubricating oil system is provided by lube oil coolers that are cooled by the service water system.

The main feedwater pumps do not perform a safety function. Following most postulated accidents, the main feedwater flow is isolated and the steam generator inventory is maintained by the auxiliary feedwater system. The loss of normal (main) feedwater, however, is a design basis transient analyzed in FSAR Chapter 14 (FSAR Section 14.1.9.1). The loss of normal feedwater can be initiated by the failure of piping, valves, or pumps. Thus, adequate lube oil cooling should be provided to support main feedwater operation and prevent sudden pump failure during power operation.

An evaluation of the adequacy of main feedwater pump lube oil cooling is not provided as part of this evaluation, but will be provided as part of the follow-up effort to evaluate non-safety related equipment for operational impacts. Lube oil temperature is monitored in the control room and alarmed on high oil temperature. Thus, if service water cooling is insufficient to maintain lube oil temperature, the operators will be aware of the high oil temperature condition, and action to decrease oil temperature can be taken or the plant can be shutdown before pump failure could occur. Thus, operation with 95°F service water is not expected to increase the probability of a loss of feedwater transient.

5.1.1.4 Turbine/Generator Cooling

Service Water cooling is provided to several components that are required to support operation of the turbine/generator. The sudden failure of the

turbine/generator could lead to a loss of external electrical load transient. The loss of external electrical load transient is analyzed in FSAR Chapter 14.1.8.

SW cooling is supplied to the following equipment that is required to support safe turbine/generator operation:

a. Main turbine oil coolers,
b. Generator hydrogen coolers,
c. Generator stator cooling water coolers, and
d. Generator seal oil coolers

The affect of 95°F service water on the ability of the above equipment to operate without long term damage will be addressed in a separate report. This separate evaluation will be provided to address economic not safety considerations.

The SWS provides cooling to the turbine lube oil coolers. Two coolers are provided but only one is normally in service at a time. The lube oil coolers remove heat from the oil used to cool and lubricate the turbine rotor bearings. Normally, service water flow is modulated to maintain lube oil temperature at 120°F.

SWS provides cooling to the generator hydrogen coolers. The hydrogen cooler's function is to remove heat created in the generator rotor. Service water flow is controlled to maintain hydrogen temperature at 42 $\pm$ 3°C [108 $\pm$ 5°F].

SWS provides cooling to the generator hydrogen seal oil coolers. Two coolers are provided, one for the hydrogen side seal oil flow path and one for the air side seal oil flow path. Service water flow to the coolers is normally modulated to maintain the seal oil outlet temperature at 100°F.

The SWS provides cooling to the generator stator cooling water coolers.

The generator stator cooling is provided to maintain stator temperatures below acceptable limits.

When service water temperature is above 85°F, important equipment process temperature (e.g., turbine lube oil temperature, generator hydrogen temperature, hydrogen seal oil temperature, and stator cooling water temperature) should be monitored. Service water flow rates to the various coolers may need to be increased to maintain acceptable process temperature conditions.

As important turbine/generator parameters will be monitored during operations at high service water temperatures, and actions can be taken to increase service water flow to various coolers if required, operation with 95°F service water is not expected to increase the probability of a loss of load transient.

5.1.1.5 CCW Heat Exchanger Cooling

The SWS non-essential header cools the CCWS via the CCW heat exchangers. The CCWS in turn cools other plant equipment required for safe plant operations including the spent fuel pit heat exchangers, reactor coolant pumps, charging pumps, sample coolers, and the reactor vessel support cooling blocks. The various aspects of safe CCWS operation are addressed below.

Safe CCWS operation is defined, for this evaluation, to be the ability to maintain CCWS structural integrity (i.e, system temperatures below design limits and system flow rates below maximum limits), to support CCWS pump operability (i.e., CCW pump operation within NPSH and runout limits), and to provide adequate cooling to system users to support cooled equipment operation as required for safe plant operations.

Indian Point Unit 2 will operate the CCWS in a manner that will ensure

that post-accident safety functions can be supported, yet have available, some flexibility to adjust flows to various equipment required for power operations. This is accomplished, relative to the CCWS configuration, by specifying a minimum acceptable CCW pump discharge header pressure (P(min)) that will ensure that post-accident safety functions can be supported. P(min) is established based on preventing CCW pump runout in the post-accident alignment as well as ensuring adequate CCW flow through the RHR heat exchangers to support adequate post-LOCA ECCS recirculation cooling. Within this P(min) limit, CCW flow can be adjusted to system users to maintain adequate cooling to support safe plant operations.

As many of the CCWS flow paths can be adjusted during normal operations, and are not isolated or adjusted following an accident, the manner in which the CCWS is operated during normal operations must address CCWS operability concerns not only during normal operations, but must also support system operability in the post-accident alignments.

The following evaluation, therefore, addresses the structural integrity and CCW pump operability aspects of CCWS operation during normal and post-accident operation. In addition, the CCWS cooling functions during normal operations are addressed. The CCWS cooling functions during post-accident operation are addressed in Section 5.1.3.5.

5.1.1.5.1 CCWS Structural Integrity

CCWS structural integrity is based on maintaining CCW temperatures below acceptable limits, and maintaining CCW flow rates below acceptable maximum limits.

The design temperature of the CCWS is 200 ^{o}F, except for portions of the system located downstream of the cooling water piping to the RCP thermal barriers, which were designed based on the RCS design temperature of 650°F. This is well above the CCW temperatures that must be maintained to support system cooling functions. As such, structural integrity will

not be jeopardized, during normal operations, due to CCW temperature.

To address higher system temperatures as a result of elevated SWS temperature, component flows will likely be increased in order to ensure adequate equipment cooling. As component flows are increased, the fluid velocity of the cooling water in the system piping will also increase. In order to maintain CCWS structural integrity, maximum flow rates must be limited to prevent structural failure due to erosion in piping, and flow induced tube vibration in the heat exchangers and coolers.

In general, the carbon steel CCWS piping was sized to maintain fluid velocities at or below 15 feet per second. This velocity limit was selected to ensure that system piping would not be the limiting hydraulic resistance of the network. With this approach, component throttle valves could be used to established required system flows. The velocity limit combined with the material selection ensure adequate erosion protection.

A review of the piping design basis was performed to determine potential areas where fluid velocities could exceed 15 feet per second. The results of this review, presented in Section 3.1.2.3, identified two potential problem areas. These are the following:

- The 8 inch supply and return piping to the SFP heat exchanger
- The 10 inch piping at the CCW pump discharge

High flow rates to the SFP heat exchanger could occur during refueling/core unload operations when maximum cooling is needed. High flow rates at the pump discharge piping could occur during both Power Operation and post-LOCA recirculation when only one CCW pump is in service as well as plant cooldown/refueling when two CCW pumps are operating.

The potential concern for higher fluid velocity in these locations is pipe erosion. Over the last five years, significant progress has been made in

the area of pipe erosion technology and the ability to predict potential erosion locations. Since layout is also a critical parameter, provided in Section 6 is a recommendation that the plant monitor these sections of piping for potential thinning and erosion.

The mechanical integrity of the various coolers and heat exchangers must be assured to prevent cooler failure and subsequent leakage from the CCWS. This structural integrity is based on (1) maximum flow rates through the coolers and heat exchangers remaining below acceptable limits that are based on tube vibration and tube errosion criteria, and (2) CCW temperatures remaining below design temperature limits that are based on stress criteria.

Most of the coolers and heat exchangers are of the shell and tube design. Typically, tube side flow is limited by erosion of the tubes, which is a function of the flow velocity and tube material. Maximum shell side flow is typically limited by flow induced tube vibration limits. Because the station has the flexibility to adjust CCW flow rates to the various users, within P(min) limits, and higher CCW temperatures may required increased cooling flow rates, the potential exists to increase CCW flow rates above the original design limits. The maximum recommended flow rates for the various users are listed in Table 4-6.

The design temperatures for all of the CCWS cooled equipment is greater than or equal 200°F. This is well above the CCWS temperatures that must be maintained during normal operations to support CCW cooling functions. Therefore, cooled equipment structural integrity is not jeopardized due to CCWS temperatures exceeding design temperatures.

5.1.1.5.2 CCW Pump Operability

CCW pump operability is based on maintaining pump flow rate below runout and providing adequate NPSH. The most limiting condition for pump

operation will be during post-LOCA recirculation operations when only one pump may be operating, CCW temperatures are highest, and CCW system resistance is at a minimum. CCW system resistance is at a minimum during post-LOCA recirculation, because the RHR heat exchanger shells are aligned for CCW cooling. Even though some other flow paths are isolated (i.e., the RCPs and the RV support cooling blocks), the RHR heat exchangers provide a significant flow path, requiring the RHR HX throttle valves to be throttled to prevent pump runout.

Maximum allowable pump flow rate has been established to be 5500 gpm based on NPSH and pump motor criteria. The minimum allowable CCW system resistance during post-LOCA recirculation was established to prevent the strongest CCW pump from exceeding runout. The CCW system resistance is set by limiting RHR HX throttle valve positions and by establishing minimum resistance limits on the other CCW flow paths, that are not isolated post-LOCA. The minimum allowed system resistance through the other flow paths is established by defining a minimum allowable CCW pump discharge pressure, P(min). As long as system pressure remains above P(min), CCW system resistance will remain above the minimum allowable resistance. The method used to establish P(min) is discussed in Section 3.1.1.2

Pump operability during normal operations and during post-accident operations will be ensured as long as the P(min) criteria is met.

Within this P(min) restriction, the flow rates to system users can be adjusted to support cooling required to support safe plant operations. The cooling requirements that must be met to support safe plant operations, during normal operations, is discussed below.

5.1.1.5.2 Spent Fuel Pit Cooling

CCW cooling is provided to the shell-side of the SFP heat exchanger in order to remove decay heat generated by spent fuel assemblies in storage. Normally, approximately one third of the fuel assemblies are placed in the SFP each refueling. Upon return to power operation, the SFP would contain the recent one-third core discharge along with previous discharge fuel. Since the SFP heat exchanger is cooled by the CCWS, the SFP temperature is dependent on the CCW flow to the SFP heat exchanger, the heat rejection capability of the system, and the amount of heat generated by the various spent fuel assemblies. The SFP decay heat load decreases with time due to radioactive decay. The design temperature of the SFP cooling system is 200 ^{o}F. The temperature of the SFP is normally kept well below this limit by adjusting CCW flow rate to the SFP HX. The evaluation presented in Section 3.3 indicates the expected SFP temperature as a function of CCW temperature, CCW flow rate, and SFP heat load. CCW flow rate can be adjusted as necessary, with the P(min) restrictions, to maintain SFP temperature.

5.1.1.5.3 Reactor Coolant Pump Cooling

The CCW provides cooling to the RCP thermal barriers and the upper and lower bearing lube oil coolers.

The loss of reactor coolant flow is analyzed in FSAR Chapter 14.1.6. Loss of reactor coolant flow may result from a mechanical or electrical failure in one or more RCPs. In addition, the sudden seizure of a reactor coolant pump rotor is analyzed in FSAR Chapter 14.1.6.5. Although it is highly unlikely that reduced cooling to the RCPs would results in the sudden failure of one or more pumps, adequate cooling should be provided to the RCPs.

The RCP thermal barriers cool the controlled seal leakage to prevent the seals from exceeding design temperatures. The thermal barriers provide backup to seal injection, provided by the charging pumps, which is the

normal means of cooling the seals. The required CCW flow rates required to provide adequate thermal barrier cooling, as a function of CCW temperature are provided in Section 4.2.2.5.1.

Cooling water to the RCP motor lower bearing cooler is provided to maintain the lower bearing temperature within design limits. Oil is used to transfer heat from the bearing to the CCW fluid. For CCW supply temperatures between 70 and 105°F, the recommended flow range is 5 to 8 gpm. For supply temperatures higher than 105°F, but less than 120°F, the recommended flow range is 7 to 8 gpm. CCW supply temperatures greater than 120°F are not recommended.

Cooling water to the RCP motor upper bearing is provided via a cooler to maintain the upper bearing temperature within design limits. Oil is used to transfer heat from the bearing to the CCW fluid. For CCW supply temperatures between 70 and 105 ^{o}F, the recommended flow range is 150 to 219 gpm. For supply temperatures higher than 105°F, but less than 110°F, the recommended flow range is 200 to 219 gpm. CCW supply temperatures greater than 110°F are not recommended for continuous service. Fouling on the oil side of the cooler may occur at temperatures greater than 110°F. A RCP upper bearing alarm is provided in the central control room to alert of inadequate cooling to the upper bearing.

CCW flow rates to the RCPs should be adjusted, if required (and within P(min) restrictions), to provide adequate cooling to the RCP lube oil coolers. However, RCP lube oil temperature is indicated in the control room and alarmed on high temperature. Thus, an inadequate cooling situation would be detected and corrected, or the plant would be shut down. As discussed in FSAR Chapter 4.2.2.4, a complete loss of bearing lubrication will not cause a sudden seizure of the reactor coolant pump. Therefore, increasing the service water temperature to 95°F is not expected to increase the probability of a loss of reactor coolant flow transient.

5.1.1.5.4 Charging Pump Cooling

The positive displacement charging pumps are not used to mitigate design basis accidents but are used during plant operations to provide CVCS charging functions. These include providing seal injection to the RCPs, controlling reactor coolant chemistry, inventory, and boron concentration.

CCW cooling is provided to the charging pump Gyrol drive coolers and the lube oil coolers. An adequate cooling water supply is needed to prevent the oil temperatures in the Gyrol drive and pump power frame from increasing to the point of oil breakdown and subsequent bearing failure.

CCW flow to both the Gyrol drive and lube oil coolers is through the tube side of each cooler.

In order to ensure adequate cooling of the Gyrol oil, the vendor recommended cooling water flow is 85 gpm at 125°F. The maximum recommended CCW temperature during normal operations is 110°F, which is based on RCP cooling requirements. Therefore, 85 gpm of CCW should be adequate to cool the Gyrol drive during normal operations. Since the CCW temperature is allowed to increase to 125°F during Appendix R cooldown, at least 85 gpm of CCW flow must be insured during this mode of operation.

The vendor recommended cooling water flow to the lube oil cooler is 4.0 gpm at 125°F. As long as this limit is met, the power frame lube oil will be adequately cooled during pump operation.

Therefore, as long as 85 gpm of cooling water is provided to the Gyrol drive coolers, and 4.0 gpm is provided to the power frame lube oil cooler, the charging pumps will be adequately cooled and increasing the service water temperature to 95°F will not have an adverse effect on the safe operation of the charging pumps.

5.1.1.5.5 Sample Coolers

A sampling system is provided for the analysis of liquid and gaseous samples obtained during normal and post-accident conditions according to the requirements of NUREG-0737, Item II.B.3. Sample coolers are provided where required to cool the sample to acceptable temperatures for processing. The CCWS provides cooling to the pressurizer steam space and liquid space sample coolers, the reactor coolant sample coolers, and the steam generator blowdown sample coolers.

Sampling capability is required during normal and post-accident operations. Sampling during post-LOCA operation, however, will be performed from the ECCS recirculation flow path, which does not require cooling. Therefore, CCWS sample cooling is only required during normal and abnormal modes of operation.

As discussed in Section 4.2.2.7, the design process conditions were specified as a shell-side flow of 14 gpm at inlet and outlet temperatures of 105°F and 125°F, respectively. Tube-side conditions are based on approximately 0.5 gpm sample flow and inlet and outlet temperatures of 653°F and 127°F, respectively. The tube-side inlet temperature is based on the saturation temperature of the pressurizer fluid at a pressure of 2250 psia. The tube-side outlet temperature is based on the normal operating temperature of the volume control tank (VCT) and coolant discharge to the Waste Disposal System.

In general, higher CCW supply temperatures will result in higher sample outlet temperatures with all other parameters held constant. At CCW supply temperatures greater than 105 ^{o}F, additional cooling may be needed to maintain sample temperatures to present values. Note, a 10 to 20 ^{o}F higher sample temperature returned to the VCT during Power Operation should be acceptable since sample flow rates are very small (< 1 gpm) compared to the normal flow through the VCT with a charging pump inservice (75 gpm).

As discussed in Section 4.2.2.7, adequate cooling is provided to these coolers to support their functions. Thus, increasing the service water temperature to 95°F will not adversely affect the ability to sample primary and secondary coolant systems.

5.1.1.5.6 Reactor Vessel Support Cooling Blocks

The reactor vessel has supports located at alternate nozzles. The nozzle blocks are cooled by CCW to prevent the supporting concrete from overheating.

As discussed in Section 4.2.2.6, adequate cooling should be provided to the nozzle block coolers if the throttle valves are left in a "wide open" position. Thus, a service water temperature of 95°F will not have an adverse effect on the safe operation of the reactor vessel support cooling blocks.

5.1.1.6 Main Condenser Cooling via the CWS

Cooling water from the UHS also cools the main condenser via the circulating water system (CWS). Increasing the cooling water temperature to the condenser coolers, could decrease condenser vacuum. The turbine/generator is automatically tripped on low condenser vacuum. Turbine trip will cause a loss of external electrical load transient. The loss of external electrical load transient is analyzed in FSAR Chapter 14.1.8. As condenser vacuum may be affected by increasing UHS temperatures, condenser vacuum should be monitored and appropriate actions taken to maintain condenser vacuum at acceptable levels.

As condenser vacuum can be monitored during operations with high CWS temperatures, the probability of a turbine trip/loss of load transient is not expected to be increased.

5.1.2 Cooling Performance During Abnormal Conditions

SWS and CCW cooling is required to support safe plant shutdown under abnormal plant conditions including loss-of-offsite power and following postulated plant fires.

5.1.2.1 Loss-of-Offsite Power

The loss of all AC power to the station auxiliaries is analyzed in FSAR Chapter 14.1.12. This event is mitigated by starting the emergency diesel generators and restoring component cooling water flow to the RCP thermal barriers. Thus, the service water system must supply adequate cooling to the emergency diesel generators to support their continued operations, and also to the CCWS to provide adequate cooling to the RCP thermal barriers (lube oil cooling is not required as the RCPs will not be running).

As discussed in Section 4.1.4, adequate service water cooling is provided to the diesel generator heat exchangers to support diesel generator operation following a loss-of-offsite power for SWS temperatures up to 95°F. In addition, as discussed in Section 3.1.1.4.1, CCW temperatures during a loss-of-offsite power (station blackout event) would be bounded by normal operations. Therefore, cooling flow to the RCP thermal barriers is adequate to ensure pump seal integrity. Thus, safe plant shutdown following a loss-of-offsite power is supported with a service water temperature of 95°F.

5.1.2.2 Safe Shutdown Following Postulated Plant Fires

The safe shutdown capability following postulated plant fires is discussed in Section 3.2.3.2. The equipment available to cool the plant during the second part (RHR cooling) of plant cooldown is RHR pump 21, CCW pump 23, charging pump 21, and SW pumps 23 and 24 (one SW pump is aligned to cool the designated essential header and one is aligned to cool the

nonessential header, including the CCWS). Adequate SW and CCW cooling must be provided to (1) support CCWS operability, (2) support RHR and charging pump operation, and (3) support RHR cooling so that cold shutdown can be reach in 72 hours.

5.1.2.2.1 CCWS Operability

In order to support adequate RHR cooling during Appendix R cooldown, the CCWS configuration must be adjusted from the normal alignment. The CCW flow through the RHR heat exchangers must be increased, and flow to other users decreased or isolated as required to prevent CCW pump runout. In addition, to support charging and RHR pump cooling, the RHR flow through the RHR heat exchanger must be controlled to limit CCW temperature to 125°F. With CCW temperature limited to 125°F, and pump flow rate maintained below runout, CCWS operability is bounded by the post-LOCA evaluation in terms of system temperature, flow rate and pump operability.

5.1.2.2.2 RHR Pump Cooling

The RHR pump is equipped with a shell and tube mechanical seal cooler as well as a jacket cooler, similar to that used on the HHSI pump, which are serviced by CCW. The mechanical seal coolers are intended to maintain temperature in the mechanical seal chamber within limits that will prevent abnormal seal wear.

For Appendix R cooldown operation, the CCW temperature can go as high as 125°F, which is 5°F higher than for normal cooldown. Also, during Appendix R cooldown, the pump suction temperature remains above 300°F (mechanical seal design temperature) for about 12 hours longer than during normal cooldown. These conditions are not considered to be severe enough to cause significant degradation of the mechanical seals.

Therefore, it is concluded that the CCW cooling water temperatures during Appendix R cooldown will have an insignificant effect on the mechanical seal life, compared to operation with 85°F SWS temperature.

5.1.2.2.3 Charging Pump Cooling

In order to ensure adequate cooling of the Gyrol oil, the vendor recommended cooling water flow is 85 gpm at 125°F. Since the CCW temperature is allowed to increase to 125°F during Appendix R cooldown, at least 85 gpm of CCW flow must be insured during this mode of operation. The vendor recommended cooling water flow to the lube oil cooler is 4.0 gpm at 125°F. As long as this limit is met, the power frame lube oil will be adequately cooled during pump operation.

Therefore, as long as 85 gpm of cooling water is provided to the Gyrol drive coolers, and 4.0 gpm is provided to the power frame lube oil cooler, the charging pumps will be adequately cooled and increasing the service water temperature to 95°F will not have an adverse effect on the safe operation of the charging pumps.

5.1.2.2.4 RHR Cooldown Capability

As discussed in Section 3.2.3.2, the CCW total flow and the fraction required to be deliver to the RHR heat exchangers was determined such that cold shut down could be reach within 72 hours. The CCW flow rate required is within the capability of one CCW pump. At stretch rating power, however, cooling flow to the SFP may need to be restricted or isolated so that sufficient CCW flow can be delivered to the RHR HXs.

5.1.3 Cooling Following Design Basis Accidents

The SWS and CCWS are required to provide cooling to safety-related equipment following design basis accidents. In particular, the SWS provides cooling to the RCFCs and the RCFC motor coolers, the instrument air compressors, the diesel generators, and the CCWS heat exchangers. The CCWS, in turn, provides cooling to the recirculation pumps, the SI pumps, the RHR heat exchangers, and the RHR pumps (if required as a backup to the recirculation pumps)

5.1.3.1 Reactor Containment Fan Coolers

The RCFCs transfer the heat discharged from the RCS into the containment, post-accident, to the SWS and therefore the ultimate heat sink. This containment heat removal is required to limit post-accident pressure and temperature within containment design limits and thus maintain containment integrity. During the post-LOCA operating mode, the RCFCs also provide filtration functions by passing a portion of the air-steam flow through the filtration train, then mixing it with unfiltered air before it passes through the cooling coils.

The RCFC performance during design basis accident conditions, assuming 95°F service water, was supplied to Westinghouse for inclusion in the containment integrity analysis. The Containment Integrity Analysis for Indian Point Unit 2 (WCAP-12187, Reference 5-1) notes that the heat removal capability of the containment cooling systems is sufficient to absorb the energy releases and still keep the maximum calculated pressure below the design pressure assuming a service water temperature of 95°F.

5.1.3.2 RCFC Motors

The RCFC Motors are cooled in part by the service water system. These fan motors are required to operate following design basis accidents to provide air flow over the RCFC cooling coils. The RCFC fan motor heat exchanger

is a component of the motor/motor base assembly which is designed to absorb heat due to motor heat losses and external effects under all operating conditions and limit the maximum thermal environment consistent with the motor design. The motor/motor base assembly serve as an enclosure to isolate the major functional elements of the motor from the containment environment which would exist in the post accident condition. Air exiting the motor passes through the heat exchanger and is directed by the ductwork in the enclosure back through the motor. A relief valve mounted on the enclosure allows the pressure inside the enclosure to equalize with the pressure outside in the post accident condition. In this case, moisture is condensed from the air by the heat exchanger to protect the motor.

As discussed in Section 4.1.2, a motor life expectancy calculation was completed which evaluates the performance of the motor cooling coil against conservatively calculated heat loads for the normal and post accident conditions. The cooling coil was evaluated by determining the maximum motor winding temperatures permitted to provide an expected motor life of 40 years of normal operation plus one year of post-accident operation. The heat exchanger was then evaluated to determine if it could remove the calculated heat load to maintain these temperatures. The following conservative assumptions were made:

1) For the normal condition, the conservative assumption of 85°F service water for nine months and 95°F service water for three months of each of 40 years of normal operation was made. No credit was taken for actual operation data to date.

2) For the accident condition, the conservative assumption of 95°F service water year round was made. The heat load was assumed constant for the entire year where in reality it would be reduced significantly shortly after the accident.

The maximum permitted motor winding temperatures were established from the relationship of motor winding life to insulation temperature.

It was concluded from the calculations that the heat exchanger performance is adequate, with a minimum service water flow rate of 17 gpm, to maintain motor winding temperatures below a level which will provide for the required motor life. Therefore, an increase in the service water temperature to a maximum of 95°F for three months and 85°F for nine months of each year will not impact the life expectancy of the RCFC motors of 40 years of normal operation plus one year of post-accident operation.

5.1.3.3 RCFC Service Water Return Radiation Monitors

RCFC Service Water Return Radiation Monitors (R-46 and R-53) serve to detect radiation leakage from the containment into the service water return lines from the containment fan coolers and motor coolers.

Sample flow from the SWS return lines is induced via a motor driven pump through the sample heat exchanger associated with each of the radiation monitors. Temperature switch TS100 monitors sample temperature coming out of the heat exchanger, and opens cooling water solenoid valve ECV17 when sample temperature exceeds 120°F, which allows additional cooling water to flow through the heat exchanger. The rate of sample flow through the skid assembly, indicated by flowmeter FI102, can be regulated between one and five gpm. The function of temperature switch TS101 is to shut down the pump motor when sample temperature exceeds the appropriate setpoint. The maximum permissible sample temperature into the radiation monitor is 160°F.

Due to the relatively low temperatures (approximately 100°F) of the return service water during the normal condition there is no impact to the radiation monitors of raising the inlet service water temperature to 95°F.

For the post-LOCA condition, the evaluation discussed in Section 4.1.3.3 has shown that the possibility exists for the sample water temperature to exceed the current temperature setpoint (130°F) at which TS101 will isolate the sample flow to the radiation monitor. Therefore, in order to

maintain radiation monitoring capability post-LOCA, the setpoint of TS101 must be revised upward to a level high enough to ensure that the radiation monitor will not be isolated for sample temperatures predicted during post-LOCA operation. The revised setpoint must also be limited to below 160°F, which is the maximum inlet temperature allowed to the radiation monitor.

5.1.3.4 Instrument Air Compressors

The instrument air compressors are restarted after cooling water and electrical power are established following an accident. The cooling water required to support instrument air compressor operations following an accident is similar to that required for normal operations. Thus, as discussed in Section 4.1.5 and 5.1.1.2, adequate service water cooling is provided to support air compressor operation, during normal operations and following a design basis accident. Thus, a service water temperature of 95°F will not adversely affect the Instrument Air System from performing its post-accident safety functions.

5.1.3.5 CCWS Cooling

The thermal capacity of the CCWS provides a heat sink for the SI, RHR and recirculation pumps during ECCS injection. During this mode, the ACC pumps circulate CCW through the recirculation pumps and SI pump shaft driven ACC pumps circulate CCW cooling water through the SI pumps. The CCW pumps, however, are not started following a loss-of-offsite power, and would not be running following the early stages of the design basis LOCA. Therefore, the CCWS will absorb the heat and slowly heatup until a CCW pump is started.

The SWS provides cooling to the CCWS during the recirculation phase following a design basis LOCA. The CCWS in turn, cools the recirculation pumps, the safety injection pumps, the RHR pumps (if required as a backup to the recirculation pumps), and the RHR heat exchangers.

5.1.3.5.1 CCWS Operability

CCW temperature during the injection phase is expected to remain below 138°F. As such, there is no concern for the CCW temperature exceeding the CCWS design temperature during this mode of operation. The CCW pumps are not operating, therefore, there is no concern for violating pump NPSH or runout limits. The cooling ability of the CCWS during the injection phase is adequate as discussed below. Thus, CCWS operability is supported during the injection phase post-accident.

CCWS operability during post-LOCA recirculation is affected by the system flow rates and temperatures. CCW temperature is based on the heat being input into the system, primarily from the containment sump water via the RHR heat exchangers, and the heat that can be rejected to the SWS via the CCW heat exchangers.

The CCWS recirculation evaluation presented in Section 3.1.2, indicates that CCW temperature exiting the RHR heat exchangers may exceed the 200°F system design temperature. Although this maximum calculated temperature is higher than the design temperature of the RHR heat exchanger shell-side and the system, as discussed in Section 3.1.2.2, the temperature is evaluated to be acceptable based of the following:

1. The post-LOCA mode is considered a faulted condition. As such, the major concern is to ensure that component structural integrity is maintained. The applicable ASME Code is Section VIII, Division 1. For carbon steel, the allowable stress is unchanged at the expected temperatures and pressures. Therefore, the vessels are considered adequate for a maximum temperature of 230 °F.

2. The maximum calculated temperature is less than the saturation temperature, therefore, the fluid leaving the RHR heat exchangers would remain subcooled and flashing would not occur. Downstream of the heat exchangers, CCW flow would mix with other flows which are at a lower temperature as CCW is returned to the pump suction. Since the mixed mean temperature at the pump suction is less than 165°F and adequate pump NPSH is available, the system fluid would remained subcooled and flashing would not occur.

3. Although the design temperature of the CCWS is 200 ^{o}F, the actual design temperature of the low pressure portion of the CCWS piping is 500 ^{o}F at the system design pressure of 150 psig. Since the maximum calculated CCWS temperature is significantly lower than the maximum allowable design temperature, structural integrity of the piping is ensured.

4. The low pressure portion of the system are provided with 150# class system valves and flanges built to USAS B16.5 requirements. For a pressure of 225 psig, the maximum allowable temperature is 250 ^{o}F. Since the maximum calculated CCWS temperature is lower than the allowable maximum temperature, structural integrity of the components are ensured.

5. Sump temperature will decrease with time into the event as decay heat levels drop and ACS cooling is established.

Operation of the CCWS with the P(min) restrictions will ensure that CCW pump operability is supported. As discussed in Section 3.1.2.2, pump NPSH and runout are acceptable and pump motor performance is adequate.

The CCW flow rates during post-accident operations, will be lower than during normal operations as the flow path through the RHR heat exchangers will be available to divert flow from other users. The evaluation in Section 3.1.2.3, however, indicates that CCW flows at the CCW pump

discharge may exceed maximum limits that are based on erosion concerns. The potential for pipe erosion is not considered to be a significant concern during post-LOCA operation as CCW flow rates can be reduced after the initial phase of operation and CCW pump duty can be switched between pumps during long-term operations.

The ability of the CCWS to provide adequate cooling to safety-related equipment is addressed below.

5.1.5.3.2 Recirculation Pump Cooling

The SI recirculation pump motors are totally enclosed water to air cooled motors. The motor exhaust air is cooled by heat exchangers and recirculated to the motor air intakes in an enclosed system.

As discussed in Section 4.2.2.1, increased CCW supply temperature will result in increased stator winding and bearing temperatures. These motors were originally qualified by Reference 4-15 for a containment ambient temperature of 324°F. This qualification demonstrated that the stator winding and bearing temperatures were well within acceptable limits with the ambient temperature of 324°F and various component cooling water temperatures. Maximum predicted containment temperature for Indian Point Unit 2 is 261°F, which is less than 324°F and is therefore acceptable for this component.

With CCW temperatures of 134°F peak and 124°F steady state, at a flow rate of 40 gpm, the stator winding temperatures are expected to remain within the maximum allowable temperature limit for Class F insulation systems. Thus no abnormal insulation degradation is expected to occur and there will be no reduction of the motor qualified life. The motor bearing temperatures are predominantly dependent upon the ambient temperature and not the component cooling water temperature.

The test results for the ambient temperature of 324°F are bounding for the actual ambient temperature in conjunction with the increased component cooling water temperature. Therefore, the recirculation pump motors will remain operable for the component cooling water temperatures experienced during the post-LOCA recirculation phase. Thus, 95°F service water does not have an adverse effect on the ability of the recirculation pumps to perform their safety function.

5.1.3.5.3 Safety Injection Pump Cooling

CCW provides cooling to the SI pump mechanical seal coolers, mechanical seal jacket coolers, and the lube oil coolers.

As discussed in Section 4.2.2.2, the SI pumps operate during the injection and recirculation phases following a LOCA. During the injection phase the SI pumps take suction from the RWST and inject this coolant into the RCS cold legs. With a Blackout event, the CCW pumps are not running, but auxiliary component cooling pumps, driven off the SI pump shafts, circulate CCW through the SI pump coolers. As the SI pumped fluid during injection is cool water from the RWST, the cooling requirements during injection are not as severe as during the recirculation phase. As discussed in Section 3.1.1.4.2, at least 4.5 gpm of CCW flow is provided to the SI pump coolers during the injection phase of a LOCA. The CCW temperature slowly increases during the injection phase as no CCW heat is rejected to the SWS during this mode (the CCW and nonessential SW pumps are not operating). The CCW flow rates and temperatures expected during ECCS injection are adequate to support SI pump operation for this limited period of operation.

During the ECCS recirculation phase, the SI pumps pump recirculate core coolant provided by the recirculation pumps and cooled by the RHR heat exchangers

The SI pumps each contain two mechanical seal coolers, two mechanical seal jacket coolers and a lube oil cooler which are serviced by component cooling water through a common header. The mechanical seal coolers are intended to maintain temperatures in the mechanical seal chambers within limits that will prevent abnormal seal wear. The lube oil cooler is required to maintain the oil temperature at a level which will provide adequate lubrication to the bearings and prevent accelerated viscosity breakdown.

The SI pumps were originally provided with mechanical seals, which are qualified for operation at temperatures of up to 300°F. The mechanical seals are cooled by component cooling water which flows through the pump seal coolers. Seal chamber fluid is pumped by a pumping ring through the mechanical seal coolers and returned to the seal chambers. Mechanical seals are installed on both ends of the pump shaft and each seal has its own mechanical seal cooler.

The cooling water temperature to the seal coolers was determined to be 134°F at the switchover to the recirculation phase, decaying to 125.5^{o}F within 24 hours. The seal chamber temperature is influenced by the pump suction temperature due to migration of the pumped fluid into the seal chamber. The maximum pump suction temperature will correspond to the containment sump temperature, which is 250°F at the beginning of the recirculation phase, reducing with time.

The effect of elevated temperatures on the seal would be an increase in seal wear and a reduction in seal life. Tests performed by the manufacturer of the origionally supplied seals (John Crane) with 300°F seal cavity temperatures and no seal cooling resulted in only minor wear to the seals. The seal temperature conditions posed here are much less severe, especially since there will be cooling of the seal cavity from the seal coolers. Consequently, it was determined that the post-LOCA recirculation conditions will have little effect in reducing seal life

expectancy, compared to operation with 85°F SWS temperature. Lastly, both of these seals are furnished with a safety bushing which, in the event of catastrophic failure to the primary seal, will limit leakage from the seal to maintain the operability of the HHSI pump.

The safety injection pumps utilize a pressurized lubrication system which provides oil to the two shaft journal bearings and a thrust bearing. The hot oil leaving the bearings is drained to a 3 gallon reservoir. This reservoir is the source of oil for the lube oil pump which supplies oil through the lube oil cooler to the pump bearings. The oil recommended by the vendor for use in these pumps has a nominal viscosity rating of 150 SSU at 100°F.

Increased component cooling water temperature will result in increased oil temperatures at both the inlet and outlet of the pump bearings. From Section 3.1.1.4.3, the maximum CCW supply temperatures to the SI pump coolers is 138°F, which occurs at the end of the injection phase. This temperature quickly reduces as SWS and CCWS pumps are started at the beginning of the recirculation phase. Shortly after the recirculation phase is initiated the CCWS supply temperature decreases to approximately 134°F reducing to about 126°F within 24 hours. The flow rate to each of the coolers will be at least 4.5 gpm for post-accident operation. Based upon the results of a thermal evaluation of the lube oil system, it has been determined that the SI pumps will operate satisfactorily under these conditions.

5.1.3.5.4 RHR Pump Cooling

The RHR pumps operate during the LOCA injection phase. In addition, the RHR pumps provide a backup to the recirculation pumps during post-LOCA ECCS recirculation.

The RHR pump is equipped with a shell and tube mechanical seal cooler as well as a jacket cooler, similar to that used on the HHSI pump, which are

serviced by CCW. The mechanical seal coolers are intended to maintain temperature in the mechanical seal chamber within limits that will prevent abnormal seal wear.

The mechanical seals originally specified for use in the RHR pumps are very similar in design to the HHSI pump mechanical seals. The RHR pump mechanical seals will be subjected to a peak post-LOCA pump suction temperature of 250°F, reducing with time, and a peak CCW temperature of 134°F, also reducing with time. Thus the manufacturer test which qualified the seal for 300°F seal chamber temperatures with no seal cooling bounds the RHR pump mechanical seal operating conditions, post-LOCA.

Therefore, it is concluded that the CCW cooling water temperatures during post-LOCA injection and recirculation will have an insignificant effect on the mechanical seal life, compared to operation with 85°F SWS temperature.

5.1.3.5.5 RHR Heat Exchanger Cooling

During post-LOCA recirculation, the RHR heat exchangers are used to cool the recirculated reactor coolant before it is returned to the RCS. As discussed in Section 3.2.2, sufficient CCW cooling is provided to maintain the recirculated emergency core coolant subcooled.

In addition, cooling provided by the RHR heat exchangers, removes heat from the containment via the containment spray system and from the containment sump. As discussed in WCAP-12187 (Reference 5-1), the cooling provided by the RHR heat exchanger, in conjunction with the cooling provided by the RCFCs, will prevent the containment pressure from exceeding design limits due to core boiloff during recirculation.

5.2 CONTAINMENT INTEGRITY ANALYSIS

Westinghouse recently re-evaluated the containment integrity analyses in support of the Indian Point Unit 2 Stretch Rating effort to determine the impact of increasing the SWS maximum inlet temperature to 95°F (Reference 5-1).

During the recirculation mode of safety injection, the containment recirculation sump water is cooled by the RHR system. Since cooling for the RHRS comes ultimately from the SWS, through the CCWS, the increased SWS temperature impacts the results of the containment integrity analyses.

The purpose of the containment integrity LOCA analyses is to demonstrate the acceptability of the containment safeguards systems to mitigate the consequences of a hypothetical rupture of the main RCS pipe. The impact of LOCA mass and energy discharges on containment pressure was addressed to ensure that the containment pressure remains below its design pressure of 47 psig and to assure that the pressure is rapidly reduced to 50% of the peak in a period of 24 hours. Due to the extended mass and energy discharges associated with a large break LOCA, the containment must also be capable of maintaining the long-term temperature response of the containment to values that are less than the long-term equipment qualification temperature envelope.

The Indian Point Unit 2 containment structure has a design pressure of 47 psig. The limiting design basis LOCA for containment design is a RCS double-ended rupture; this accident results in the highest containment pressure after a LOCA. The results of the analysis show that the maximum calculated containment pressure for the double-ended pump suction minimum safeguards case and for the double-ended hot leg break case remain below the design limits. An NSSS power of 3083.4 MWt was used.

Operation of minimum ECCS equipment and failure of one diesel generator was assumed which resulted in minimum containment safeguards of three fan

coolers and one containment spray pump operating. The containment model also included an initial containment temperature of 130°F and a 95°F SWS temperature.

The purpose of the containment Integrity MSLB analysis is to demonstrate the acceptability of the containment safeguards systems to mitigate the consequences of a hypothetical rupture of a main steam line pipe. The impact of steam line break mass and energy discharges on containment pressure was addressed to ensure the containment pressure remains below its design pressure of 47 psig. The worst case secondary system pipe rupture has also been analyzed to determine containment integrity. The calculated containment pressure for the MSLB event remained below design limits.

The calculated pressure for both design basis events is below the 47 psig design value. Reference 5-1 discusses the containment integrity analysis for Indian Point Unit 2. The model discussed in Reference 5-2 was used for the mass and energy release calculation. The COCO computer program, Reference 5-3, was used for the containment response.

REFERENCES

5-1 Westinghouse topical report, WCAP-12187, "Consolidated Edison Company of New York, Inc., Indian Point Unit 2, NSSS Stretch Rating - 3083.4 MWt, Engineering Report", March 1989

5-2 Westinghouse topical report, WCAP-10325-A, "Westinghouse LOCA Mass and Energy Release Model for containment Design - March 1979 Version," May 1983

5.3 Westinghouse topical report, WCAP-8326, "Containment Pressure Analysis Code (COCO)," July 1974.

6.0 CONCLUSIONS

Based on the evaluations performed in support of this project, safe plant operation with a 95°F SWS temperature is acceptable provided that the requirements defined in the safety assessment for this amendment application are addressed. Provided below are specific requirements resulting from this evaluation.

6.1 AUXILIARY COOLANT SYSTEM

Provided below are specific requirements for the ACS:

1) Nonessential SWS flows to the CCW heat exchanger must be verified to be greater than or equal to the following:

   - Post-LOCA recirculation and Appendix R alignments - 2500 gpm per heat exchanger with one nonessential SWS pumps operating;
   - Post-LOCA recirculation alignment - 4500 gpm per heat exchanger with two nonessential SWS pumps operating; and
   - Power Operation alignment - 4500 gpm per heat exchanger.

2) Institute an erosion/pipe thinning monitoring program for the following sections of CCWS piping:

   - The 8 inch supply and return piping to the SFP heat exchanger
   - The 10 inch piping at the CCW pump discharge

3) The CCWS throttle valves for the SI pumps and the SI recirculation pump motor coolers are acceptable as is. With the valves in their current positions, the auxiliary coolant pumps can provide sufficient cooling water flow. These valves are not to be altered without performing a flow test.

4) The setpoint for control loop PIC-600 is required to be set to the appropriate P(min) value defined in Section 3.1.1.2.

5) In accordance with use of P(min), CCWS throttle valves for the RHR heat exchangers (820 A&B) must be set at the following position whenever the RCS is above above 350°F to ensure adequate pump runout protection during post-LOCA recirculation:

   - RHR Heat Exchanger 21 (Valve 820A) - 27.5% open
   - RHR Heat Exchanger 22 (Valve 820B) - 25.5% open

6.2 COMPONENT PERFORMANCE

6.2.1 SWS Components

The components evaluated in this program are capable of performing their required functions provided the minimum cooling water flows as defined in Section 4.0 can be supplied and the requirements discussed below are addressed.

6.2.1.1 RCFC Service Water Return Radiation Monitor

For the post-LOCA condition, the evaluation has shown that the possibility exists for the sample water temperature to exceed the current setpoint (130°F) at which temperature switch TS101 will isolate the sample flow to the radiation monitors. Therefore, in order to maintain radiation monitoring capability post-LOCA, the setpoint of TS101 must be revised upward, consistent with the maximum predicted sample water temperature of 140°F, and less than the maximum allowable radiation monitor supply temperature of 160°F.

6.2.1.2 Diesel Generators

EDG jacket water and lube oil temperatures for some modes of operation and various levels of heat exchanger tube plugging are predicted to exceed normal operating temperatures, and may therefore exceed current high

temperature alarm setpoints. Therefore, resetting of alarm setpoints, consistent with the maximum recommended operating temperatures of 190°F for the jacket water and 210°F for the lube oil, as defined in Section 4.1.4, should be considered.

6.2.2 CCWS Components

The components evaluated in this program are capable of performing their required functions provided 1) the minimum cooling water flows as defined in Section 4.0 can be supplied and 2) component flows are maintained within the maximum flow limits established in Table 4-6. Provided below are additional component requirements.

6.2.2.1 RCPs

Operation with a CCW heat exchanger outlet temperature greater than 110 ^{o}F is not recommended for continuous operation. At elevated CCW supply temperatures, the cooler vendor has indicated that "fouling" could occur which would significantly reduce the heat removal capability of the motor upper bearing coolers. Operation between 110°F and 120°F is acceptable for a period of 2 hours or less. If CCW supply temperature to the RCPs exceeds this limit, the vendor requires that the bearing cooler be inspected during the next refueling outage to determine if "fouling" has occurred.

6.2.2.2 Reactor Vessel Nozzle Blocks

The CCWS throttle valves for the subject coolers should be left in a "wide-open" position to ensure adequate cooling.

APPENDIX A
CCW PUMP MINIMUM/MAXIMUM PERFORMANCE DATA

Provided in this appendix is the minimum and maximum pump performance data for the following sets of pumps used in this project to evaluate CCWS performance:

- Component Cooling Water
- Auxiliary Component Cooling Water
- Safety Injection Circulating Water

The CCW and ACC pump performance criteria is based on a composite curve taking in to account the original design performance of the supplied pumps. Provided in Tables A-1 and A-3 are the design head as a function of flow for the three CCW pump and two ACC pump certified vendor curves, respectively. At each flow point provided in the two tables, the lowest and highest head was determined. The lowest value was then degraded by seven percent to define the minimum pump performance criteria. The maximum performance curve was defined in a similar way except that the highest value was enhanced by three percent. Provided in Tables A-2 and A-4 are the composite minimum and maximum performance criteria for the CCW and ACC pumps, respectively.

For the SI circulating water pumps, a nominal pump curve was located and a seven percent reduction and a three percent increase was uniformily applied to the vendor performance curve. Provided in Table A-5 are the minimum and maximum pump perfomance criteria for these pumps.

TABLE A-1
CCW PUMP DESIGN PERFORMANCE DATA

Flow (gpm)	Design Head (feet) Curve No. 46060	Curve No. 46059	Curve No. 46058
0	280	280	280
500	279	279	279
1000	276	277	277
1500	273	274	274
2000	267	269	269
2500	259	262	260
3000	248	251	247
3500	233	236	232
4000	215	218	213
4500	192	194	191
5000	164	164	163
5400	135	118	129

TABLE A-2
CCW PUMP ANALYSIS PERFORMANCE DATA

Flow (gpm)	Pump Head (feet) Minimum/Maximum	Degraded	Enhanced
0	280/280	260.4	288.4
500	279/279	259.5	287.4
1000	276/277	256.7	285.3
1500	273/274	253.9	282.2
2000	267/269	248.3	277.1
2500	259/262	240.9	269.9
3000	247/251	229.7	258.5
3500	232/236	215.8	243.1
4000	213/218	198.1	224.5
4500	191/194	177.6	199.8
5000	163/164	151.6	168.9
5400	118/135	109.7	139.1

TABLE A-3
ACC PUMP DESIGN PERFORMANCE DATA

Flow (gpm)	Design Head (feet) Curve No. 39815	Design Head (feet) Curve No. 39822
0	114	114
20	113.9	113.9
40	112.5	113
60	108.8	109.4
80	101	101
100	91.2	91
120	78.2	77.9
140	54.4	54.2

TABLE A-4
ACC PUMP ANALYSIS PERFORMANCE DATA

Flow (gpm)	Pump Head (feet) Minimum/Maximum	Degraded	Enhanced
0	114/114	106.0	117.4
20	114/114	105.9	117.3
40	112/113	104.6	116.4
60	109/109	101.2	112.7
80	101/101	93.9	104.0
100	91/ 91	84.6	93.9
120	78/ 78	72.4	80.5
140	54/ 54	50.4	56.0

TABLE A-5
SI CIRCULATING WATER PUMP PERFORMANCE DATA

Flow (gpm)	Nominal Head (ft.)	Min. Head (ft.)	Max. Head (ft.)
0	119	110.7	122.6
10	118	109.7	121.5
20	114	106.0	117.4
30	110	102.3	113.3
40	102	94.9	105.1
50	88	81.8	90.6

Enclosure 2

to

Attachment B

Consolidated Edison Company of New York, Inc.
Indian Point Unit No. 2
Docket No. 50-247
July, 1989

14.3.5 CONTAINMENT INTEGRITY ANALYSIS

The results discussed in this section (14.3.5) supersede the results discussed in Appendix 14.3.5A because of changes in specific plant data between the older Appendix 14.3.5A analyses and the present analyses. Although the specific results in Appendix 14.3.5A have been superseded the trends, sensitivities and conclusions are still applicable.

14.3.5.1 Containment Structure

14.3.5.1.1 Design Bases - The Indian Point Unit 2 containment structure performs a safety-related function. Its design pressure is 47 psig. The limiting design basis LOCA for containment design is a reactor coolant system double-ended pump suction (DEPS) rupture; this accident results in the highest containment pressure after a LOCA. For long-term conditions, the DEPS rupture, assuming operation of the minimum emergency safeguards system equipment and failure of one diesel generator, is the limiting case. The calculated pressure resulting from that DEPS accident at an NSSS power of 3216 MWt is 41.12 psig with minimum containment safeguards of three fan coolers and one containment spray pump operating. The containment model also included no credit for recirculation spray, an initial containment temperature of 130°F and a 95°F Service Water Temperature. This calculated pressure is well below the containment design pressure of 47 psig. The worst case secondary system pipe rupture has also been analyzed to determine containment integrity. The calculated containment pressure for this case is 39.99 psig.

Sources and amounts of energy that may be available for release to the containment are discussed in Paragraph 14.3.5.3. Energy is added to the containment in the conservative manner most detrimental to peak pressure response in order to obtain the limiting pressure.

Systems for removing energy from within the containment include the component cooling water system, the service water system, the recirculation system (which is backed up by the residual heat removal system), containment fan coolers, and containment spray system. Heat removal by recirculation spray, which is part of the Engineered Safety Features (ESF), was not assumed in this analysis. Heat removal by recirculation spray is discussed in Appendix 14.3.5A. During the recirculation phase, the recirculation system removes the heat from the reactor fuel via containment sump water. Containment spray is used for rapid pressure reduction and for containment iodine removal. The containment fan coolers remove energy from the containment atmosphere.

The ESF systems are redundant and independent such that any single active failure in the engineered safety features system during the injection phase or any single active or passive failure during recirculation will not affect the ability to achieve required safety functions.

14.3.5.1.2 <u>System Design</u> - Structural design of the containment and containment internal structures is discussed in Chapter 5.

14.3.5.1.3 <u>Design Evaluation</u> - The results of the transient analysis of the containment for the loss-of-coolant accidents are shown in Figures 14.3-109 through 14.3-110, respectively for the 3216 MWt and the 3083.3 MWt Power Levels for the double-ended pump suction break. The results at 3083.3 MWt are presented only for comparison. Appendix 14.3.5A illustrates the effects of the full range of large reactor coolant break sizes up to and including a double-ended rupture. Cases illustrating the sensitivity to break location are also shown.

Calculation of containment pressure and temperature transients is accomplished by use of the digital computer code, COCO (Reference [1]). Transient phenomena within the reactor coolant system affect containment conditions by means of mass and energy transport through the pipe break.

For analytical rigor and convenience, the containment air-steam-water mixture is separated into systems. The first system consists of the air-steam phase; the second consists of the water phase. Sufficient relationships to describe the transient are provided by the equations of conservation of mass and energy as applied to each system, together with appropriate boundary conditions. Thermodynamic equations of state and conditions may vary during the transient. The equations have been derived for all possible cases of superheated or saturated steam and subcooled or saturated water. Switching between states is handled automatically within the COCO code. The following are the major assumptions made in the containment analysis:

(a) Discharge mass and energy flow rates through the reactor coolant system break are established from the analysis in Paragraph 14.3.5.3.

(b) For the blowdown portion of the LOCA analysis, the discharge flow separates into steam and water phases at the break point. The saturated water phase is at the total containment pressure, while the steam phase is at the partial pressure of the steam in the containment. For the post-blowdown portion of the LOCA analysis, steam and water releases are input separately.

(c) Homogeneous mixing is assumed. The steam-air mixture and the water phase each have uniform properties. More specifically, thermal equilibrium between the air and steam

is assumed. This does not imply thermal equilibrium between the steam-air mixture and the water phase, which may be at different temperature.

(d) Air is taken as an ideal gas, while compressed water and steam tables are employed for water and steam thermodynamic properties.

14.3.5.1.4 Initial Conditions - The pressure, temperature, and humidity of the containment atmosphere prior to the postulated reactor coolant system rupture are conservatively specified in the analysis. Also, conservative values for the temperature of the service water and refueling water storage tank water solution are assumed, along with the initial water inventory of the refueling water storage tank. All of these values are as shown in Table 14.3-23.

In each of the transients, the safeguards systems shown in Table 14.3-24 are assumed to operate with a 60 second delay in startup. The assumed spray flow rate is based on one of two trains of the containment spray system operating.

14.3.5.1.5 Heat Removal - The significant heat removal source during the early portion of the transient are structural heat sinks. Provision is made in the containment pressure transient analysis for heat transfer through, and heat storage in, both interior and exterior walls. Every wall is divided into many nodes; for each node, a conservation of energy equation expressed in finite-difference form accounts for transient conduction into and out of the node and temperature rise of the node. Tables 14.3-25 and 14.3-26 are summaries of the containment structural heat sinks used in the analysis.

The heat transfer coefficient to the containment structure is calculated by the code based primarily on the work of Tagami (Reference [3]). From this work, it was determined that the

value of the heat transfer coefficient increases parabolically to peak value at the end of blowdown for LOCA. The value then decreases exponentially to a stagnant heat transfer coefficient which is a function of steam-to-air-mass ratio.

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

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

From this, the maximum h of steel is calculated:

$$h_{max} = 75 \left[\frac{E}{t_p V}\right]^{0.60} \qquad (14.3\text{-}1)$$

where:

h_{max} = maximum value of h (Btu/hr ft^2 °F).

t_p = time from start of accident to end of blowdown

V = containment volume (ft^3).

E = coolant energy discharge (Btu).

The parabolic increase to the peak value is given by:

$$h_s = h_{max} \left(\frac{t}{t_p}\right)^{0.5}, \quad 0 \leq t \leq t_p \qquad (14.3\text{-}2)$$

where:

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

t = time from start of accident (sec).

For concrete, the heat transfer coefficient is taken as 40 percent of the value calculated for steel.

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

$$h_s = h_{stag} + (h_{max} - h_{stag})\, e^{-0.05(t-t_p)},\ t > tp \qquad (14.3\text{-}3)$$

where:

h_{stag} = $2 + 50X,\ 0 \leq X \leq 1.4$.

h_{stag} = h for stagnant conditions (Btu/hr ft^2 °F).

X = steam-to-air mass ratio in containment.

For a large break, the engineered safety features are quickly brought into operation. Because of the brief period of time required to depressurize the reactor coolant system, the containment safeguards do not influence the blowdown peak pressure; however, they significantly reduce the containment pressure after the blowdown and maintain a low long-term pressure. Also, although the containment structure is not a very effective heat sink during the initial reactor coolant system blowdown, it still contributes significantly as a form of heat removal.

14.3.5.2 Engineered Safety Features

During the injection phase of post-accident operation, the emergency core cooling system pumps water from the refueling water storage tank (RWST) into the reactor vessel (the containment spray pumps also inject RWST water into the containment). Since this water enters the vessel at refueling water storage tank temperature, which is less than the temperature of the water in the vessel, it can absorb heat from the core until saturation temperature is reached. During the recirculation phase of operation, water is taken from the containment sump and cooled in the residual heat removal heat exchanger. The cooled water is then pumped back to the reactor vessel to absorb more decay heat. The heat is removed from the residual heat exchanger by component cooling water and from the component cooling heat exchanger by service water.

14.3.5.2.1 Containment Spray

Another containment heat removal system is the containment spray. During the injection phase of operation, the containment spray pumps draw water from the RWST and spray it into the containment through nozzles mounted high above the operating deck. As the spray droplets fall, they absorb heat from the containment atmosphere. Since the water comes from the RWST, the entire heat capacity of the spray from the RWST temperature to the temperature of the containment atmosphere is available for energy absorption. During the recirculation phase of post-accident operation, water can be drawn from the residual heat removal heat exchanger outlet and sprayed into the containment atmosphere via the recirculation spray system. However, no-credit is taken for the recirculation spray system in the analyses provided herein.

When a spray drop enters the hot, saturated, steam-air containment environment following a loss-of-coolant accident, the vapor pressure of the water at its surface is much less than the partial pressure of the steam in the atmosphere. Hence, there will be diffusion of steam to the drop surface and condensation on the drop. This mass flow will carry energy to the drop. Simultaneously, the temperature difference between the atmosphere and the drop will cause the drop temperature and vapor pressure to rise. The vapor pressure of the drop will eventually become equal to the partial pressure of the steam, and the condensation will cease. The temperature of the drop will equal the temperature of the steam-air mixture.

The equations describing the temperature rise of a falling drop are as follows:

$$\frac{d}{dt}(Mu) = mh_g + q \qquad (14.3\text{-}4)$$

$$\frac{d}{dt}(M) = m \qquad (14.3\text{-}5)$$

where:

$q = h_c A (T_s - T).$

$m = K_g A (P_s - P_v).$

The coefficients of heat transfer (h_c) and mass transfer (k_g) are calculated from the Nusselt number for heat transfer, Nu, and the Nusselt number for mass transfer, Nu'.

Both Nu and Nu' may be calculated from the equations of Ranz and Marshall (Reference [4]).

$$Nu = 2 + 0.6\,\underline{(Re)}^{1/2}\,\underline{(Pr)}^{1/3} \qquad (14.3\text{-}6)$$

$$Nu' = 2 + 0.6\,\underline{(Re)}^{1/2}\,\underline{(Sc)}^{1/3} \qquad (14.3\text{-}7)$$

Thus, Equations 14.3-4 and 14.3-5 can be integrated numerically to find the internal energy and mass of the drop as a function of time as it falls through the atmosphere. Analysis shows that the temperature of the (mass) mean drop produced by the SPRACO 1713A spray nozzles rises to a value within 99 percent of the bulk containment temperature in less than 2 seconds. Drops of approximately 1000 micron average size (as discussed in Chapter 6) will reach temperature equilibrium with the steam-air containment atmosphere after falling through less than half the available spray fall height.

Detailed calculations of the heatup of spray drops in post-accident containment atmospheres by Parsly (Reference[2]) show that drops of all sizes encountered in the containment spray reach equilibrium in a fraction of their residence time in a typical pressurized water reactor containment.

These results confirm the assumption that the containment spray will be 100 percent effective in removing heat from the atmosphere. Nomenclature in this section is as follows:

A = area.

h_c = coefficient of heat transfer.

k_g = coefficient of mass transfer.

h_g = steam enthalpy.

M = droplet mass.

m = diffusion rate.

$\underline{Nu}$ = Nusselt number for heat transfer.

$\underline{Nu'}$ = Nusselt number for mass transfer,

P_s = steam partial pressure.

P_v = droplet vapor pressure.

$\underline{Pr}$ = Prandtl number.

q = heat flow rate.

$\underline{Re}$ = Reynolds number.

$\underline{Sc}$ = Schmidt number.

T_s = droplet temperature.

T = steam temperature.

t = time.

u = internal energy.

14.3.5.2.2 Reactor Containment Fan Coolers (RCFCs)

The reactor containment fan coolers are a principal means of post-accident containment heat removal. The fans draw the dense atmosphere through banks of finned cooling coils and mix the cooled steam/air mixture with the rest of the containment atmosphere. The coils are kept at a low temperature by maintaining the required flow of cooling water from the service

water system. Since the RCFCs do not use water from the RWST, the mode of operation remains the same before and after the switchover to the recirculation mode.

The ability of the containment air recirculation coolers to function properly in the accident environment is demonstrated by the coil vendor's analysis. This analysis determines the plate-fin cooling coil heat removal rate when operating in a saturated steam-air mixture.

In the heat removal analysis of the RCFC coils, a mass flow rate of cooling water is first established. This determines the inside film coefficient of the tube. Next, the resistance to heat transfer between the cooling water and the outside of the fin collars is computed, including inside film coefficient, fouling factor,* tube radial conduction, fin-collar interface resistance, and conduction across the fin collars. The analysis now becomes iterative. One assumes an overall heat transfer rate Q_{tot} and the temperature at the outside of the fin collars is determined from Q_{tot} and the sum of the resistances cited above.

---

* A fouling factor of 0.001 hr-ft^2-°F/Btu, under both normal and design basis accident conditions, has been assumed for cooling coil design purposes. This value is conventionally used in sizing heat exchangers cooled by river water at 125°F or less and with tube water velocity greater than 3 ft/sec (Reference 5), and is considered sufficiently conservative for this application. Computer analysis of the coils selected shows that the required post-accident heat removal rate can be achieved even with a slight increase in fouling.

A second iterative procedure is now established. The variable whose value is assumed is the effective film coefficient between the fins and the gas stream, which involves the effect of convective heat transfer and mass transfer. With this value of $h_{effective}$, fin efficiency and the fin temperature distribution can be determined. It is assumed that a condensate film exists on the vertical fins. An analysis is performed which relates this film thickness to the rate of removal due to gravity and shear and the rate of addition of condensate by mass transfer from the bulk gas. In the process, from an energy balance the temperature of the interface between the bulk gas and the condensate can be determined; this is necessary for determining the mass transfer rate from the gas. Now that the thickness of the condensate film is known, the value of the assumed $h_{effective}$ is checked from the relation $h_{eff} = K_{water}/\delta_{film}$. If the assumed and computed values are not the same, a new value is selected and calculations repeated until the assumed and computed values are equal.

When this occurs, the heat transfer rate from the fins and fin collar is computed, using the standard equations for fin and fin collar heat transfer and the values of $h_{effective}$ and film-bulk gas interface temperature. If this value is not the same as Q_{tot}, initially assumed in order to determine fin collar temperature, the whole analysis is repeated with a new estimate of Q_{tot}. When, finally, the heat transfer rate to the cooling water from the fin collar equals the resulting computed rate to the fin collar and fins from the gas, the effect of this heat transfer rate on the cooling water is computed. The water exit temperature is established, and this value is used as the inlet temperature for the next heat exchanger pass. Also, the effect of convective heat transfer and condensate mass transfer is determined relative to the gas composition and thermodynamic state. The updated gas state is used as inlet conditions for the next pass. The process is repeated for the second, third, etc., passes until the gas exits the heat exchanger.

The mass transfer coefficients used in the computer code were derived from analyses and reports of experimental data contained in References 5, 6 and 7. From Reference 6, the mass flow rate of condensate is defined by*

$$\dot{m} = \bar{h}_D \, (\rho_{sg} - \rho_{sw}) \qquad (14.3\text{-}8)$$

From Reference 6, pp. 471-473, experimental data for mass and heat transfer correlate well with the expression

$$\frac{\bar{h}_D}{u_s} (Sc)^{-2/3} = St \, (Pr)^{-2/3} \qquad (14.3\text{-}9)$$

* Nomenclature used is given at the end of this discussion.

as shown in Figure 16-10 of Reference 6. Thus,

$$\bar{h}_D = u_s \times St \left(\frac{Sc}{Pr}\right)^{2/3}$$

$$\bar{h}_D = \frac{u_s \times h}{\rho C \; u_s} \times \left(\frac{Sc}{Pr}\right)^{2/3} \qquad (14.3\text{-}10)$$

As Reference 6 points out, for large partial pressures of the condensing components, Equation 14.3-10 must be corrected by a factor P_t/P_{am}. Thus, h_D is defined by

$$\bar{h}_D = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times \left(\frac{Sc}{Pr}\right)^{2/3} \qquad (14.3\text{-}11)$$

This is essentially the same result as reported by Reference 7 p. 343 and Reference 8.

Reference 6 states that experiments show Equation (14.3-8) to be valid when the Schmidt number does not differ greatly from 1.0. Equations (14.3-8) and (14.3-10) are combined to give the mass transfer rate, which is

$$\dot{m} = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times \left(\frac{Sc}{Pr}\right)^{2/3} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3\text{-}12)$$

An approximation was made in assuming that $(Sc/Pr)^{2/3} \approx 1.0$, thus the local mass transfer rate was computed from

$$\dot{m} = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3\text{-}13)$$

The heat transfer rate due to condensation is computed from

$$q_1 = \frac{\dot{m}\ \lambda h P_t}{\rho C P_{am}} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3\text{-}14)$$

where

ρ_{sg} is evaluated at the local bulk gas temperature

ρ_{sw} is evaluated at the local gas-condensate interface temperature

λ is evaluated at the local gas-condensate interface temperature

P_t and C is evaluated at the local bulk gas temperature

The heat transfer coefficient, h, was determined from experiments on the same geometry used in this application.

The heat transfer rate, locally, is computed from

$$q_2 = h \times (T_g - T_i) \qquad (14.3\text{-}15)$$

The basis for selecting these values is that the authorities cited as references have shown, through analyses and through cited experiments, that the methods used are accurate.

The air side pressure drop across the cooling coils at a conservative design-basis accident condition of 47 psig is estimated to be approximately 2.1 in. of water, or 0.076 psi. This will have a negligible effect on the heat removal capability of the cooling coils.

The pressure of noncondensible gases are taken into consideration because the theory behind the analysis assumed that the condensible vapor must diffuse through a noncondensible gas.

The nomenclature is as follows:

$\dot{m}$ mass flow rate of condensate, lbm/hr-ft^2

$\bar{h}_D$ mass transfer coefficient, ft/hr

ρ_{sg} density of saturated steam at local bulk gas temperature, lbm/ft^3

ρ_{sw} density of saturated steam at local condensate-gas interface temperature, lbm/ft^3

u_s free steam gas velocity, ft/min

Sc Schmidt number, $M/\rho D$, dimensionless

μ viscosity of bulk gas, lbm/ft-hr

ρ bulk gas density, lbm/ft^3

D gas-air diffusion coefficient, ft^2/hr

St Stanton number, $h/\rho C u_s$, dimensionless

h convective heat transfer coefficient, Btu/hr-ft^2-°F

C specific heat of bulk gas, Btu/lbm-°F

Pr Prandtl number, $\mu c/k$, dimensionless

k thermal conductivity of bulk gas, Btu/hr-ft-°F

P_t total gas pressure, lbf/ft^2

P_{am} air log-mean $\dfrac{P_{aw} - P_{ag}}{\ln \dfrac{P_{aw}}{P_{ag}}}$, lbf/ft^2

P_{aw} partial pressure of air at the local gas-condensate interface, lbf/ft^2

P_{ag} partial pressure of air at the local bulk gas temperature, lbf/ft^2

λ latent heat of vaporization (or condensation) at the local gas-condensate interface temperature, Btu/lbm

q_1 local heat transfer rate due to condensation, Btu/hr-ft^2

q_2 local heat transfer rate due to convection, Btu/hr-ft^2

T_g local bulk gas temperature, °F

T_i local gas-condensate interface temperature, °F

A similar heat removal analysis of the currently installed RCFC coils results in the fan-cooler heat removal rate per fan as presented in Figure 14.3-105.

References

[1] WCAP-8326, E. T. Murphy, Containment Pressure Analysis Code (COCO), July 1974.

[2] L. F. Parsly, "Spray Tests at the Nuclear Safety Pilot Plant," in: Nuclear Safety Program Annual Progress Report for Period Ending December 31, 1970, ORNL-4647, 1971, p. 82.

[3] Takashi Tagami, "Interim Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June 1965," No. 1.

[4] E. W. Ranz and W. R. Marshall, Jr., "Evaporation for Drops," Chemical Engineering Progress, 48, pp. 141-146, March 1952.

[5] W. H. McAdams, Heat Transmission, 3rd Edition, McGraw-Hill Book Company, Inc., New York, 1954.

[6] E. R. G. Eckert and P. M. J. Drake, Heat and Mass Transfer, McGraw-Hill Book Company, Inc., New York, 1959.

[7] D. Q. Kern, Process Heat Transfer, McGraw-Hill Book Company, Inc., New York, 1950.

[8] T. H. Chilton and A. P. Colburn, "Mass Transfer (Absorption) Coefficients Prediction from Data on Heat Transfer and Fluid Friction," Ind. Eng. Chem., No. 26, 1934, pp. 1183-1187.

14.3.5.3 Mass and Energy Release Analyses for Postulated Loss-of-Coolant Accidents

This analysis presents the mass and energy releases to the containment subsequent to a hypothetical loss-of-coolant accident (LOCA) at 3216 MWt. The release rates are calculated for pipe failure at the pump suction. Appendix 14.3.5A illustrates the effects at three distinct locations:

1. Hot leg (between vessel and steam generator)
2. Pump suction (between steam generator and pump)
3. Cold leg (between pump and vessel)

The LOCA transient is typically divided into four phases:

1. Blowdown - which includes the period from accident occurrence (when the reactor is at steady state operation) to the time when the total break flow stops.

2. Refill - the period of time when the lower plenum is being filled by accumulator and safety injection water. (This phase is conservatively neglected in computing mass and energy releases for containment evaluations.)

3. Reflood - begins when the water from the lower plenum enters the core and ends when the core is completely quenched.

4. Post-Reflood - describes the period following the reflood transient. For the pump suction and cold leg breaks, a two-phase mixture exits the core, passes through the hot legs, and is superheated in the steam generators. After the broken loop steam generator cools, the flow out of the break becomes two phase.

14.3.5.3.1 Mass and Energy Release Data

Blowdown Mass and Energy Release Data

Tables 14.3-17 presents the calculated mass and energy releases for the blowdown phase analyzed.

The mass and energy releases for the double-ended pump suction break, given in Table 14.3-17, terminate 27.5 seconds after the postulated accident. Since safety injection does not become effective until about the time blowdown terminates, these releases apply for both maximum and minimum safety injection.

Reflood Mass and Energy Release Data

Tables 14.3-18 presents the calculated mass and energy releases for the reflood phase.

Two Phase Post-Reflood Mass and Energy Release Data

Tables 14.3-19 presents the two phase (froth) mass and energy release data for a double-ended pump suction break using minimum safety injection assumptions.

Equilibrium and Depressurization Energy Release Data

The equilibrium and depressurization energy release has been incorporated in the post-reflood mass and energy release data. This eliminates the need to determine additional releases due to the cooling of steam generator secondary and primary metal.

14.3.5.3.2 Mass and Energy Sources

The sources of mass considered in the LOCA mass and energy release analysis are given in the mass balance Tables 14.3-20. These sources are the reactor coolant system, accumulators and pumped injection.

The energy inventories considered in the LOCA mass and energy release analysis are given in Tables 14.3-20a. The energy sources include:

1. Reactor coolant system
2. Accumulators
3. Pumped injection
4. Decay heat
5. Core stored energy
6. Primary metal energy
7. Secondary metal energy
8. Steam generator secondary energy
9. Secondary transfer of energy (feedwater into and steam out of the steam generator secondary)

The inventories are presented at the following times, as appropriate:

1. Time zero (initial conditions)
2. End of blowdown time
3. End of refill time
4. End of reflood time
5. Time of full depressurization
6. End of analysis

The methods and assumptions used to release the various energy sources are given in NRC-approved WCAP-10325 (Reference [1]).

The following items ensure that the core energy release is conservatively analyzed for maximum containment pressure:

1. Maximum expected operating temperature of the reactor coolant system

2. Allowance in operating temperature for instrument error and dead band (+7.5°F)

3. Margin in volume (1.4 percent)

4. Allowance in volume for thermal expansion (1.6 percent)

5. A power level of 3216 MWt was assmued

6. Allowance for calorimetric error (2 percent of 3216 MWt)

7. Conservatively modified coefficients of heat transfer

8. Allowance in core stored energy for effect of fuel densification

9. Margin in core stored energy (+15 percent)

10. Allowable for RCS pressure uncertainty (+60 psi)

14.3.5.3.3 Blowdown Model Description

The model used for blowdown transient (SATAN-VI) is the same as that used for the emergency core cooling system (ECCS) calculation. This model is described in WCAP-9220-P-A. (Reference [1]) provides the method by which the model is used.

14.3.5.3.4 Refill Model Description

At the end of blowdown, a large amount of water remains in the cold legs, downcomer, and lower plenum. To conservatively model the refill period for the purpose of containment mass and energy releases, this water is instantaneously transferred to the lower plenum along with sufficient accumulator water to completely fill the lower plenum. Thus, the time required for refill is conservatively neglected.

14.3.5.3.5 Reflood Model Description

The model used for the reflood transient (WREFLOOD) is a slightly modified version of that used in the ECCS calculation. This model is also described in WCAP-9220-P-A. WCAP-10325 describes the method by which this model is used and the modifications. Transients of the principal parameters during reflood are given in Tables 14.3-21.

14.3.5.3.6 Post-Reflood Model Description

Two-Phase (FROTH)

The transient model (FROTH), along with its method of use, is described in Reference [2]. The mass and energy rates calculated by FROTH are utilized in the containment analysis to the time of containment depressurization.

Long Term (Dry Steam)

After depressurization, the mass and energy release from decay heat for 3216 MWt is based on ANS (1979) and the following input:

1. Decay heat sources considered are fission product decay and heavy element decay of U-239 and Np-239.

2. Decay heat power from fissioning isotopes other than U-235 is assumed to be identical to that of U-235.

3. Fission rate is constant over the operating history of maximum power level.

4. The factor accounting for neutron capture in fission products has been taken from Table 10 of ANS (1979).

5. Operation time before shutdown is 3 years.

6. The total recoverable energy associated with one fission has been assumed to be 200 MeV/fission.

7. Two sigma uncertainty has been applied to the fission product decay.

14.3.5.3.7 Single Failure Analysis

The effect of single failures of various ECCS components on the mass and energy releases is considered.

For the minimum safeguards case, the single failure assumed is the loss of one emergency diesel generator, which failure results in not only the loss of one pumped safety injection train but also the loss of the containment safeguards on that diesel. Appendix 14.3.5A describes the single failure analysis. The analysis of both maximum and minimum safeguards cases as discussed in Appendix 14.3.5A ensure that the effect of all credible single failures on mass and energy releases is bounded.

14.3.5.3.8 Metal-Water Reaction

In the mass and energy release data presented, no zirconium-water reaction heat was considered because the clad temperature did not rise high enough for the rate of reaction to be of any significance.

14.3.5.3.9 Additional Information

System parameters needed to perform confirmatory analyses are provided in Table 14.3-22. The chronology of events for the DEPS break is presented in Table 14.3-27.

14.3.5.4 Containment Pressure Transients

Consistent with the mass/energy release analysis, the failure of that diesel generator to start which leaves a minimum of equipment available constitutes the minimum safeguards condition. The minimum safeguards case models one containment spray pump and the fan cooler heat removal equivalent to three units operating. The calculated pressure resulting from this limiting event, for the DEPS break, is 41.12 psig. Figure 14.3-109 graphically illustrates the pressure time history.

14.3.5.4.1 Energy Sinks

The integrated containment energy balance at the end of blowdown is given by:

$$U_f = U_i + \Sigma(mh)_{in} + \Sigma Q_{in} - \Sigma Q_{out} \qquad (14.3\text{-}21)$$

where

U_f = final internal energy in the containment
U_i = initial internal energy in the containment
$\Sigma(mh)_{in}$ = enthalpy added by blowdown sources
ΣQ_{in} = energy added directly to containment atmosphere
ΣQ_{out} = heat removal by containment structure and cooling system

The internal energy is made up of three sources: air, steam, and sump water. Only the air-steam mixture with the respective partial pressures contributes to the containment total pressure. The initial internal energy is based on the initial assumed containment conditions, 130°F and 16.7 psia.

Figure 14.3-108 shows the heat transfer coefficient calculated.

14.3.5.4.2 Containment Margin Evaluation

The evaluation of the capability of the containment and containment cooling systems to absorb energy additions without exceeding the containment design pressure requires the consideration of two periods of time following a postulated large area rupture of the reactor coolant system.

The first period is the blowdown phase. Since blowdown occurs too rapidly for the containment cooling system to be activated, there must be sufficient energy absorption capability in the free volume of the containment (with due credit for energy absorption in the containment structures) to limit the resulting pressure to below design.

The second period is the post-blowdown period where the containment cooling systems must be able to absorb any postulated post-blowdown energy additions and continue to limit the containment pressure to below the design value.

A detailed discussion of containment margin is included in Appendix 14.3.5A.

14.3.5.4.3 Evaluation of Containment Internal Structures

The containment internal structures such as the reactor coolant loop compartments and the reactor shield wall are designed for the pressure that could occur immediately following a loss of coolant. Details of the current design basis are included in Section 14.3.5A.4.3 of Appendix 14.3.5A.

Additional analyses for initial conditions, including prior operation parameters and 3083.3 MWt power operation parameters, were evaluated relative to short term subcompartment pressurization effects. The mass and energy releases from postulated full double-ended Reactor Coolant System (RCS) breaks were determined with the SATAN-V computer program, reference [2]. The TMD computer program, reference [3], was used to evaluate the subcompartment containment response to the hypothetical pipe ruptures. The results of the evaluation indicate that for the full double-ended breaks the peak calculated

differential presure across the wall of the loop compartment was conservatively calculated to be greater than the current design basis of 6.4 psi, as discussed in Section 14.3.5A.4.3.

References [4] and [5] demonstrate that RCS primary loop pipe breaks need not be considered in the structural design basis of the Indian Point 2 Plant. Therefore, implementation of Leak-Before-Break (LBB) Technology has eliminated the large RCS breaks from dynamic consideration. For the LOCA event, the break locations and the break sizes are significantly less severe than the previously mentioned RCS double-ended breaks. The subcompartment pressure loadings have been evaluated and it has been determined that the loadings, including LBB and operation at 3083.3 MWt, are less than the current loadings. The peak calculated differential pressure across the wall of the loop compartment is bounded by the current design basis of 6.4 psi, as discussed in Section 14.3.5A.4.3. The peak differential pressure across the primary shield wall is bounded by the design pressure of 1000 psi, as discussed in Section 14.3.5A.4.3. The effects of the different operating parameters at 3083.3 MWt do not result in a challenge to the subcompartment designs.

14.3.5.5 Evaluation of Long Term Fan Cooler Capability

The ability of the fan coolers to limit containment pressure following loss of the component cooling system has been examined. If the component cooling loop were lost for any reason during long-term recirculation, core subcooling could be lost and boiling in the core would begin. Since the cooling units of the fans are cooled by service water, the energy from the core would be removed from the containment via the fans.

The model employed in this analysis does not consider recirculation spray to operate and conservatively considers decay heat from the core to enter the containment as steam during the entire LOCA long-term transient. Therefore, the pressures calculated are not affected with a postulated component cooling

system failure, because core energy is already postulated to enter the containment as boiloff. Containment pressure at various times for the DEPS case with minimum safeguards is shown below:

Time After Accident Occurs	P (psig)
At 12 hr	14.6
At 1 day	10.7
At 1 week	6.7

Reference:

[1] WCAP-10325, "Westinghouse LOCA Mass and Energy Release Model for Containment Design - March 1979 Version," April 25, 1979.

[2] WCAP-8264-PA (Proprietary), WCAP-8312-A (Non-Proprietary), Rev. 1, "Topical Report Westinghouse Mass and Energy Release Data for Containment Design", August, 1975.

[3] WCAP-8077, "Ice Condenser Containment Pressure Transient Analysis", March, 1973.

[4] WCAP-10977, "Technical Bases for Eliminating Large Primary Loop Pipe Rupture as the Structural Design Basis for Indian Point Unit 2," Original - November 1985, Rev. 1 - March 1986, Rev. 2 - December 1986.

[5] WCAP-10977 Supplement 1, "Additional Information in Support of the Technical Justification for Eliminating Large Primary Loop Pipe Rupture as the Structural Design Basis for Indian Point Unit 2," January 1989.

TABLE 14.3-17

DOUBLE ENDED PUMP SUCTION GUILLOTINE
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0	0.0	0.0
0.0502	41050.5	22471.8	22674.3	12335.0
0.100	41098.5	22572.9	19676.4	10742.1
0.400	43932.4	25043.2	23947.9	13109.4
0.600	43671.8	25582.5	23783.3	13035.0
1.40	32953.8	21105.4	21905.9	12028.3
2.30	27417.4	18404.1	20540.3	11280.3
2.90	21563.4	14868.3	19298.9	10607.3
4.30	17561.0	12111.0	15972.4	8809.3
5.00	16367.5	11098.5	14502.4	8011.2
5.75	10529.5	8068.9	13185.9	7295.4
6.25	11370.9	8281.8	13308.4	7369.5
7.00	13697.1	9481.9	12833.9	7114.8
9.25	9150.8	6496.4	11681.3	6472.0
11.5	6897.7	5405.4	10401.2	5758.2
15.8	4845.3	3866.9	7978.5	4419.6
16.8	4457.6	3516.0	7433.0	3993.5
17.0	4373.7	3453.0	8740.1	4618.7
17.3	4254.1	3374.4	6476.6	3434.0
17.5	4180.1	3337.4	11382.7	5979.4
17.8	4038.7	3283.7	8710.3	4600.2
18.3	3832.4	3271.8	11032.0	5716.6
18.5	3734.7	3277.8	5754.5	2959.1
19.0	3440.1	3200.5	6454.0	3119.1
20.3	2479.5	2869.6	4997.5	2222.6
20.5	2278.5	2737.0	6354.0	2781.4
20.8	2098.8	2563.4	4164.8	1824.4
21.0	1919.6	2359.5	6922.3	2894.0
21.8	1528.2	1897.4	2908.6	1182.3
22.0	1385.5	1723.3	6698.1	2508.9
22.5	1172.0	1464.0	3455.8	1286.2
23.0	972.4	1218.7	3886.7	1356.4
24.5	266.2	336.1	2319.0	688.2
25.5	0.0	0.0	2344.4	672.9
27.5	0.0	0.0	0.0	0.0

TABLE 14.3-18

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
27.5	0.0	0.0	0.0	0.0
27.9	118.2	139.4	1826.2	176.4
28.3	116.2	136.9	1798.7	173.7
28.5	86.9	102.4	1772.5	171.0
29.1	108.9	128.4	1746.0	168.4
33.6	147.6	174.0	1513.5	145.3
35.6	160.9	189.8	1435.0	137.4
37.6	173.2	204.4	1365.8	130.5
38.6	300.3	355.1	3353.2	485.1
39.6	352.3	416.9	3970.8	623.3
40.6	352.1	416.8	3965.6	630.9
41.6	346.6	410.2	3901.7	623.9
43.6	335.0	396.4	3765.6	607.0
45.6	324.1	383.5	3636.5	590.8
47.6	314.1	371.5	3515.0	575.4
49.6	304.8	360.5	3400.7	560.9
50.6	300.4	355.2	3346.0	553.9
54.6	284.3	336.1	3141.8	527.8
55.6	280.6	331.7	3094.0	521.7
57.6	273.5	323.3	3002.1	510.0
58.7	391.8	464.0	344.0	231.7
59.7	392.5	464.9	344.1	232.2
61.7	381.1	451.3	338.7	224.7
68.7	346.3	409.9	322.2	202.1
69.7	342.2	405.0	320.3	199.4
77.7	313.5	370.8	306.8	181.1
79.7	307.4	363.5	303.9	177.2
102.7	257.9	304.8	280.9	146.7
130.7	233.6	275.9	269.8	132.2
144.7	229.9	271.5	268.1	130.0
150.7	231.2	273.1	270.5	130.8
166.7	238.7	281.9	294.7	136.4
176.7	239.9	283.4	311.1	138.3
186.7	237.4	280.4	326.3	138.6
202.3	228.8	270.2	352.8	138.0

TABLE 14.3-19

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
POST-REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
202.3	198.8	244.1	492.4	149.0
207.3	198.1	243.3	493.0	148.8
237.3	192.6	236.6	498.5	148.4
252.3	189.6	232.8	501.5	148.3
257.3	188.7	231.7	502.4	148.2
277.3	184.8	226.9	506.4	148.0
282.3	183.7	225.6	507.4	147.9
287.3	183.0	224.7	508.1	147.8
297.3	180.7	221.9	510.5	147.8
302.3	179.8	220.9	511.3	147.6
307.3	178.6	219.3	512.6	147.7
322.3	175.2	215.1	516.0	147.6
327.3	185.5	227.8	505.6	148.2
347.3	181.3	222.6	509.8	148.0
352.3	179.9	220.9	511.2	148.0
362.3	177.5	218.0	513.7	147.9
382.3	172.6	212.0	518.5	147.8
392.3	169.8	208.5	521.3	147.8
397.3	168.5	207.0	522.6	147.8
682.3	168.5	207.0	522.6	147.8
682.4	87.6	106.8	603.5	161.4
712.3	86.8	105.9	604.3	161.1
717.3	86.7	105.8	604.4	160.5
752.3	85.9	104.7	605.3	162.0
757.3	85.7	104.5	605.4	161.3
857.3	83.5	101.8	607.6	159.0
982.3	81.0	98.8	610.1	157.7
997.3	80.7	98.4	610.4	156.6
1110.1	80.7	98.4	610.4	156.6
1110.2	78.0	89.5	613.1	48.7
3600.0	58.3	66.9	95.3	28.8
3600.1	48.5	55.7	105.1	16.2
10000.0	35.3	40.5	118.4	18.3
100000.0	18.9	21.6	134.8	20.8
1000000.0	8.1	9.3	145.6	22.5

TABLE 14.3-20

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
MASS BALANCE

		MASS BALANCE						
	TIME (SECONDS)	0.00	27.50	27.50	202.29	687.30	1110.09	3600.00
		MASS (THOUSAND LBM)						
INITIAL	IN RCS AND ACC	715.13	715.13	715.13	715.13	715.13	715.13	715.13
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00	115.81	451.01	685.27	1067.85
	TOTAL ADDED	0.00	0.00	0.00	115.81	451.01	685.27	1067.85
*** TOTAL AVAILABLE ***		715.13	715.13	715.13	830.94	1166.14	1400.41	1782.98
DISTRIBUTION	REACTOR COOLANT	519.00	55.13	63.59	132.36	132.36	132.36	132.36
	ACCUMULATOR	196.13	134.64	126.17	0.00	0.00	0.00	0.00
	TOTAL CONTENTS	715.13	189.77	189.77	132.36	132.36	132.36	132.36
EFFLUENT	BREAK FLOW	0.00	525.36	525.36	698.57	1033.77	1268.04	1650.61
	ECCS SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	525.36	525.36	698.57	1033.77	1268.04	1650.61
*** TOTAL ACCOUNTABLE ***		715.13	715.12	715.12	830.93	1166.13	1400.40	1782.97

TABLE 14.3-20a

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
ENERGY BALANCE

		ENERGY BALANCE						
	TIME (SECONDS)	0.00	27.50	27.50	202.29	687.30	1110.09	3600.00
		ENERGY (MILLION BTU)						
INITIAL ENERGY	IN RCS,ACC,S GEN	805.35	805.35	805.35	805.35	805.35	805.35	805.35
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00	7.88	30.67	48.03	107.07
	DECAY HEAT	0.00	8.22	8.22	27.59	68.35	98.41	235.95
	HEAT FROM SECONDAR	0.00	-1.19	-1.19	-1.19	1.53	3.30	3.30
	TOTAL ADDED	0.00	7.04	7.04	34.28	100.56	149.74	346.32
*** TOTAL AVAILABLE ***		805.35	812.39	812.39	839.63	905.91	955.09	1151.68
TRIBUTION	REACTOR COOLANT	307.73	13.20	14.04	35.94	35.94	35.94	35.94
	ACCUMULATOR	19.52	13.40	12.56	0.00	0.00	0.00	0.00
	CORE STORED	26.63	13.91	13.91	3.95	3.78	3.60	2.57
	PRIMARY METAL	172.18	162.86	162.86	131.21	89.76	74.58	54.11
	SECONDARY METAL	78.03	78.23	78.23	69.48	52.12	40.32	29.53
	STEAM GENERATOR	201.27	207.75	207.75	180.42	132.53	103.08	76.01
	TOTAL CONTENTS	805.35	489.35	489.35	420.99	314.12	257.52	198.15
EFFLUENT	BREAK FLOW	0.00	323.05	323.05	410.95	584.10	689.88	945.83
	ECCS SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	323.05	323.05	410.95	584.10	689.88	945.83
*** TOTAL ACCOUNTABLE ***		805.35	812.39	812.39	831.93	898.21	947.39	1143.98

TABLE 14.3-21

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
PRINCIPAL PARAMETERS DURING REFLOOD

TIME	FLOODING TEMP	FLOODING RATE	CARRYOVER FRACTION	CORE HEIGHT	DOWNCOMER HEIGHT	FLOW FRACTION	INJECTION TOTAL	INJECTION ACCUMULATOR	INJECTION SPILL	ENTHALPY
SECONDS	DEGREE F	IN/SEC		FT	FT		(POUNDS MASS PER SECOND)			BTU/LBM
27.5	235.8	0.000	0.000	0.00	0.00	0.250	0.0	0.0	0.0	0.00
28.1	232.5	19.563	0.000	0.52	0.61	1.000	7244.0	6562.1	0.0	96.57
28.2	231.6	20.501	0.000	0.69	0.62	1.000	7216.8	6534.8	0.0	96.56
28.4	229.9	19.154	0.000	1.02	0.62	1.000	7163.2	6481.1	0.0	96.53
28.9	228.7	1.569	0.112	1.33	1.27	1.000	7017.1	6334.6	0.0	96.47
29.2	228.8	3.329	0.189	1.39	1.80	0.682	6916.2	6233.4	0.0	96.42
29.9	228.9	2.615	0.308	1.50	2.85	0.573	6770.6	6087.5	0.0	96.35
31.6	229.5	2.300	0.481	1.70	5.69	0.466	6413.3	5729.4	0.0	96.17
35.1	230.9	2.432	0.623	2.00	11.22	0.404	5812.1	5126.9	0.0	95.82
39.6	232.8	3.675	0.701	2.36	16.06	0.531	4720.4	4078.6	0.0	95.25
41.2	233.4	3.576	0.714	2.50	16.07	0.530	4541.2	3898.9	0.0	95.08
42.6	234.0	3.476	0.722	2.62	16.07	0.526	4419.2	3774.3	0.0	94.93
47.8	236.6	3.205	0.738	3.01	16.07	0.513	4027.4	3374.2	0.0	94.42
55.4	241.2	2.941	0.748	3.50	16.07	0.496	3568.6	2906.7	0.0	93.69
57.6	242.6	2.880	0.749	3.64	16.07	0.491	3453.6	2789.9	0.0	93.48
58.7	243.3	3.591	0.752	3.71	16.00	0.565	627.3	0.0	0.0	68.00
62.8	246.3	3.428	0.754	4.01	15.55	0.563	631.5	0.0	0.0	68.00
70.7	252.9	3.117	0.758	4.53	14.89	0.555	643.0	0.0	0.0	68.00
78.6	259.9	2.886	0.762	5.00	14.46	0.548	651.1	0.0	0.0	68.00
87.7	266.7	2.678	0.766	5.50	14.18	0.540	657.8	0.0	0.0	68.00
97.7	272.7	2.507	0.771	6.00	14.07	0.534	662.5	0.0	0.0	68.00
108.7	278.0	2.372	0.776	6.51	14.13	0.527	665.8	0.0	0.0	68.00
120.3	282.6	2.273	0.782	7.00	14.34	0.523	668.0	0.0	0.0	68.00
132.7	286.6	2.206	0.788	7.50	14.66	0.520	669.3	0.0	0.0	68.00
145.9	290.0	2.165	0.795	8.00	15.08	0.518	670.0	0.0	0.0	68.00
146.7	290.2	2.166	0.795	8.03	15.11	0.518	669.9	0.0	0.0	68.00
148.7	290.7	2.165	0.796	8.10	15.17	0.519	669.8	0.0	0.0	68.00
160.7	293.1	2.176	0.802	8.64	15.53	0.525	668.6	0.0	0.0	68.00
164.7	293.9	2.178	0.804	8.68	15.63	0.528	668.2	0.0	0.0	68.00
173.7	294.4	2.174	0.805	9.00	15.80	0.532	667.7	0.0	0.0	68.00
188.7	293.5	2.135	0.802	9.53	15.96	0.536	668.1	0.0	0.0	68.00
202.3	294.2	2.056	0.804	10.00	16.03	0.537	669.4	0.0	0.0	68.00

TABLE 14.3-22

SYSTEM PARAMETERS

	Design
Plant model	4 loop, 12.0 ft core
NSSS Power	3216 MWt
Core inlet temperature	546.4 °F
Steam pressure	750 psia

TABLE 14.3-23

ASSUMPTIONS FOR CONTAINMENT ANALYSIS - PART 1

Service water temperature (°F)	95
Refueling water temperature (°F)	100
RWST available water volume (gal)	340,000
Initial containment temperature (°F)	130
Initial pressure (psia)	16.7
Initial relative humidity (%)	20
Net free volume (ft^3)	2.61×10^6

TABLE 14.3-24

ASSUMPTIONS FOR CONTAINMENT ANALYSIS - PART 2

Number of Fan Coolers	
Total	5
Operating maximum	5
Operating minimum	3
Number of spray pumps	
Minimum safeguards injection spray flow (gpm)	2200

TABLE 14.3-25

CONTAINMENT HEAT SINKS

No.	Material	Heat Transfer Area ft^2	Thickness in
1	Carbon Steel Concrete	41530	0.375 54.0
2	Carbon Steel Concrete	26012	0.5 42.0
3	Concrete	13636	12.0
4	Concrete	55454	12.0
5	Stainless Steel Concrete	9091	0.375 12.0
6	Carbon Steel	62538	0.5
7	Carbon Steel	74276	0.375
8	Carbon Steel	25407	0.25
9	Carbon Steel	63454	0.1875
10	Carbon Steel	2727	0.125
11	Carbon Steel	20000	0.138
12	Carbon Steel	9090	0.0625

TABLE 14.3-25 (Continued)

CONTAINMENT HEAT SINKS

No.	Material	Heat Transfer Area ft^2	Thickness in
13	Stainless Steel	714	0.019
	PVC Insulation		1.25
	Carbon Steel		0.75
	Concrete		54.0
14	Stainless Steel	6226	0.019
	PVC Insulation		1.25
	Carbon Steel		0.5
	Concrete		54.0
15	Stainless Steel	3469	0.025
	Foam Insulation		1.5
	Carbon Steel		0.5
	Concrete		54.0
16	Stainless Steel	3965	0.025
	Foam Insulation		1.5
	Carbon Steel		0.375
	Concrete		54.0

NOTE:

All carbon steel exterior surfaces are modeled with a layer of paint with a thickness equaling 0.00033 ft. followed by another paint layer of Carbozinc at a thickness of 0.000258 ft.

TABLE 14.3-26

THERMOPHYSICAL PROPERTIES OF CONTAINMENT HEAT SINKS

Material	Thermal Conductivity (Btu/hr-ft - °F)	Volumetric Heat Capacity (Btu/ft^3 - °F)
Paint layer 1, Phenoline	0.08	28.8
Paint layer 2, Carbozinc	0.9	28.8
Carbon Steel	26.0	56.35
Stainless Steel	8.6	56.35
Concrete	0.8	28.8
PVC Insulation	0.0208	1.20
Foam Insulation	0.0417	1.53

TABLE 14.3-27

DESIGN BASIS ACCIDENT CHRONOLOGY OF EVENTS

Time (Seconds)	Event
0.0	Start of accident
27.5	End of blowdown phase
60.0	Containment fan coolers start
72.0	Containment sprays start
202.3	End of reflood phase
695.0	Peak Pressure Reached
2811.0	RWST empties
2811.0	Sump recirculation starts

FIGURE 14.3-105

FAN COOLER HEAT REMOVAL AS A
FUNCTION OF CONTAINMENT PRESSURE

Service Water Temperature = 95°F

Service Water Flow Rate = 1600 gpm

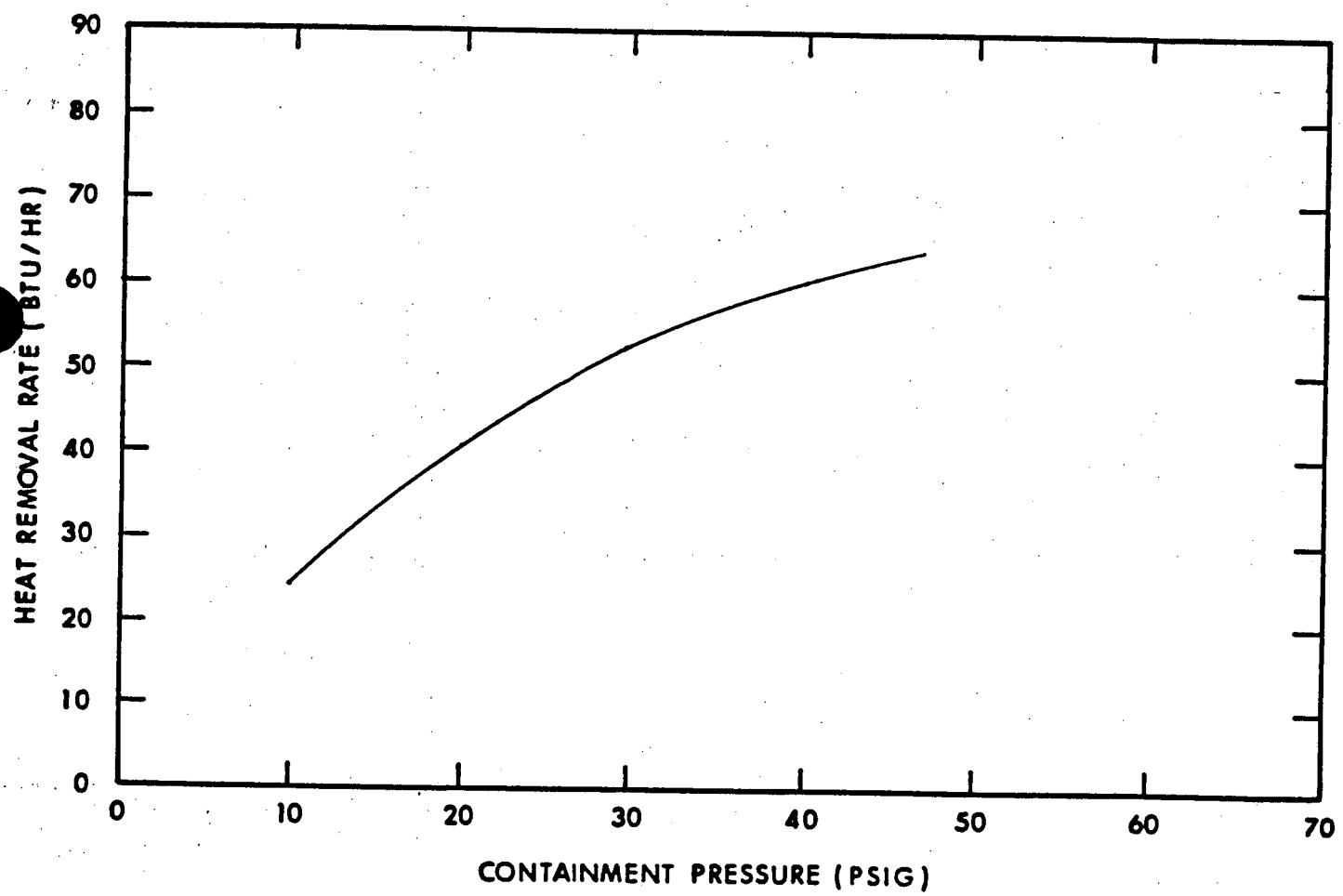


FIGURE 14.3-106

INSTANTANEOUS ENERGY RELEASE RATES

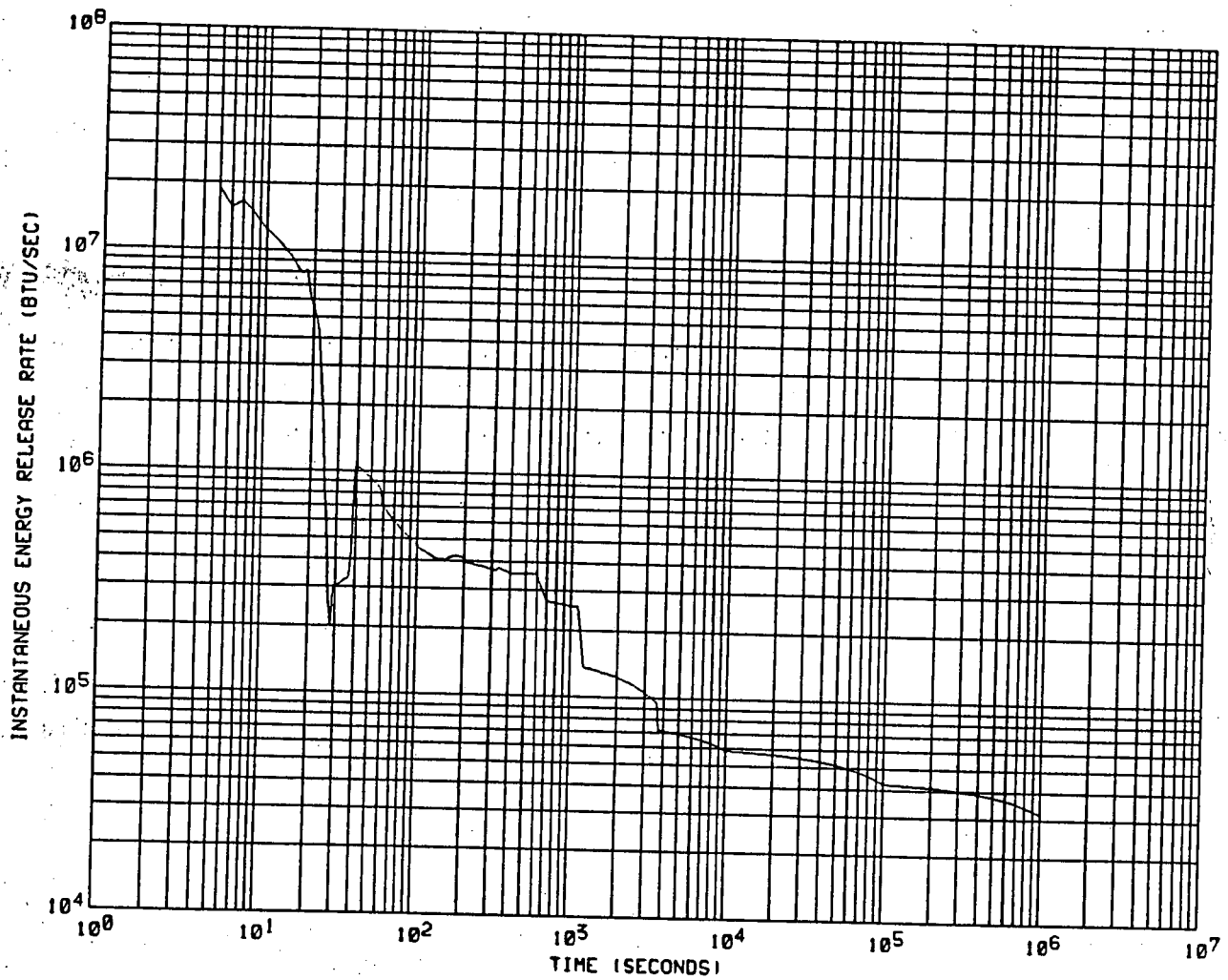


FIGURE 14.3-107

DOUBLE ENDED PUMP SUCTION BREAK
WALL HEAT REMOVAL

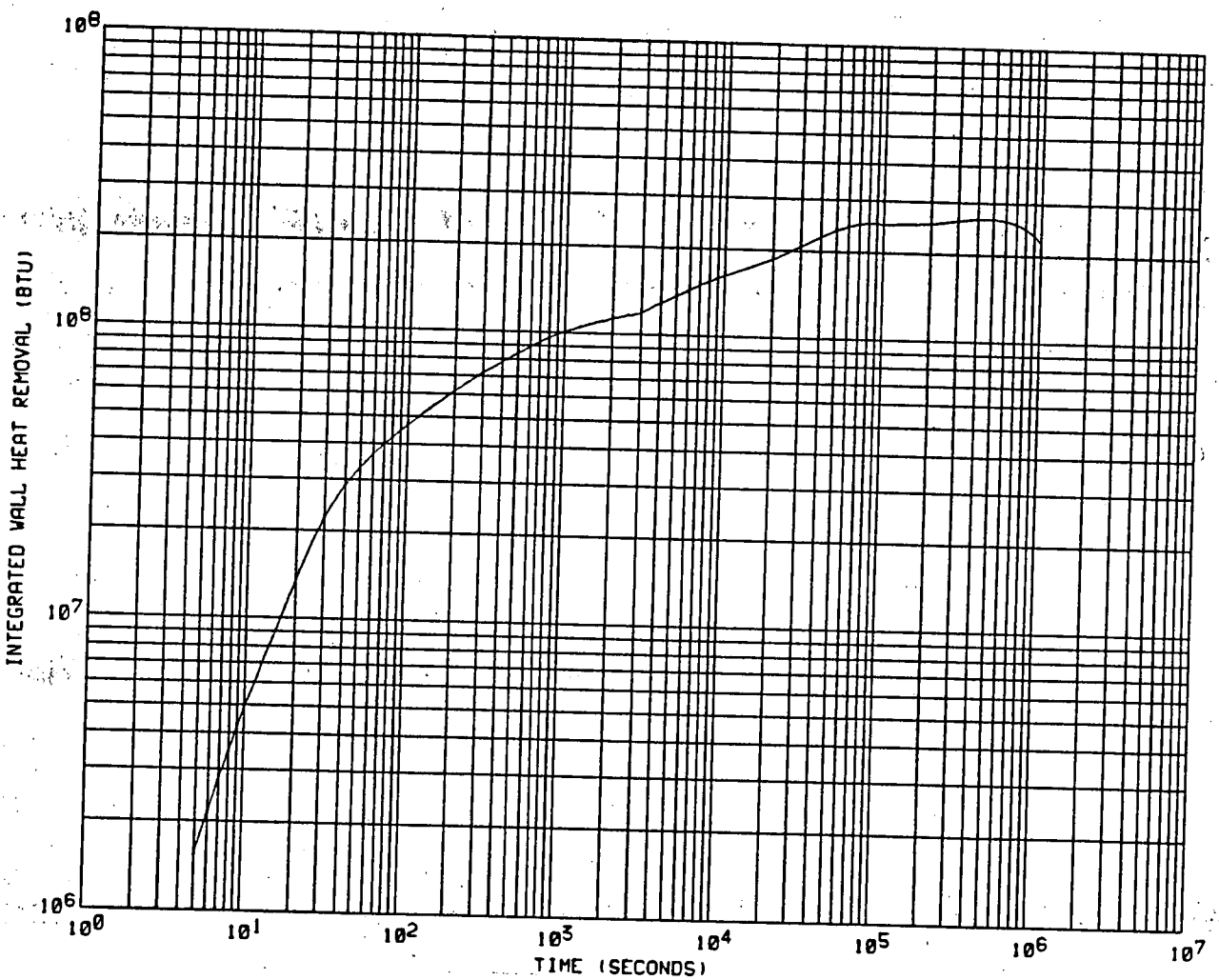


FIGURE 14.3-107A

DOUBLE ENDED PUMP SUCTION BREAK
FAN COOLER HEAT REMOVAL

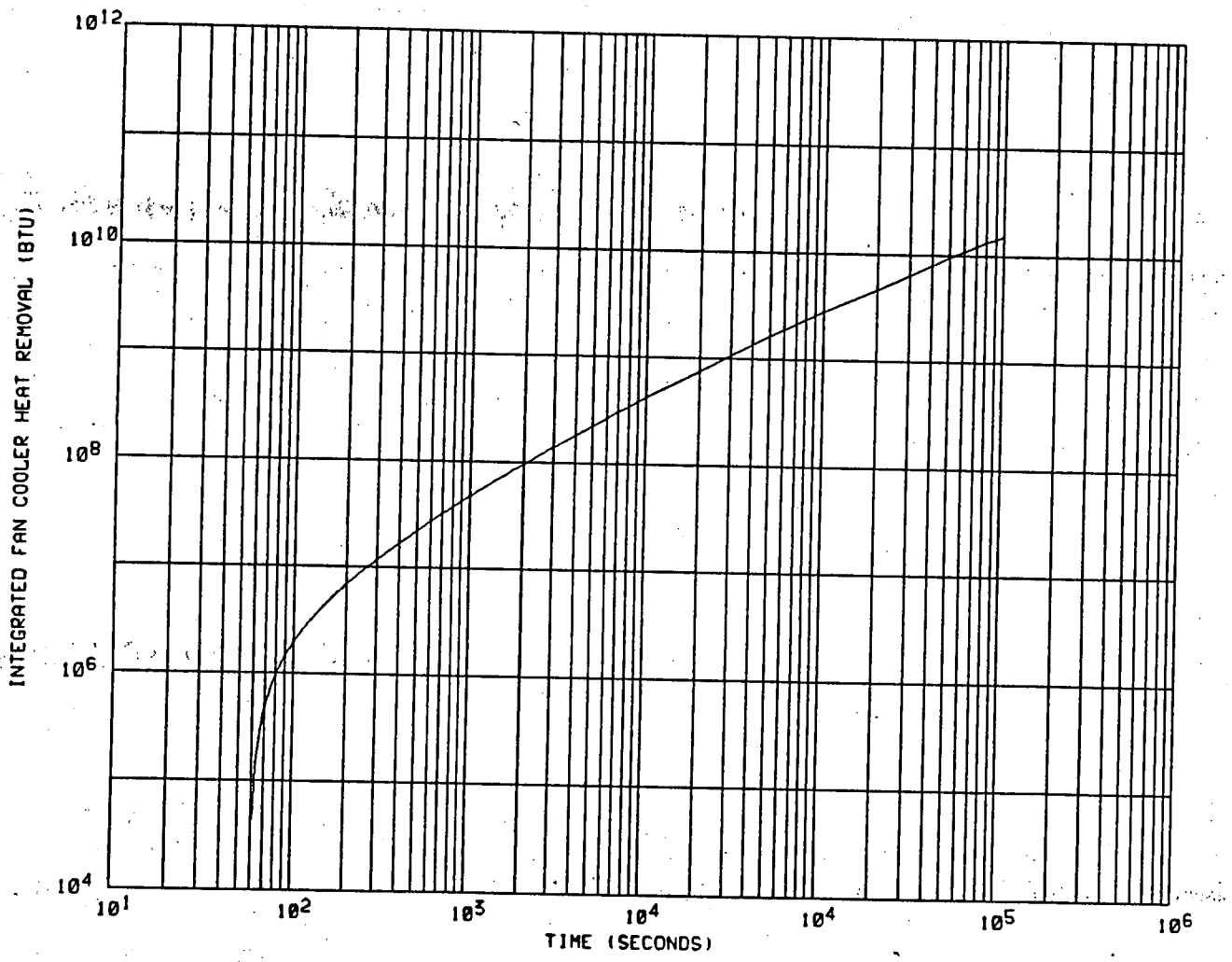


FIGURE 14.3-107B

DOUBLE ENDED PUMP SUCTION BREAK
SPRAY HEAT REMOVAL

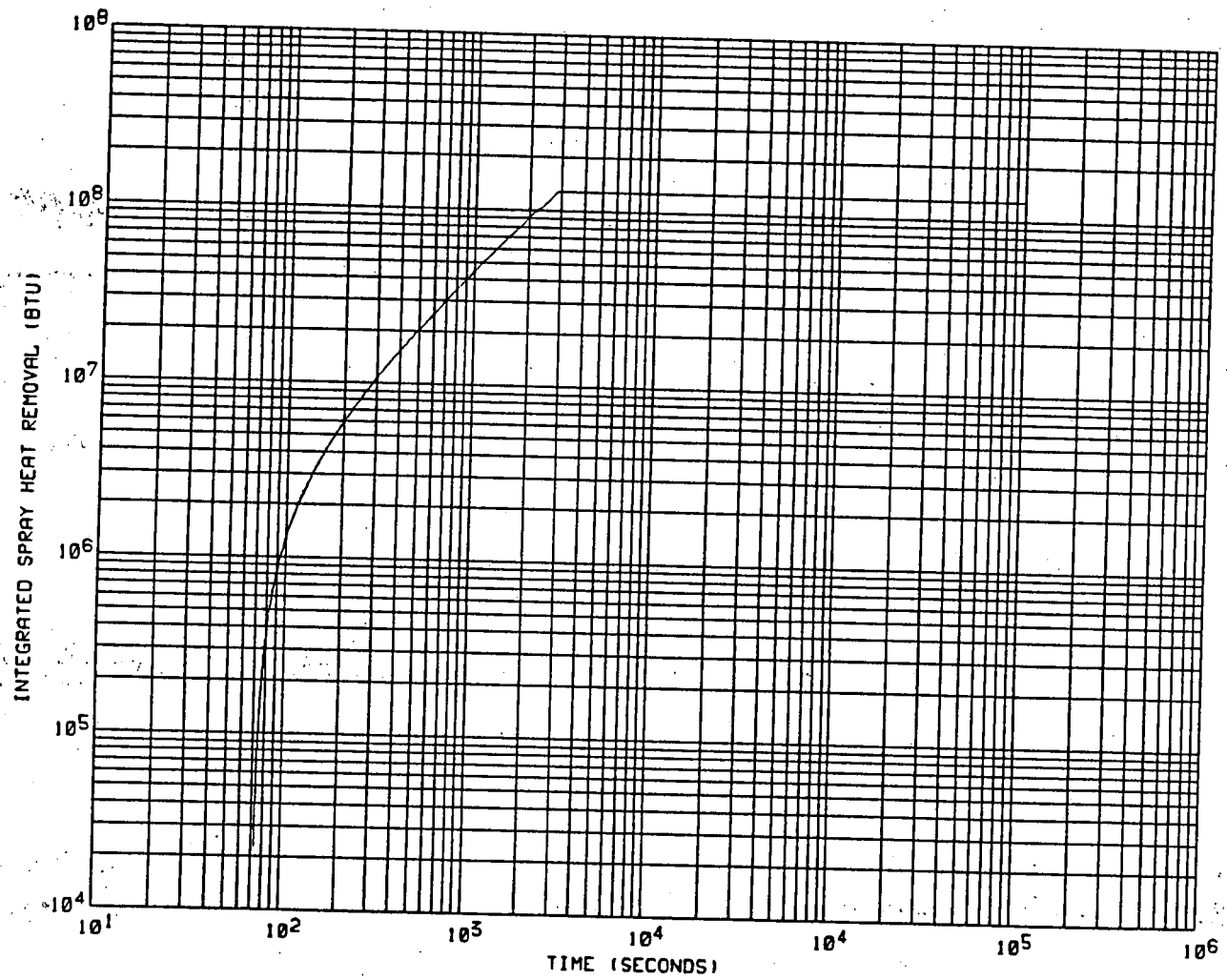


FIGURE 14.3-108

STRUCTURAL HEAT TRANSFER COEFFICIENT

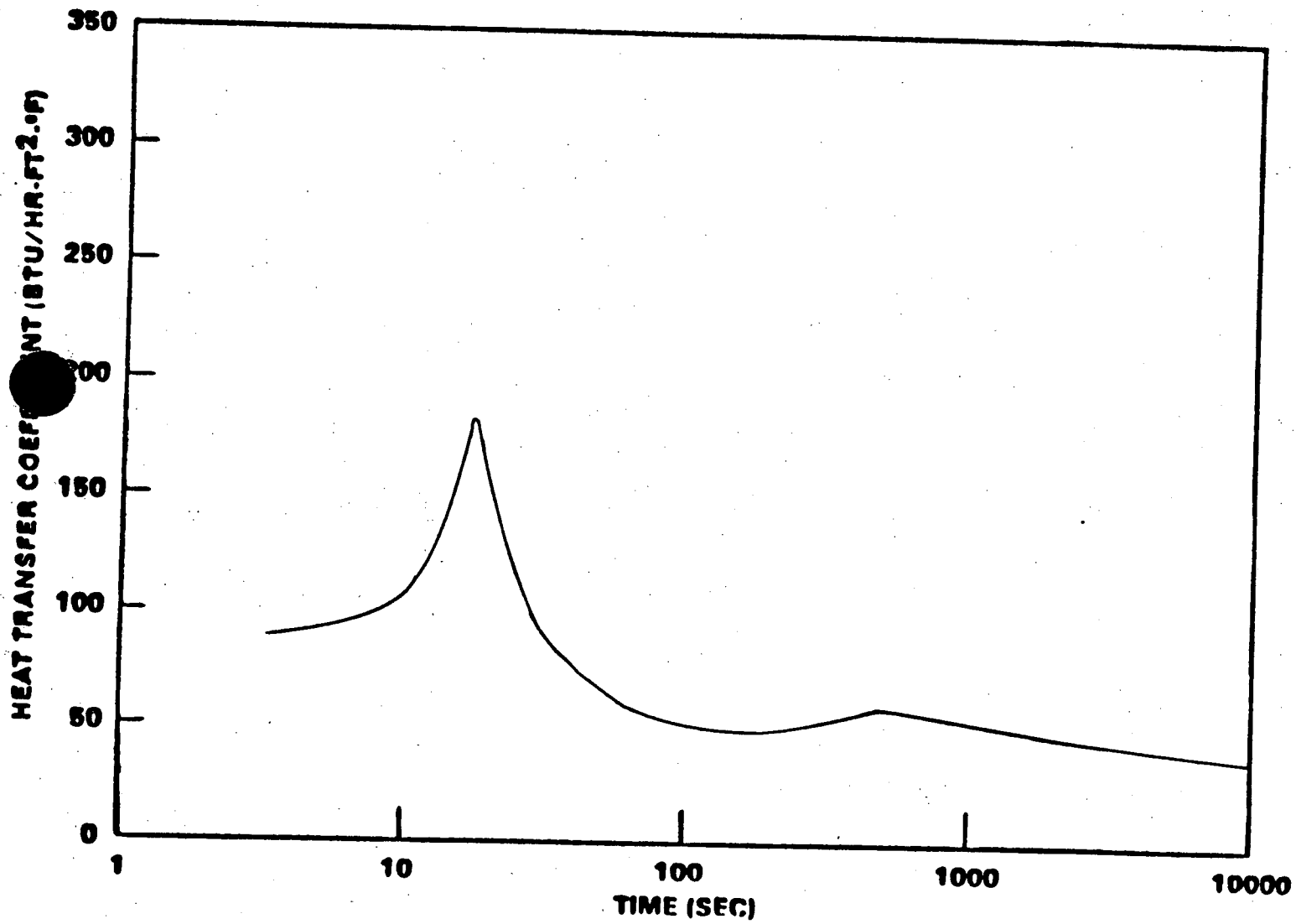


FIGURE 14.3-109

DOUBLE ENDED PUMP SUCTION BREAK
MINIMUM SAFEGUARDS
3216 MWT

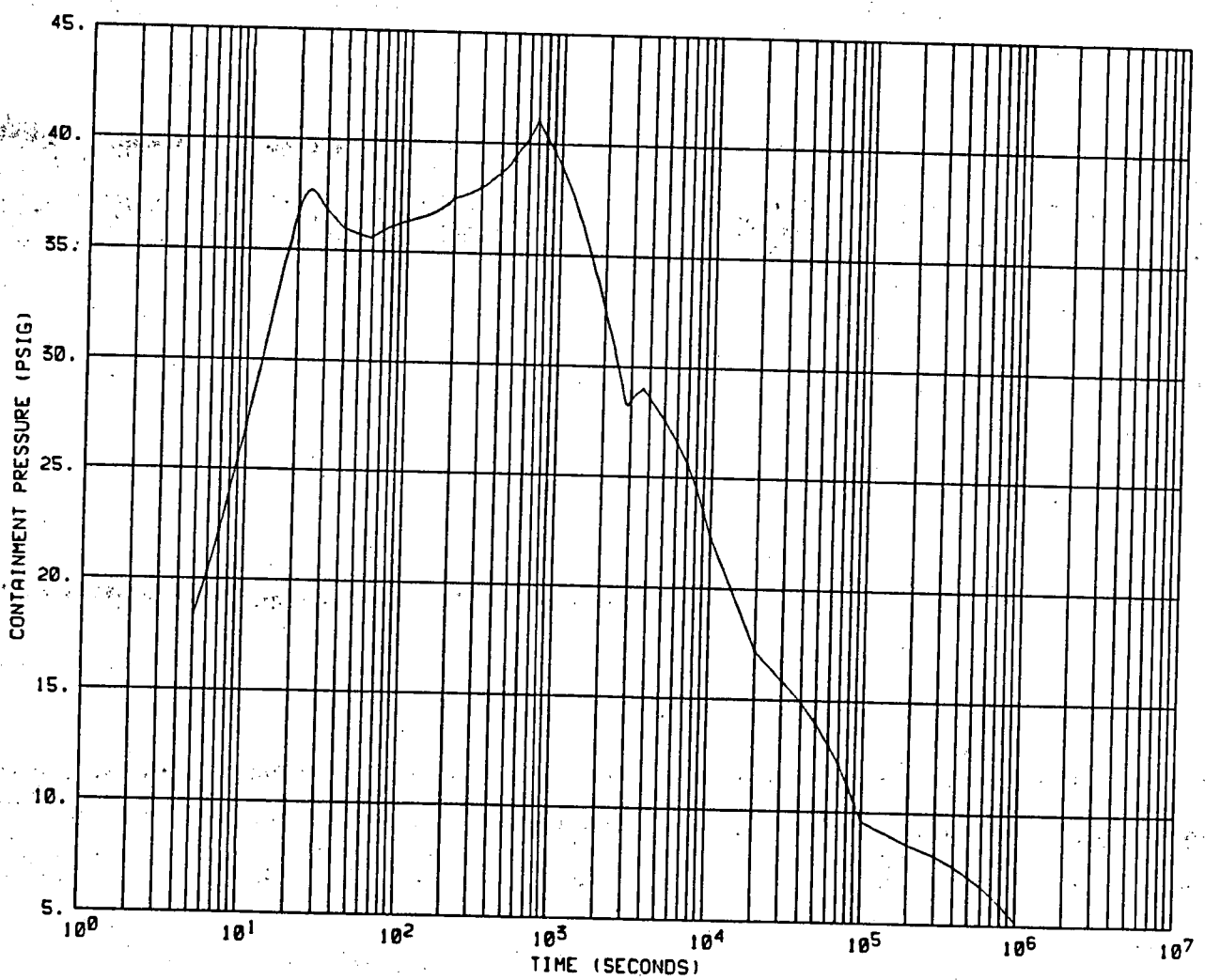
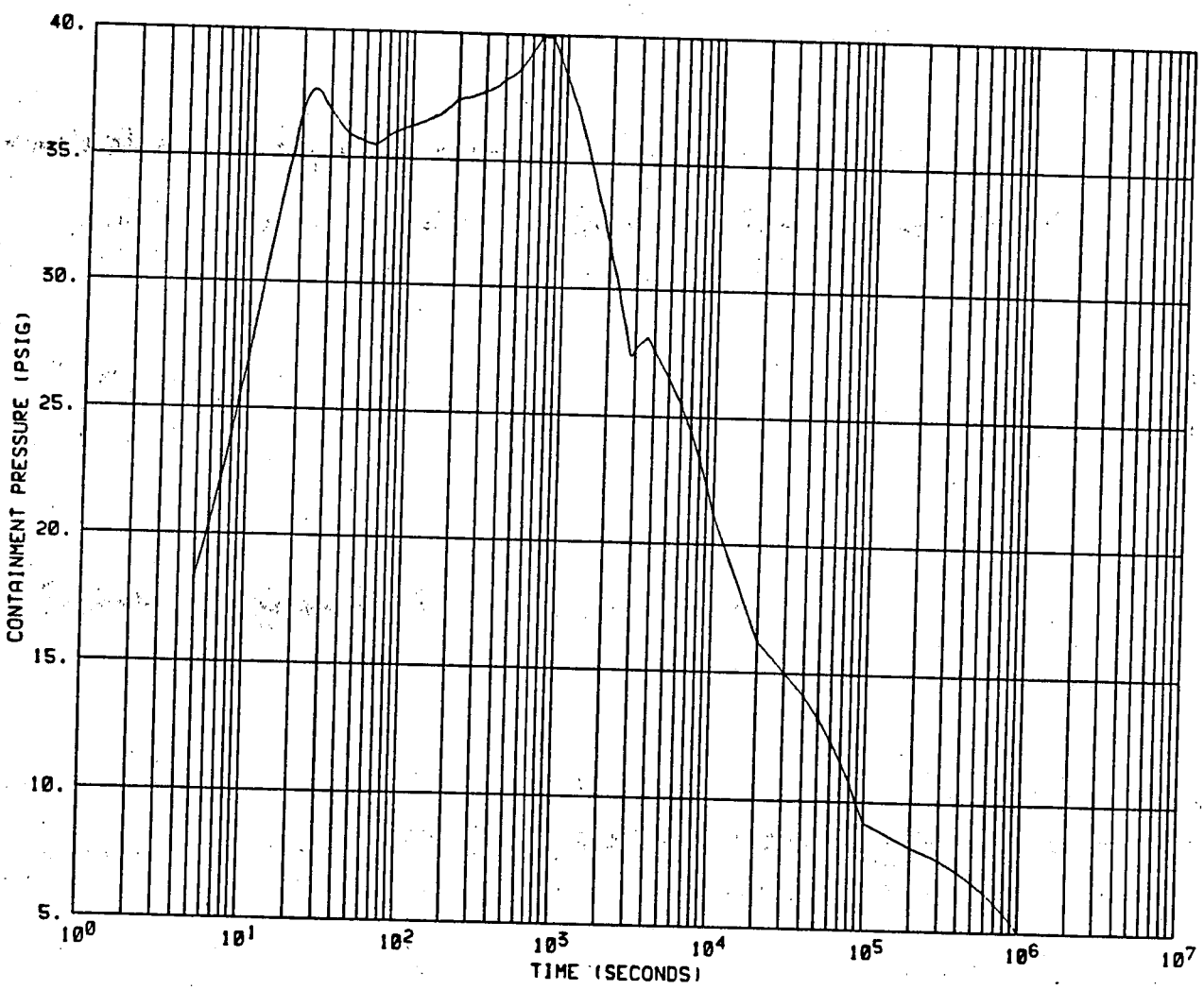


FIGURE 14.3-110

DOUBLE ENDED PUMP SUCTION BREAK
MINIMUM SAFEGUARDS
3083.3 MWT



APPENDIX 14.3.5A

This Appendix reflects analyses previously submitted to the NRC in Con Edison's Application for License Amendment dated June 12, 1987, supplemented on August 3, 1987 and May 10, 1988 and was subsequently approved by the NRC per their SER dated June 29, 1988.

APPENDIX 14.3.5A

14.3.5A CONTAINMENT INTEGRITY ANALYSIS

14.3.5A.1 Containment Structure

14.3.5A.1.1 Design Bases - The Indian Point Unit 2 containment structure performs a safety-related function. Its design pressure is 47 psig. The limiting design basis LOCA for containment design is a reactor coolant system double-ended pump suction (DEPS) rupture; this accident results in the highest containment pressure after a LOCA. For long-term conditions, the DEPS rupture, assuming operation of the minimum emergency safeguards system equipment and failure of one diesel generator, is the limiting case. The calculated pressure resulting from the DEPS accident is 40.5 psig with minimum containment safeguards of three fan coolers and one containment spray pump operating. This calculated pressure is well below the containment design pressure of 47 psig. The worst case secondary system pipe rupture has also been analyzed to determine containment integrity (Section 14.2.5.6). The calculated containment pressure for this case is less than 31 psig.

Sources and amounts of energy that may be available for release to the containment are discussed in Paragraph 14.3.5A.3. Energy is added to the containment in the conservative manner most detrimental to peak pressure response in order to obtain the limiting pressure.

Systems for removing energy from within the containment include the component cooling water system, the service water system, the recirculation system (which is backed up by the residual heat removal system), containment fan coolers, and containment spray system. Heat removal by recirculation spray, which is part of the Engineered Safety Features (ESF), was not assumed in this analysis. For informational purposes only, the DEPS minimum safeguards case was run with a recirculation spray flow

rate of 1494 gpm. The resulting containment transient exhibits a pressure 8 hours after the LOCA event which is five psig less than the design basis case. During the recirculation phase, the recirculation system removes the heat from the reactor fuel via containment sump water. Containment spray is used for rapid pressure reduction and for containment iodine removal. The containment fan coolers remove energy from the containment atmosphere.

The ESF systems are redundant and independent such that any single active failure in the engineered safety features system during the injection phase or any single active or passive failure during recirculation will not affect the ability to achieve required safety functions.

14.3.5A.1.2 System Design - Structural design of the containment and containment internal structures is discussed in Chapter 5.

14.3.5A.1.3 Design Evaluation - The results of the transient analysis of the containment for the loss-of-coolant accidents are shown in Figures 14.3A-110 through 14.3A-116. The cases examined in this analysis determine the effects of the full range of large reactor coolant break sizes up to and including a double-ended rupture. Cases illustrating the sensitivity to break location are also shown. All of these design basis cases show that the containment pressure will remain below design pressure with margin without taking credit for the recirculation spray. After the peak pressure is attained, the performance of the minimum safeguards system reduces the containment pressure. At the end of the first day following the accident, the containment pressure has been reduced to a low value. The peak pressures are shown in Table 14.3A-37 for a variety of containment safeguards availability assumptions. The 3-ft^2 pump suction is not carried out into reflood because its blowdown performance demonstrates it to be less limiting than the DEPS case.

Calculation of containment pressure and temperature transients is accomplished by use of the digital computer code, COCO (Reference [1]). Transient phenomena within the reactor coolant system affect containment conditions by means of mass and energy transport through the pipe break.

For analytical rigor and convenience, the containment air-steam-water mixture is separated into systems. The first system consists of the air-steam phase; the second consists of the water phase. Sufficient relationships to describe the transient are provided by the equations of conservation of mass and energy as applied to each system, together with appropriate boundary conditions. Thermodynamic equations of state and conditions may vary during the transient. The equations have been derived for all possible cases of superheated or saturated steam and subcooled or saturated water. Switching between states is handled automatically within the COCO code. The following are the major assumptions made in the containment analysis:

(a) Discharge mass and energy flow rates through the reactor coolant system break are established from the analysis in Paragraph 14.3.5A.3.

(b) For the blowdown portion of the LOCA analysis, the discharge flow separates into steam and water phases at the break point. The saturated water phase is at the total containment pressure, while the steam phase is at the partial pressure of the steam in the containment. For the post-blowdown portion of the LOCA analysis, steam and water releases are input separately.

(c) Homogeneous mixing is assumed. The steam-air mixture and the water phase each have uniform properties. More specifically, thermal equilibrium between the air and steam

is assumed. This does not imply thermal equilibrium between the steam-air mixture and the water phase, which may be at different temperature.

(d) Air is taken as an ideal gas, while compressed water and steam tables are employed for water and steam thermodynamic properties.

14.3.5A.1.4 Initial Conditions - The pressure, temperature, and humidity of the containment atmosphere prior to the postulated reactor coolant system rupture are conservatively specified in the analysis. Also, conservative values for the temperature of the service water and refueling water storage tank water solution are assumed, along with the initial water inventory of the refueling water storage tank. All of these values are as shown in Table 14.3A-38.

In each of the transients, the safeguards systems shown in Table 14.3A-39 are assumed to operate with a 60 second delay in startup. The assumed spray flow rate is based on one of two trains of the containment spray system operating.

14.3.5A.1.5 Heat Removal - The significant heat removal source during the early portion of the transient are structural heat sinks. Provision is made in the containment pressure transient analysis for heat transfer through, and heat storage in, both interior and exterior walls. Every wall is divided into many nodes; for each node, a conservation of energy equation expressed in finite-difference form accounts for transient conduction into and out of the node and temperature rise of the node. Tables 14.3A-40 and 14.3A-41 are summaries of the containment structural heat sinks used in the analysis.

The heat transfer coefficient to the containment structure is calculated by the code based primarily on the work of Tagami (Reference [3]). From this work, it was determined that the

value of the heat transfer coefficient increases parabolically to peak value at the end of blowdown for LOCA. The value then decreases exponentially to a stagnant heat transfer coefficient which is a function of steam-to-air-mass ratio.

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

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

From this, the maximum h of steel is calculated:

$$h_{max} = 75 \left[\frac{E}{t_p V}\right]^{0.60} \qquad (14.3A\text{-}1)$$

where:

h_{max} = maximum value of h (Btu/hr ft^2 °F).

t_p = time from start of accident to end of blowdown

V = containment volume (ft^3).

E = coolant energy discharge (Btu).

The parabolic increase to the peak value is given by:

$$h_s = h_{max} \left(\frac{t}{t_p}\right)^{0.5}, \quad 0 \leq t \leq t_p \qquad (14.3A\text{-}2)$$

where:

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

t = time from start of accident (sec).

For concrete, the heat transfer coefficient is taken as 40 percent of the value calculated for steel.

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

$$h_s = h_{stag} + (h_{max} - h_{stag})\, e^{-0.05(t-t_p)},\ t > tp \qquad (14.3A\text{-}3)$$

where:

h_{stag} = $2 + 50X,\ 0 \leq X \leq 1.4.$

h_{stag} = h for stagnant conditions (Btu/hr ft^2 °F).

X = steam-to-air mass ratio in containment.

For a large break, the engineered safety features are quickly brought into operation. Because of the brief period of time required to depressurize the reactor coolant system, the containment safeguards do not influence the blowdown peak pressure; however, they significantly reduce the containment pressure after the blowdown and maintain a low long-term pressure. Also, although the containment structure is not a very effective heat sink during the initial reactor coolant system blowdown, it still contributes significantly as a form of heat removal.

14.3.5A.2 Engineered Safety Features

During the injection phase of post-accident operation, the emergency core cooling system pumps water from the refueling water storage tank (RWST) into the reactor vessel (the containment spray pumps also inject RWST water into the containment). Since this water enters the vessel at refueling water storage tank temperature, which is less than the

temperature of the water in the vessel, it can absorb heat from the core until saturation temperature is reached. During the recirculation phase of operation, water is taken from the containment sump and cooled in the residual heat removal heat exchanger. The cooled water is then pumped back to the reactor vessel to absorb more decay heat. The heat is removed from the residual heat exchanger by component cooling water and from the component cooling heat exchanger by service water.

14.3.5A.2.1 Containment Spray

Another containment heat removal system is the containment spray. During the injection phase of operation, the containment spray pumps draw water from the RWST and spray it into the containment through nozzles mounted high above the operating deck. As the spray droplets fall, they absorb heat from the containment atmosphere. Since the water comes from the RWST, the entire heat capacity of the spray from the RWST temperature to the temperature of the containment atmosphere is available for energy absorption. During the recirculation phase of post-accident operation, water can be drawn from the residual heat removal heat exchanger outlet and sprayed into the containment atmosphere via the recirculation spray system. However, recirculation spray is not modeled in the COCO code and no-credit is taken for this system in the analyses provided herein; Figure 14.3A-111 is provided for information only.

When a spray drop enters the hot, saturated, steam-air containment environment following a loss-of-coolant accident, the vapor pressure of the water at its surface is much less than the partial pressure of the steam in the atmosphere. Hence, there will be diffusion of steam to the drop surface and condensation on the drop. This mass flow will carry energy to the drop. Simultaneously, the temperature difference between the atmosphere and the drop will cause the drop temperature and

vapor pressure to rise. The vapor pressure of the drop will eventually become equal to the partial pressure of the steam, and the condensation will cease. The temperature of the drop will equal the temperature of the steam-air mixture.

The equations describing the temperature rise of a falling drop are as follows:

$$\frac{d}{dt}(Mu) = mh_g + q \qquad (14.3A\text{-}4)$$

$$\frac{d}{dt}(M) = m \qquad (14.3A\text{-}5)$$

where:

$q = h_c A (T_s - T).$

$m = K_g A (P_s - P_v).$

The coefficients of heat transfer (h_c) and mass transfer (k_g) are calculated from the Nusselt number for heat transfer, Nu, and the Nusselt number for mass transfer, Nu'.

Both Nu and Nu' may be calculated from the equations of Ranz and Marshall (Reference [4]).

$$Nu = 2 + 0.6\,\underline{(Re)}^{1/2}\,\underline{(Pr)}^{1/3} \qquad (14.3A\text{-}6)$$

$$Nu' = 2 + 0.6\,\underline{(Re)}^{1/2}\,\underline{(Sc)}^{1/3} \qquad (14.3A\text{-}7)$$

Thus, Equations 14.3A-4 and 14.3A-5 can be integrated numerically to find the internal energy and mass of the drop as a function of time as it falls through the atmosphere. Analysis shows that the temperature of the (mass) mean drop produced by the SPRACO 1713A spray nozzles rises to a value within

99 percent of the bulk containment temperature in less than 2 seconds. Drops of approximately 1000 micron average size (as discussed in Chapter 6) will reach temperature equilibrium with the steam-air containment atmosphere after falling through less than half the available spray fall height.

Detailed calculations of the heatup of spray drops in post-accident containment atmospheres by Parsly (Reference[2]) show that drops of all sizes encountered in the containment spray reach equilibrium in a fraction of their residence time in a typical pressurized water reactor containment.

These results confirm the assumption that the containment spray will be 100 percent effective in removing heat from the atmosphere. Nomenclature in this section is as follows:

A = area.

h_c = coefficient of heat transfer.

k_g = coefficient of mass transfer.

h_g = steam enthalpy.

M = droplet mass.

m = diffusion rate.

$\underline{Nu}$ = Nusselt number for heat transfer.

$\underline{Nu'}$ = Nusselt number for mass transfer,

P_s = steam partial pressure.

P_v = droplet vapor pressure.

$\underline{Pr}$ = Prandtl number.

q = heat flow rate.

$\underline{Re}$ = Reynolds number.

$\underline{Sc}$ = Schmidt number.

T_s = droplet temperature.

T = steam temperature.

t = time.

u = internal energy.

14.3.5A.2.2 Reactor Containment Fan Coolers (RCFCs)

The reactor containment fan coolers are a principal means of post-accident containment heat removal. The fans draw the dense atmosphere through banks of finned cooling coils and mix the cooled steam/air mixture with the rest of the containment atmosphere. The coils are kept at a low temperature by maintaining the required flow of cooling water from the service water system. Since the RCFCs do not use water from the RWST, the mode of operation remains the same before and after the containment spray and emergency core cooling systems are changed to the recirculation mode.

The ability of the containment air recirculation coolers to function properly in the accident environment is demonstrated by the coil vendor's analysis. This analysis determines the plate-fin cooling coil heat removal rate when operating in a saturated steam-air mixture.

In the heat removal analysis of the RCFC coils, a mass flow rate of cooling water is first established. This determines the inside film coefficient of the tube. Next, the resistance to heat transfer between the cooling water and the outside of the fin collars is computed, including inside film coefficient, fouling factor,* tube radial conduction, fin-collar interface resistance, and conduction across the fin collars. The analysis now becomes iterative. One assumes an overall heat transfer rate Q_{tot} and the temperature at the outside of the fin collars is determined from Q_{tot} and the sum of the resistances cited above.

A second iterative procedure is now established. The variable whose value is assumed is the effective film coefficient between the fins and the gas stream, which involves the effect of convective heat transfer and mass transfer. With this value of $h_{effective}$, fin efficiency and the fin temperature distribution can be determined. It is assumed that a condensate film exists on the vertical fins. An analysis is performed which relates this film thickness to the rate of removal due to gravity and shear and the rate of addition of condensate by mass transfer from the bulk gas. In the process, from an energy balance the temperature of the interface between the bulk gas and the condensate can be determined; this is necessary for determining the mass transfer rate from the gas. Now that the thickness of the condensate film is known, the value of the assumed $h_{effective}$ is checked from the relation $h_{eff} = K_{water}/\delta_{film}$. If the assumed and computed values are not the same, a new value is selected and calculations repeated until the assumed and computed values are equal.

---

* A fouling factor of 0.001 hr-ft^2-°F/Btu, under both normal and design basis accident conditions, has been assumed for cooling coil design purposes. This value is conventionally used in sizing heat exchangers cooled by river water at 125°F or less and with tube water velocity greater than 3 ft/sec (Reference 5), and is considered sufficiently conservative for this application. Computer analysis of the coils selected shows that the required post-accident heat removal rate can be achieved even with a slight increase in fouling.

When this occurs, the heat transfer rate from the fins and fin collar is computed, using the standard equations for fin and fin collar heat transfer and the values of $h_{effective}$ and film-bulk gas interface temperature. If this value is not the same as Q_{tot}, initially assumed in order to determine fin collar temperature, the whole analysis is repeated with a new estimate of Q_{tot}. When, finally, the heat transfer rate to the cooling water from the fin collar equals the resulting computed rate to the fin collar and fins from the gas, the effect of this heat transfer rate on the cooling water is computed. The water exit temperature is established, and this value is used as the inlet temperature for the next heat exchanger pass. Also, the effect of convective heat transfer and condensate mass transfer is determined relative to the gas composition and thermodynamic state. The updated gas state is used as inlet conditions for the next pass. The process is repeated for the second, third, etc., passes until the gas exits the heat exchanger.

The mass transfer coefficients used in the computer code were derived from analyses and reports of experimental data contained in References 5, 6 and 7. From Reference 6, the mass flow rate of condensate is defined by*

$$\dot{m} = \bar{h}_D \, (\rho_{sg} - \rho_{sw}) \qquad (14.3A\text{-}8)$$

From Reference 6, pp. 471-473, experimental data for mass and heat transfer correlate well with the expression

$$\frac{\bar{h}_D}{u_s} (Sc)^{-2/3} = St \, (Pr)^{-2/3} \qquad (14.3A\text{-}9)$$

* Nomenclature used is given at the end of this discussion.

as shown in Figure 16-10 of Reference 6. Thus,

$$\bar{h}_D = u_s \times St\left(\frac{Sc}{Pr}\right)^{2/3}$$

$$\bar{h}_D = \frac{u_s \times h}{\rho C\ u_s} \times \left(\frac{Sc}{Pr}\right)^{2/3} \qquad (14.3A\text{-}10)$$

As Reference 6 points out, for large partial pressures of the condensing components, Equation 14.3A-10 must be corrected by a factor P_t/P_{am}. Thus, h_D is defined by

$$\bar{h}_D = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times \left(\frac{Sc}{Pr}\right)^{2/3} \qquad (14.3A\text{-}11)$$

This is essentially the same result as reported by Reference 7 p. 343 and Reference 8.

Reference 6 states that experiments show Equation (14.3A-8) to be valid when the Schmidt number does not differ greatly from 1.0. Equations (14.3A-8) and (14.3A-10) are combined to give the mass transfer rate, which is

$$\dot{m} = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times \left(\frac{Sc}{Pr}\right)^{2/3} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3A\text{-}12)$$

An approximation was made in assuming that $(Sc/Pr)^{2/3} \approx 1.0$, thus the local mass transfer rate was computed from

$$\dot{m} = \frac{h}{\rho C} \times \frac{P_t}{P_{am}} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3A\text{-}13)$$

The heat transfer rate due to condensation is computed from

$$q_1 = \frac{\dot{m}\ \lambda h P_t}{\rho C P_{am}} \times (\rho_{sg} - \rho_{sw}) \qquad (14.3A\text{-}14)$$

where

ρ_{sg} is evaluated at the local bulk gas temperature

ρ_{sw} is evaluated at the local gas-condensate interface temperature

λ is evaluated at the local gas-condensate interface temperature

P_t and C is evaluated at the local bulk gas temperature

The heat transfer coefficient, h, was determined from experiments on the same geometry used in this application.

The heat transfer rate, locally, is computed from

$$q_2 = h \times (T_g - T_i) \qquad (14.3A\text{-}15)$$

The basis for selecting these values is that the authorities cited as references have shown, through analyses and through cited experiments, that the methods used are accurate.

The air side pressure drop across the cooling coils at a conservative design-basis accident condition of 47 psig is estimated to be approximately 2.1 in. of water, or 0.076 psi. This will have a negligible effect on the heat removal capability of the cooling coils.

The pressure of noncondensible gases are taken into consideration because the theory behind the analysis assumed that the condensible vapor must diffuse through a noncondensible gas.

The nomenclature is as follows:

$\dot{m}$ mass flow rate of condensate, lbm/hr-ft^2

$\bar{h}_D$ mass transfer coefficient, ft/hr

ρ_{sg} density of saturated steam at local bulk gas temperature, lbm/ft^3

ρ_{sw} density of saturated steam at local condensate-gas interface temperature, lbm/ft^3

u_s free steam gas velocity, ft/min

Sc Schmidt number, $M/\rho D$, dimensionless

μ viscosity of bulk gas, lbm/ft-hr

ρ bulk gas density, lbm/ft^3

D gas-air diffusion coefficient, ft^2/hr

St Stanton number, $h/\rho C u_s$, dimensionless

h convective heat transfer coefficient, Btu/hr-ft^2-°F

C specific heat of bulk gas, Btu/lbm-°F

Pr Prandtl number, $\mu c/k$, dimensionless

k thermal conductivity of bulk gas, Btu/hr-ft-°F

P_t total gas pressure, lbf/ft^2

P_{am} air log-mean $\dfrac{P_{aw} - P_{ag}}{\ln \dfrac{P_{aw}}{P_{ag}}}$, lbf/ft^2

P_{aw} partial pressure of air at the local gas-condensate interface, lbf/ft^2

P_{ag} partial pressure of air at the local bulk gas temperature, lbf/ft^2

λ latent heat of vaporization (or condensation) at the local gas-condensate interface temperature, Btu/lbm

q_1 local heat transfer rate due to condensation, Btu/hr-ft^2

q_2 local heat transfer rate due to convection, Btu/hr-ft^2

T_g local bulk gas temperature, °F

T_i local gas-condensate interface temperature, °F

A similar heat removal analysis of the currently installed RCFC coils results in the fan-cooler heat removal rate per fan as presented in Figure 14.3A-105.

References

[1] WCAP-8326, E. T. Murphy, Containment Pressure Analysis Code (COCO), July 1974.

[2] L. F. Parsly, "Spray Tests at the Nuclear Safety Pilot Plant," in: Nuclear Safety Program Annual Progress Report for Period Ending December 31, 1970, ORNL-4647, 1971, p. 82.

[3] Takashi Tagami, "Interim Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June 1965," No. 1.

[4] E. W. Ranz and W. R. Marshall, Jr., "Evaporation for Drops," Chemical Engineering Progress, 48, pp. 141-146, March 1952.

[5] W. H. McAdams, Heat Transmission, 3rd Edition, McGraw-Hill Book Company, Inc., New York, 1954.

[6] E. R. G. Eckert and P. M. J. Drake, Heat and Mass Transfer, McGraw-Hill Book Company, Inc., New York, 1959.

[7] D. Q. Kern, Process Heat Transfer, McGraw-Hill Book Company, Inc., New York, 1950.

[8] T. H. Chilton and A. P. Colburn, "Mass Transfer (Absorption) Coefficients Prediction from Data on Heat Transfer and Fluid Friction," Ind. Eng. Chem., No. 26, 1934, pp. 1183-1187.

14.3.5A.3 Mass and Energy Release Analyses for Postulated Loss-of-Coolant Accidents

This analysis presents the mass and energy releases to the containment subsequent to a hypothetical loss-of-coolant accident (LOCA) at 3216 MWt. The release rates are calculated for pipe failure at three distinct locations:

1. Hot leg (between vessel and steam generator)
2. Pump suction (between steam generator and pump)
3. Cold leg (between pump and vessel)

The LOCA transient is typically divided into four phases:

1. Blowdown - which includes the period from accident occurrence (when the reactor is at steady state operation) to the time when the total break flow stops.

2. Refill - the period of time when the lower plenum is being filled by accumulator and safety injection water. (This phase is conservatively neglected in computing mass and energy releases for containment evaluations.)

3. Reflood - begins when the water from the lower plenum enters the core and ends when the core is completely quenched.

4. Post-Reflood - describes the period following the reflood transient. For the pump suction and cold leg breaks, a two-phase mixture exits the core, passes through the hot legs, and is superheated in the steam generators. After the broken loop steam generator cools, the flow out of the break becomes two phase.

During the reflood phase, these breaks have the following different characteristics. For a cold leg pipe break, all of the fluid which leaves the core must vent through a steam generator and becomes locally superheated. However, relative to breaks at the other locations, the core flooding rate (and therefore the rate of fluid leaving the core) is low, because all the core vent paths include the resistance of the reactor coolant pump. For a hot leg pipe break, the vent path resistance is relatively low, which results in a high core flooding rate, but the majority of the fluid which exits the core bypasses the steam generators in venting to the containment. The pump suction break combines the effects of the relatively high core flooding rate, as in the hot leg break, and steam generator heat addition, as in the cold leg break. As a result, the pump suction break yields the highest energy flow rates during the post-blowdown period, thereby bounding the hot leg breaks.

The spectrum of breaks analyzed includes the largest cold and hot leg breaks, reactor inlet and outlet, respectively, and a range of pump suction breaks from the largest (10.48 ft^2) to a 3.0 ft^2 break. Because of the phenomena of reflood as discussed above, the pump suction break location is the worst case for long term containment depressurization. Smaller hot leg breaks have been shown on similar plants to be less severe than the double-ended hot leg. Cold leg breaks, however, are lower both in the blowdown peak and in the reflood pressure rise. Thus, an analysis of smaller pump suction breaks is representative of the spectrum of break sizes.

14.3.5A.3.1 Mass and Energy Release Data

Blowdown Mass and Energy Release Data

Tables 14.3A-17 through 14.3A-21 present the calculated mass and energy releases for the blowdown phase of the various breaks analyzed.

The mass and energy releases for the double-ended pump suction break, given in Table 14.3A-17, terminate 29.0 seconds after the postulated accident. Since safety injection does not become effective until about the time blowdown terminates, these releases apply for both maximum and minimum safety injection.

Reflood Mass and Energy Release Data

Tables 14.3A-22 through 14.3A-25 present the calculated mass and energy releases for the reflood phase of the various breaks analyzed along with the corresponding safety injection assumption (maximum or minimum).

Two Phase Post-Reflood Mass and Energy Release Data

Tables 14.3A-26 and 14.3A-27 present the two phase (froth) mass and energy release data for a double-ended pump suction break using maximum and minimum safety injection assumptions, respectively.

Table 14.3A-28 presents the post-reflood mass and energy release data for 0.6 double-ended pump suction break using minimum safety injection.

Equilibrium and Depressurization Energy Release Data

The equilibrium and depressurization energy release has been incorporated in the post-reflood mass and energy release data. This eliminates the need to determine additional releases due to the cooling of steam generator secondary and primary metal.

14.3.5A.3.2 Mass and Energy Sources

The sources of mass considered in the LOCA mass and energy release analysis are given in the mass balance Tables 14.3A-29 through 33. These sources are the reactor coolant system, accumulators and pumped injection.

The energy inventories considered in the LOCA mass and energy release analysis are given in Tables 14.3A-29a through 33a. The energy sources include:

1. Reactor coolant system

2. Accumulators

3. Pumped injection

4. Decay heat

5. Core stored energy

6. Primary metal energy

7. Secondary metal energy

8. Steam generator secondary energy

9. Secondary transfer of energy (feedwater into and steam out of the steam generator secondary)

The inventories are presented at the following times, as appropriate:

1. Time zero (initial conditions)

2. End of blowdown time

3. End of refill time

4. End of reflood time

5. Time of full depressurization

6. End of analysis

The methods and assumptions used to release the various energy sources are given in NRC-approved WCAP-10325 (Reference [1]).

The following items ensure that the core energy release is conservatively analyzed for maximum containment pressure:

1. Maximum expected operating temperature of the reactor coolant system

2. Allowance in operating temperature for instrument error and dead band (+4°F)

3. Margin in volume (1.4 percent)

4. Allowance in volume for thermal expansion (1.6 percent)

5. A power level of 3216 MWt was assmued

6. Allowance for calorimetric error (2 percent of 3216 MWt)

7. Conservatively modified coefficients of heat transfer

8. Allowance in core stored energy for effect of fuel densification

9. Margin in core stored energy (+15 percent)

14.3.5A.3.3 Blowdown Model Description

The model used for blowdown transient (SATAN-VI) is the same as that used for the emergency core cooling system (ECCS) calculation. This model is described in WCAP-9220 and WCAP-8302. WCAP-10325 (Reference [1]) provides the method by which the model is used.

14.3.5A.3.4 Refill Model Description

At the end of blowdown, a large amount of water remains in the cold legs, downcomer, and lower plenum. To conservatively model the refill period for the purpose of containment mass and energy releases, this water is

instantaneously transferred to the lower plenum along with sufficient accumulator water to completely fill the lower plenum. Thus, the time required for refill is conservatively neglected.

14.3.5A.3.5 Reflood Model Description

The model used for the reflood transient (WREFLOOD) is a slightly modified version of that used in the ECCS calculation. This model is described in WCAP-9220 and WCAP-8170. WCAP-10325 describes the method by which this model is used and the modifications. Transients of the principal parameters during reflood are given in Tables 14.3A-34 and 35 for the double-ended pump suction break with maximum and minimum safety injection.

14.3.5A.3.6 Post-Reflood Model Description

Two-Phase (FROTH)

The transient model (FROTH), along with its method of use, is described in WCAP-8312-A. The mass and energy rates calculated by FROTH are utilized in the containment analysis to the time of containment depressurization.

Long Term (Dry Steam)

After depressurization, the mass and energy release from decay heat for 3216 MWt is based on ANS (1979) and the following input:

1. Decay heat sources considered are fission product decay and heavy element decay of U-239 and Np-239.

2. Decay heat power from fissioning isotopes other than U-235 is assumed to be identical to that of U-235.

3. Fission rate is constant over the operating history of maximum power level.

4. The factor accounting for neutron capture in fission products has been taken from Table 10 of ANS (1979).

5. Operation time before shutdown is 3 years.

6. The total recoverable energy associated with one fission has been assumed to be 200 MeV/fission.

7. Two sigma uncertainty has been applied to the fission product decay.

14.3.5A.3.7 Single Failure Analysis

The effect of single failures of various ECCS components on the mass and energy releases is included in these data. Two analyses bound this effect for the pump suction double-ended rupture.

No failure of any ECCS component is assumed in determining the mass and energy releases for the maximum safeguards case. For the minimum safeguards case, the single failure assumed is the loss of one emergency diesel generator, which failure results in not only the loss of one pumped safety injection train but also the loss of the containment safeguards on that diesel. The analysis of both maximum and minimum safeguards cases ensure that the effect of all credible single failures on mass and energy releases is bounded.

A single failure analysis is not performed for the hot leg or cold leg double-ended ruptures since the ECCS has no effect on the maximum containment pressure, which occurs at the end of blowdown.

14.3.5A.3.8 Metal-Water Reaction

In the mass and energy release data presented, no zirconium-water reaction heat was considered because the clad temperature did not rise high enough for the rate of reaction to be of any significance.

14.3.5A.3.9 Additional Information

System parameters needed to perform confirmatory analyses are provided in Table 14.3A-36. The chronology of events for the DEPS break is presented in Table 14.3A-42.

14.3.5A.4 Containment Pressure Transients

The containment pressure was calculated for the following range of large area reactor coolant pipe ruptures: double-ended hot leg (DEHL), double-ended cold leg, double-ended pump suction (DEPS), double-ended pump suction with a discharge coefficient of 0.6, and a 3 sq. ft. pump suction break. The results obtained are presented in Table 14.3A-37 and are shown graphically in Figures 14.3A-110 through 14.3A-116. The DEPS case is analyzed for both minimum and maximum safeguards conditions. Consistent with the mass/energy release analysis, the failure of that diesel generator to start which leaves a minimum of equipment available constitutes the minimum safeguards condition. The minimum safeguards case models one containment spray pump and the fan cooler heat removal equivalent to three units operating as indicated in Figure 14.3A-105. In the maximum safeguards case five fan cooler units and one containment spray pump operate, the single failure being the failure of the second spray pump.

14.3.5A.4.1 Energy Sinks

Figure 14.3A-109 presents the energy absorption capability within the 2.61 x 10^6 ft^3 free volume of the containment. As shown at Point B, the internal energy of the steam-air mixture must be increased to 302 x 10^6 Btu for the containment pressure to reach the design pressure of 47 psig.

The integrated containment energy balance at the end of blowdown is given by:

$$U_f = U_i + \Sigma(mh)_{in} + \Sigma Q_{in} - \Sigma Q_{out} \qquad (14.3A\text{-}21)$$

where

U_f = final internal energy in the containment
U_i = initial internal energy in the containment
$\Sigma(mh)_{in}$ = enthalpy added by blowdown sources
ΣQ_{in} = energy added directly to containment atmosphere
ΣQ_{out} = heat removal by containment structure and cooling system

The internal energy is made up of three sources: air, steam, and sump water. Only the air-steam mixture with the respective partial pressures contributes to the containment total pressure. The initial internal energy is based on the initial assumed containment conditions, 120°F and 16.7 psia.

Figure 14.3A-108 shows the heat transfer coefficient calculated for the various break sizes.

14.3.5A.4.2 Containment Margin Evaluation

The evaluation of the capability of the containment and containment cooling systems to absorb energy additions without exceeding the containment design pressure requires the consideration of two periods of time following a postulated large area rupture of the reactor coolant system.

The first period is the blowdown phase. Since blowdown occurs too rapidly for the containment cooling system to be activated, there must be sufficient energy absorption capability in the free volume of the containment (with due credit for energy absorption in the containment structures) to limit the resulting pressure to below design.

The second period is the post-blowdown period where the containment cooling systems must be able to absorb any postulated post-blowdown energy additions and continue to limit the containment pressure to below the design value.

14.3.5A.4.2.1 Margin - Blowdown Peak to Design Pressure

Point A in Figure 14.3A-109 corresponds to the internal energy at the time of peak pressure during the DEHL break blowdown, 253 x 10^6 Btu. In order for the pressure to increase to design pressure (47 psig), the internal energy

must be increased to 302 x 10^6 Btu (Point B). The allowed energy addition is, therefore, 49 x 10^6 Btu. Since energy transferred to the containment from the core is in the form of steam, the total transferred core energy corresponding to allowed energy addition is as follows:

$$Q_{core} = \frac{h_{fg}}{h_g} Q_{Allowed} = 49 \times 10^6 \times \frac{914.7}{1177.9} = 38 \times 10^6 \text{ Btu} \qquad (14.3A\text{-}22)$$

This allowable value of energy could be transferred from the core to the containment without increasing the transient containment pressure to design pressure.

14.3.5A.4.2.2 Margin - Non-Mechanistic Energy Sources

Line A to C on Figure 14.3A-109 represents a constant mass line. The comparison of the energy addition allowable for the superheated case relative to the saturated case shows a lesser ability of the containment to absorb an equivalent amount of energy as superheat. An addition of 13 x 10^6 Btu of energy after blowdown would cause the containment pressure to increase to design. Therefore, a substantial margin exists for energy additions from arbitrary energy sources.

14.3.5A.4.2.3 Margin - Post-Blowdown Energy Additions

Figure 14.3A-110 presents the containment pressure transient for the limiting DEPS case with three fan coolers equal in capability to Figure 14.3A-105 operating. In this case, the decay heat generated for a 3216 MWt core operating for an infinite time is conservatively assumed. This decay heat is added to the containment in the form of steam by the boiling off of water in the reactor vessel over the long term. Mass and energy releases during the reflood and post-reflood phases are presented in Table 14.3A-35.

The containment cooling system capability conservatively assumed in the analysis was one containment spray pump together with three available containment fan coolers. This is the minimum equipment available considering the single-failure criterion in the emergency power system, the spray system, and the fan cooler system. Figure 14.3A-111 presents the containment pressure transient for a case in which the same equipment operates but containment spray continues during recirculation.

The blowdown peak for each case was 37.2 psig; a peak pressure of 40.5 psig in Figure 14.3A-110 was reached at 520 sec. when the heat removal capability of the containment cooling system assumed to be operating (one containment spray pump and three fan coolers) exceeded the energy addition. The heat removal capability associated with three fan coolers (RCFC) is clearly adequate to limit containment peak pressure.

The integrated heat addition and heat removal for the DEPS minimum safeguards case with three fan coolers are shown in Figure 14.3A-106. The curve is presented in a manner that demonstrates the capability of the containment and the cooling systems to absorb energy. The integrated heat removal capacity is started at the internal energy corresponding to design pressure, while the integrated heat additions begin from the internal energy calculated at the end of blowdown. The upper line is the containment structure and containment cooling system calculated capability to absorb energy additions without exceeding design pressure. The lower curve is the energy addition curve for the DEPS case.

The curve in Figure 14.3A-107 presents the individual contributions to the heat removal during the three fan cooler DEPS minimum safeguards case. The critical parameter as regards calculated containment pressure is the available RCFC heat removal capacity. In this analysis three RCFCs with the heat removal characteristics presented in Figure 14.3A-105 are nominally modeled. However, any RCFC configuration which assures that heat removal greater than or equal to three times that of Figure 14.3A-105 is available via the RCFC system post-LOCA is equally acceptable. Service water flow rate and the number of RCFC available under accident conditions may be modified as long as the required RCFC heat removal capability exists.

14.3.5A.4.3 Evaluation of Containment Internal Structures

The containment internal structures such as the reactor coolant loop compartments and the reactor shield wall are designed for the pressure buildup that could occur following a loss of coolant. If a LOCA were to occur in these relatively small volumes, the pressure would build up at a rate faster than the overall compartments.

A digital computer code, COMCO, was developed to analyze the pressure buildup in the reactor coolant loop compartments. The COMCO code is largely an extension of the COCO code in that a separation of the two-phase blowdown into steam and water is calculated and the pressure buildup of the steam-air mixture in the compartment is determined. Each compartment has a vent opening to the free volume of the containment.

The main calculation performed is a mass energy balance within the control volume of a compartment. The pressure builds up in the compartment until a mass and energy relief through the vent exceeds the mass and energy entering the compartment from the break. The reactor coolant loop compartments are designed for the maximum calculated differential pressure resulting from an instantaneous double-ended rupture of the reactor coolant pipe.

There are two reactor coolant loop compartments (i.e., crane wall areas) with two loops in each compartment. The total free volume of each compartment is 113,500 ft^3 with a vent area of 1000 ft^2. The calculated differential pressure across the wall of the compartment is 6.4 psi.

The primary shield around the reactor vessel is designed for a pressure of 1000 psi to provide missile protection against the highly unlikely failure of the reactor vessel by longitudinal splitting or by various modes of circumferential cracking.

14.3.5A.5 Evaluation of Long Term Fan Cooler Capability

The ability of the fan coolers to limit containment pressure following loss of the component cooling system has been examined. If the component cooling loop

were lost for any reason during long-term recirculation, core subcooling could be lost and boiling in the core would begin. Since the cooling units of the fans are cooled by service water, the energy from the core would be removed from the containment via the fans.

The model employed in this analysis does not consider recirculation spray to operate and conservatively considers decay heat from the core to enter the containment as steam during the entire LOCA long-term transient. Therefore, the pressures calculated are not affected with a postulated component cooling system failure, because core energy is already postulated to enter the containment as boiloff. Containment pressure at various times for the DEPS case with minimum safeguards is shown below:

Time After Accident Occurs	3 Fans (psig)	2 Fans (psig)
At 12 hr	17	29
At 1 day	12	20
At 1 week	7	11

Reference:

[1] WCAP-10325, "Westinghouse LOCA Mass and Energy Release Model for Containment Design - March 1979 Version," April 25, 1979.

TABLE 14.3A-17

DOUBLE ENDED PUMP SUCTION GUILLOTINE
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0	0.0	0.0
0.0502	39674.8	21217.2	22792.7	12102.2
0.100	39649.4	21260.7	18541.6	9879.6
0.600	42552.9	24014.4	22332.6	11932.3
1.20	37051.5	21897.1	21333.3	11417.4
1.50	31403.8	19394.3	21045.8	11268.1
2.50	21542.7	13823.2	20028.9	10730.7
5.00	15178.5	9604.3	14616.0	7741.0
5.50	9798.9	7157.3	13728.4	7232.0
7.00	9410.6	6890.5	11795.4	6118.5
7.75	9983.3	6408.6	11448.4	5906.8
8.50	9216.6	5754.1	11997.3	6171.7
10.5	7073.0	4932.9	11071.6	5673.3
17.5	4170.5	3142.1	7539.3	3762.2
18.0	4070.9	2968.0	9441.0	4682.5
18.3	4054.0	2917.4	6173.3	3049.7
18.6	3958.4	2812.0	13092.2	6539.9
19.0	3904.0	2791.8	5287.9	2668.2
19.5	3826.7	2786.0	12063.8	5887.5
19.8	3690.7	2744.2	5101.4	2530.7
20.0	3656.0	2721.0	12651.0	6062.3
20.5	3466.2	2692.9	4615.0	2271.4
20.8	3354.2	2604.7	8865.3	4119.4
21.3	3254.8	2591.9	4857.6	2279.6
21.5	3108.4	2511.1	9608.5	4311.7
21.8	3001.6	2490.8	4326.6	1990.5
22.5	2740.8	2428.0	8460.7	3577.9
22.8	2691.7	2478.4	3652.7	1567.2
23.3	2428.7	2435.7	9693.5	4025.7
23.5	2222.9	2404.4	2817.2	1175.9
24.0	1810.4	2185.9	7617.6	2958.4
24.5	1496.5	1835.3	3112.9	1227.7
25.3	1147.0	1415.1	6433.5	2212.9
25.8	935.9	1159.5	3388.0	1150.3
29.0	0.0	0.0	0.0	0.0

TABLE 14.3A-18

0.6 DOUBLE ENDED PUMP SUCTION GUILLOTINE
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0	0.0	0.0
0.0502	31536.3	16866.2	20370.5	10849.3
0.151	38729.8	20836.5	18912.3	10082.1
0.450	33923.7	18670.2	21180.2	11306.6
1.00	28453.1	16247.9	20822.0	11139.1
2.80	23932.6	14625.6	19726.5	10570.5
5.50	12669.2	8157.4	14579.3	7684.5
6.00	8564.1	6222.8	13753.1	7207.6
7.75	7274.7	5144.7	11881.0	6127.3
8.25	7897.6	5098.3	11186.1	5738.3
9.75	7632.0	4953.1	11856.7	6080.0
11.8	6233.6	4385.3	10890.8	5590.5
19.3	3643.2	2726.0	6391.3	3179.2
19.5	3639.1	2697.4	13254.1	6530.9
20.0	3501.5	2600.6	5140.0	2582.9
20.5	3433.6	2585.2	9746.1	4728.3
20.8	3340.5	2579.5	4601.4	2268.8
21.0	3239.9	2520.0	10720.7	5102.2
21.5	3062.9	2485.6	6626.9	3249.2
22.5	2718.2	2285.9	8057.9	3756.1
22.8	2651.7	2290.2	4282.2	2022.8
23.0	2570.6	2257.3	11352.5	5105.0
23.5	2380.5	2234.5	3739.6	1712.2
23.8	2244.4	2181.2	11698.3	5049.8
24.0	2109.2	2147.6	4427.0	1947.7
24.3	1950.7	2100.0	3438.7	1506.3
24.5	1712.3	1968.4	10315.8	4225.8
25.0	1426.5	1744.6	2759.3	1159.4
25.5	1202.5	1479.7	9144.2	3502.2
25.8	1116.5	1377.9	2418.4	936.2
26.3	982.2	1216.1	2516.1	941.3
26.5	885.8	1098.6	7393.6	2571.8
26.8	807.5	1003.7	4334.0	1494.5
29.5	147.1	185.5	0.0	0.0
30.0	0.0	0.0	0.0	0.0

TABLE 14.3A-19

3 FT^2 PUMP SUCTION SPLIT BREAK
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0
0.0501	29277.2	15640.7
0.100	43737.2	23430.6
0.150	47907.1	25726.5
0.201	42785.7	23001.0
0.401	40174.5	21766.4
1.70	34987.5	19815.6
1.90	33132.5	18824.8
2.90	32174.1	18390.3
3.30	30958.1	17745.8
4.30	25789.1	14826.5
4.60	25441.0	14634.9
6.00	22465.2	12813.0
6.50	22133.7	12813.0
6.75	19921.1	11550.3
10.3	15996.1	9092.8
13.5	14249.8	8085.0
14.0	14207.4	8065.6
16.0	12976.8	7522.1
22.3	10131.3	6147.8
24.0	9388.3	5773.7
27.5	7398.1	4689.5
30.8	5812.8	3752.7
31.3	6346.1	3926.7
32.0	4553.0	3236.7
33.3	4042.7	2772.2
33.8	4786.7	2869.2
36.5	2161.5	1423.3
37.3	2090.1	1298.9
38.3	3231.3	1455.1
39.3	3390.8	1334.2
40.8	1372.9	422.5
41.5	1444.8	430.8
41.8	272.8	76.3
42.5	0.0	0.0

TABLE 14.3A-20

DOUBLE ENDED COLD LEG
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW		SI SPILL PATH FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0	0.0	0.0	0.0	0.0
0.0502	29454.2	15707.9	30641.8	16386.9	2695.0	160.7
0.100	27855.5	14852.4	51957.2	27824.2	2682.5	159.9
0.350	23807.8	12735.0	52037.3	27869.8	2620.0	156.2
0.500	22893.8	12318.0	53274.2	28538.7	2582.5	154.0
1.10	22115.9	12006.2	50079.5	26816.5	2432.5	145.0
1.50	21164.9	11630.4	50212.6	26918.5	2332.6	139.1
1.80	20581.6	11409.9	46958.6	25211.2	2257.5	134.6
1.90	20353.1	11315.6	48096.5	25834.5	2232.6	133.1
2.00	20215.7	11272.9	44381.4	23855.7	2207.5	131.6
2.20	19957.7	11197.4	42143.8	22681.4	2157.5	128.6
2.30	19586.2	11021.9	43348.3	23340.8	2132.5	127.1
2.60	16992.9	9639.8	38945.1	21016.0	2072.5	123.6
2.70	15663.3	8903.1	42796.4	23105.9	2064.0	123.1
2.90	14119.0	8049.6	36917.6	19935.6	2046.8	122.0
3.30	12316.5	7045.9	35692.7	19283.4	2012.5	120.0
3.50	11953.4	6848.8	36013.3	19455.2	1995.5	119.0
3.60	11847.8	6782.0	33332.9	17997.8	1986.9	118.5
4.10	11335.0	6454.7	31078.3	16756.6	1944.0	115.9
4.70	10743.8	6077.1	24990.7	13371.7	1892.7	112.8
4.90	11084.9	6267.0	24695.9	13172.6	1875.5	111.8
5.50	9422.6	5473.7	20585.0	10754.7	1686.4	100.5
7.75	5881.7	4726.1	18351.7	9474.3	1558.9	93.0
9.50	4323.9	4302.8	16402.8	8477.5	1515.5	90.4
10.3	4158.2	4100.1	15259.2	8009.0	1481.9	88.4
12.5	3127.7	2746.4	11430.4	6363.5	1288.8	76.8
13.3	2919.4	2427.4	8001.6	4750.5	1286.4	76.7
14.0	2768.7	2220.8	6264.6	4182.5	1284.4	76.6
15.5	2515.3	1981.8	4544.1	3685.0	1246.6	74.3
16.0	2409.3	1934.7	5596.7	3423.1	1211.3	72.2
18.3	2061.5	1844.3	5712.8	2861.6	1111.2	66.3
19.3	1091.6	1323.8	4849.3	2182.8	1119.5	66.7
21.8	522.8	652.6	4014.8	1400.3	1016.6	60.6
24.0	120.4	153.1	1956.1	548.5	991.8	59.1
25.0	0.0	0.0	0.0	0.0	1006.5	60.0

TABLE 14.3A-21

DOUBLE ENDED HOT LEG
BLOWDOWN MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
0.0000	0.0	0.0	0.0	0.0
0.0502	42334.3	26677.7	26942.7	16714.9
0.100	47439.7	29645.9	25759.8	15974.6
0.251	31106.2	19862.0	20533.7	12533.3
0.600	30553.6	19464.8	17115.3	9934.5
1.00	29625.6	19044.0	15446.6	8528.4
1.80	27583.8	18365.2	15717.3	8119.8
3.00	22269.8	15377.5	16822.2	8420.7
3.60	20019.2	13853.2	16835.7	8396.1
4.70	17298.9	11738.2	16251.2	8075.8
5.25	16690.5	11131.3	15640.5	7766.0
6.25	18444.7	11319.2	14263.1	7104.8
6.50	13256.9	9126.3	13940.5	6960.8
7.00	13010.3	8959.7	13186.7	6624.7
7.25	11859.6	8603.0	12741.7	6422.2
7.75	11960.2	8475.5	11832.4	6003.4
8.50	13560.8	9053.4	10404.4	5330.9
9.25	17773.6	11421.3	9005.6	4653.1
11.0	18574.5	11251.7	6364.9	3356.9
12.0	19943.9	11518.9	5335.0	2861.6
12.3	8993.8	5988.8	5123.6	2760.5
13.8	10762.1	6664.9	4154.2	2300.7
14.3	10411.8	6341.3	3894.4	2169.5
14.8	8703.7	5504.2	3672.8	2052.1
15.5	8915.6	5653.9	3459.9	1924.1
16.5	7090.7	4711.5	3292.8	1796.0
17.5	6471.0	4376.1	3164.6	1706.0
18.5	5119.9	3783.7	2928.6	1577.3
19.3	4563.7	4283.9	2591.0	1455.3
19.8	2953.7	3057.3	2331.1	1367.9
23.3	1431.9	1753.4	1069.6	910.2
26.5	911.1	1106.9	459.5	559.4
29.8	642.1	634.9	369.3	453.1
32.3	0.0	0.0	370.8	454.9
36.6	0.0	0.0	74.3	94.2

TABLE 14.3A-22

DOUBLE ENDED PUMP SUCTION GUILLOTINE MAX SI
REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
29.0	0.0	0.0	0.0	0.0
29.5	91.8	107.9	1502.4	91.0
30.9	81.5	95.9	1444.3	87.6
33.1	106.1	124.8	1359.4	82.5
35.1	120.7	142.1	1296.5	78.8
37.1	133.9	157.6	1240.6	75.4
39.1	145.8	171.7	1190.2	72.4
41.1	156.7	184.5	1144.5	69.7
42.1	192.6	227.0	1819.1	171.1
43.1	272.8	322.0	3088.1	382.9
44.1	291.6	344.3	3328.6	435.2
45.1	291.1	343.7	3321.2	440.1
46.1	287.8	339.8	3278.8	437.3
50.1	273.5	322.7	3093.1	421.2
54.1	260.7	307.6	2922.7	405.9
58.1	249.3	294.1	2767.5	391.8
58.3	248.8	293.5	2760.1	391.2
62.1	239.2	282.1	2625.4	378.6
63.1	369.7	437.1	330.8	210.0
64.1	392.5	464.5	340.9	224.7
72.1	352.0	416.1	321.6	198.7
79.1	323.2	381.8	308.1	180.7
87.1	296.1	349.6	295.5	164.1
88.1	293.0	346.0	294.1	162.3
96.1	271.3	320.2	284.3	149.4
98.1	266.6	314.6	282.2	146.7
108.1	247.0	291.3	273.5	135.4
120.1	231.1	272.5	266.7	126.5
132.1	221.5	261.2	262.6	121.2
144.1	216.4	255.1	260.4	118.4
152.1	218.7	257.8	267.2	120.0
160.1	222.8	262.7	283.2	123.4
168.1	225.1	265.4	301.1	126.2
184.1	221.4	261.0	337.8	128.9
185.1	220.8	260.3	340.1	128.9

TABLE 14.3A-23

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
29.0	0.0	0.0	0.0	0.0
29.5	89.1	104.8	1463.1	88.4
30.9	79.0	92.9	1405.5	85.0
32.1	102.6	120.7	1322.3	80.0
35.1	117.1	137.8	1259.8	76.3
37.1	130.2	153.2	1204.2	73.0
41.1	152.6	179.7	1108.6	67.3
42.1	157.5	185.5	1087.9	66.0
43.1	237.7	280.4	2592.2	302.8
44.2	278.0	328.2	3146.0	410.8
44.6	281.2	332.0	3186.1	421.7
45.2	281.9	332.8	3194.1	427.2
46.2	279.4	329.8	3161.6	426.6
47.2	276.0	325.7	3116.3	423.1
51.2	262.2	309.4	2934.5	407.1
53.2	255.9	301.9	2849.5	399.5
54.2	252.9	298.4	2808.5	395.8
58.2	241.8	285.1	2653.4	381.7
59.2	239.2	282.1	2616.7	378.3
61.2	234.2	276.2	2545.7	371.7
62.2	235.8	277.9	842.5	230.8
63.2	433.1	512.9	334.5	257.8
64.2	429.0	508.0	332.4	255.0
68.2	396.2	468.9	316.2	233.3
75.2	349.0	412.6	293.2	202.6
79.2	325.6	384.7	281.9	187.6
80.2	320.1	378.1	279.2	184.1
88.2	280.9	331.5	260.5	159.6
96.2	249.6	294.4	245.8	140.6
104.2	225.3	265.7	234.7	126.2
132.2	180.3	212.4	214.5	100.5
144.2	173.0	203.7	211.2	96.4
160.2	168.7	198.7	209.3	94.0
186.2	168.5	198.5	209.2	93.8
203.2	170.4	200.7	209.9	94.7

TABLE 14.3A-24

0.6 DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
30.0	0.0	0.0	0.0	0.0
30.5	86.9	102.2	1464.0	88.5
31.0	78.4	92.2	1442.6	87.2
31.9	77.2	90.8	1406.3	85.0
33.0	90.1	106.1	1358.0	82.1
35.0	103.3	121.5	1291.3	78.2
37.0	115.2	135.5	1232.3	74.6
39.0	125.9	148.3	1179.5	71.5
43.0	145.0	170.7	1088.3	66.1
44.1	222.9	262.9	2594.9	305.3
45.1	259.6	306.4	3130.1	412.2
45.7	263.5	311.1	3182.7	427.6
46.1	263.6	311.3	3184.8	430.7
47.1	261.4	308.6	3153.9	430.4
48.1	258.1	304.7	3109.4	427.0
52.1	245.1	289.3	2929.9	410.9
53.1	242.1	285.7	2887.3	407.1
55.1	236.3	278.8	2805.3	399.5
59.1	225.7	266.3	2651.9	385.3
63.1	216.2	255.0	2511.4	372.2
64.1	406.6	481.8	335.3	259.7
65.1	414.7	491.6	339.6	266.4
69.1	382.2	452.6	322.5	243.1
73.1	354.2	419.1	307.8	223.3
77.1	329.3	389.5	294.8	205.9
85.1	286.9	339.0	273.0	176.7
93.1	253.3	299.0	255.8	154.3
101.1	227.2	268.0	242.7	137.2
109.1	207.2	244.4	232.9	124.5
121.1	186.6	220.0	222.9	111.6
133.1	174.1	205.2	216.9	104.0
145.1	167.1	196.9	213.6	99.7
161.1	162.9	191.9	211.6	97.2
177.1	162.1	191.0	211.2	96.6
202.9	164.1	193.3	212.0	97.7

TABLE 14.3A-25

DOUBLE ENDED COLD LEG MIN SI
REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW		SI SPILL PATH FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	BTU/SEC
25.0	0.0	0.0	0.0	0.0	0.0	0.0
25.6	0.0	0.0	0.0	0.0	1090.0	66168.2
26.3	0.2	0.2	0.0	0.0	1075.6	65310.8
26.5	11.2	12.2	0.0	0.0	1069.6	64950.9
26.8	2.7	3.2	0.0	0.0	1065.6	64713.5
27.4	17.7	20.8	0.0	0.0	1052.9	63954.5
29.1	35.7	42.0	0.0	0.0	1019.2	61950.3
32.1	54.1	63.7	0.0	0.0	967.8	58881.2
34.1	63.3	74.5	0.0	0.0	936.3	57003.7
38.1	78.3	92.2	0.0	0.0	878.7	53573.2
39.1	82.6	97.2	973.1	133.9	865.3	52774.3
40.2	87.2	102.7	2378.2	332.9	853.4	52063.1
41.2	88.2	103.8	2610.0	369.1	840.7	51302.6
42.2	88.0	103.6	2605.1	371.3	828.2	50561.0
43.2	87.6	103.2	2568.6	368.7	325.1	20560.7
44.2	87.3	102.8	2528.4	365.5	140.1	9532.0
46.3	86.5	101.9	2445.4	358.7	140.1	9532.0
50.2	85.3	100.4	2300.4	346.5	140.1	9532.0
52.2	84.7	99.7	2230.7	340.5	140.1	9532.0
53.2	91.5	107.7	199.6	188.3	140.1	9532.0
54.2	92.2	108.6	199.1	190.0	140.1	9532.0
63.2	91.1	107.4	208.9	188.6	140.1	9532.0
71.2	90.2	106.2	214.9	186.9	140.1	9532.0
92.2	87.8	103.3	226.2	182.4	140.1	9532.0
102.2	86.7	102.1	230.7	180.4	140.1	9532.0
132.2	83.5	98.3	242.7	174.2	140.1	9532.0
194.2	76.2	89.7	265.7	160.4	140.1	9532.0
222.2	72.6	85.4	275.9	153.9	140.1	9532.0
254.2	68.5	80.6	287.3	146.7	140.1	9532.0
270.2	66.4	78.2	292.9	143.2	140.1	9532.0
271.8	66.2	77.9	293.5	142.9	140.1	9532.0
271.9	95.5	112.3	322.5	21.9	140.1	9532.0
1000.0	70.0	82.3	348.0	23.7	140.1	9532.0
10000.0	37.0	43.5	381.1	25.9	140.1	9532.0
100000.0	19.3	22.6	398.8	27.1	140.1	9532.0

TABLE 14.3A-26

DOUBLE ENDED PUMP SUCTION GUILLOTINE MAX SI
POST-REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
185.1	208.3	253.8	487.4	146.0
190.1	207.3	252.5	488.4	145.9
200.1	205.1	249.9	490.6	145.7
210.1	203.2	247.6	492.5	145.5
220.1	201.1	245.0	494.6	145.4
225.1	200.0	243.6	495.7	145.3
230.1	199.2	242.6	496.5	145.2
235.1	197.9	241.1	497.8	145.2
245.1	195.8	238.5	499.9	145.0
250.1	204.1	248.7	491.6	145.9
260.1	202.2	246.4	493.5	145.6
270.1	199.8	243.4	495.9	145.5
280.1	197.8	241.0	497.9	145.3
300.1	193.0	235.1	502.7	145.0
305.1	191.9	233.8	503.8	144.9
315.1	189.3	230.6	506.5	144.8
525.1	189.3	230.6	506.5	144.8
525.2	91.0	110.3	604.7	164.1
530.1	90.8	110.1	604.9	163.6
565.1	89.6	108.6	606.1	162.9
610.1	88.2	106.8	607.6	163.3
630.1	87.7	106.2	608.0	160.7
650.1	86.9	105.3	608.8	161.9
680.1	86.4	104.7	609.3	161.4
685.1	86.3	104.5	609.4	160.7
705.1	85.8	103.9	609.9	159.9
790.1	83.7	101.4	612.0	158.6
835.1	82.5	100.2	613.0	157.6
910.2	82.5	100.2	613.0	157.6
910.3	89.6	102.7	606.2	45.5
3600.0	64.7	74.2	631.0	49.7
3600.1	51.1	58.6	644.6	43.9
10000.0	38.0	43.5	657.8	44.8
100000.0	19.8	22.7	675.9	46.0
1000000.0	9.5	10.9	686.2	46.7

TABLE 14.3A-27

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
POST-REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
203.3	217.6	266.1	342.8	130.3
208.3	217.3	265.8	343.1	130.0
213.3	216.5	264.8	343.9	129.9
218.3	216.1	264.3	344.3	129.7
223.3	220.6	269.9	339.8	131.7
228.3	219.9	269.0	340.4	131.6
243.3	218.6	267.4	341.8	130.9
273.3	215.2	263.2	345.2	129.7
278.3	214.9	262.9	345.5	129.4
288.3	213.7	261.4	346.7	129.1
293.3	213.0	260.6	347.3	128.9
308.3	211.4	258.5	349.0	128.2
323.3	209.5	256.2	350.9	127.7
333.3	208.3	254.7	352.1	127.3
503.3	208.3	254.7	352.1	127.3
503.4	91.7	111.5	468.7	153.7
523.3	91.0	110.7	469.4	152.0
598.3	88.4	107.5	472.0	151.0
603.3	88.3	107.4	472.1	150.5
633.3	87.5	106.4	472.8	150.0
673.3	86.5	105.2	473.8	150.7
678.3	86.4	105.1	474.0	150.1
718.3	85.4	103.9	475.0	149.8
723.3	85.3	103.7	475.1	149.1
763.3	84.3	102.5	476.1	147.7
783.3	83.8	101.9	476.6	148.9
788.3	83.7	101.7	476.7	148.0
872.3	81.9	99.6	478.4	146.8
949.5	81.9	99.6	478.4	146.8
948.6	88.7	101.7	471.7	96.6
3600.0	64.7	74.2	495.7	40.7
3600.1	51.1	58.6	509.3	34.7
10000.0	38.0	43.5	522.4	35.5
100000.0	19.8	22.7	540.6	96.8
1000000.0	9.5	10.9	550.9	97.5

TABLE 14.3A-28

0.6 DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI
POST-REFLOOD MASS AND ENERGY RELEASES

TIME	BREAK PATH NO.1 FLOW		BREAK PATH NO.2 FLOW	
SECONDS	LBM/SEC	THOUSAND BTU/SEC	LBM/SEC	THOUSAND BTU/SEC
203.0	206.2	253.8	354.1	135.1
208.0	205.5	253.0	354.8	135.0
213.0	205.4	252.8	355.0	134.7
218.0	204.6	251.9	355.8	134.6
223.0	204.4	251.6	356.0	134.3
248.0	201.4	248.0	358.9	133.4
253.0	200.9	247.3	359.4	133.2
258.0	200.9	247.3	359.5	132.9
268.0	199.5	245.6	360.8	132.6
273.0	199.3	245.3	361.1	132.3
283.0	198.0	243.7	362.4	132.0
288.0	202.7	249.5	357.7	133.9
303.0	200.8	247.1	359.6	133.3
313.0	199.9	246.0	360.5	132.9
328.0	198.1	243.8	362.3	132.2
338.0	196.8	242.3	363.6	131.8
363.0	193.7	238.4	366.7	130.8
373.0	192.4	236.8	368.0	130.4
563.0	192.4	236.8	368.0	130.4
563.1	89.8	109.8	470.6	153.6
568.0	89.6	109.6	470.8	153.1
613.0	88.2	107.9	472.2	151.6
633.0	87.7	107.2	472.7	152.3
673.0	86.7	106.0	473.7	150.4
733.0	85.2	104.2	475.2	150.2
758.0	84.6	103.4	475.8	148.8
798.0	83.6	102.2	476.8	148.9
873.0	82.1	100.4	478.3	146.4
954.1	82.0	100.2	478.4	147.0
954.2	88.7	101.8	471.7	36.6
3600.0	64.8	74.4	495.6	40.7
3600.1	51.1	58.6	509.3	34.7
10000.0	38.0	43.5	522.4	35.5
100000.0	19.8	22.7	540.6	36.8
1000000.0	9.5	10.9	550.9	37.5

TABLE 14.3A-29

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI

MASS BALANCE

	TIME (SECONDS)	0.00	29.00	29.00	203.21	508.30	949.54	3600.00
		MASS (THOUSAND LBM)						
INITIAL	IN RCS AND ACC	733.31	733.31	733.31	733.31	733.31	733.31	733.31
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00	94.32	265.24	512.50	1997.77
	TOTAL ADDED	0.00	0.00	0.00	94.32	265.24	512.50	1997.77
*** TOTAL AVAILABLE ***		733.31	733.31	733.31	827.64	998.55	1245.81	2731.08
DISTRIBUTION	REACTOR COOLANT	528.74	45.27	82.82	149.67	149.67	149.67	149.67
	ACCUMULATOR	204.57	152.66	115.11	0.00	0.00	0.00	0.00
	TOTAL CONTENTS	733.31	197.93	197.93	149.67	149.67	149.67	149.67
EFFLUENT	BREAK FLOW	0.00	535.38	535.38	677.96	848.88	1096.14	2581.40
	ECCS SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	535.38	535.38	677.96	848.88	1096.14	2581.40
*** TOTAL ACCOUNTABLE ***		733.31	733.30	733.30	827.63	998.54	1245.80	2731.07

TABLE 14.3A-29a

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI

ENERGY BALANCE

	TIME (SECONDS)	0.00	29.00	29.00	203.21	508.30	949.54	3600.00
		ENERGY (MILLION BTU)						
INITIAL ENERGY	IN RCS,ACC,S GEN	774.97	774.97	774.97	774.97	774.97	774.97	774.97
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00	6.42	18.05	34.87	135.93
	DECAY HEAT	0.00	8.69	8.69	27.93	54.64	88.25	256.82
	HEAT FROM SECONDAR	0.00	-34.61	-34.61	-34.61	-31.19	-27.03	-27.03
	TOTAL ADDED	0.00	-25.92	-25.92	-0.27	41.50	96.09	365.71
***	TOTAL AVAILABLE ***	774.97	749.04	748.04	774.70	816.47	871.05	1140.68
DISTRIBUTION	REACTOR COOLANT	305.66	10.36	12.60	38.08	38.08	38.08	38.08
	ACCUMULATOR	12.20	9.10	6.86	0.00	0.00	0.00	0.00
	CORE STORED	30.94	13.65	13.65	3.83	3.78	3.60	2.57
	PRIMARY METAL	177.86	168.49	168.49	138.16	102.62	84.09	61.55
	SECONDARY METAL	62.90	59.46	59.46	54.26	44.36	34.02	25.22
	STEAM GENERATOR	185.41	176.40	176.40	158.18	128.91	101.74	76.71
	TOTAL CONTENTS	774.97	437.46	437.46	392.51	317.75	261.54	204.13
EFFLUENT	TOTAL CONTENTS	0.00	311.59	311.59	381.90	498.43	609.23	936.26
	BREAK FLOW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	311.59	311.59	381.90	498.43	609.23	936.26
***	TOTAL ACCOUNTABLE ***	774.97	749.05	749.05	774.41	816.18	870.77	1140.39

TABLE 14.3A-30

DOUBLE ENDED PUMP SUCTION GUILLOTINE MAX SI

MASS BALANCE

	TIME (SECONDS)	0.00	29.00	29.00	185.09	530.10	910.23	3600.00
		MASS (THOUSAND LBM)						
INITIAL	IN RCS AND ACC	733.31	733.31	733.31	733.31	733.31	733.31	733.31
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00	104.91	344.93	609.40	2480.69
	TOTAL ADDED	0.00	0.00	0.00	104.91	344.93	609.40	2480.69
*** TOTAL AVAILABLE ***		733.31	733.31	733.31	838.23	1078.25	1342.71	3214.01
DISTRIBUTION	REACTOR COOLANT	528.74	45.27	82.06	151.99	151.99	151.99	151.99
	ACCUMULATOR	204.57	152.66	115.87	0.00	0.00	0.00	0.00
	TOTAL CONTENTS	733.31	197.93	197.93	151.99	151.99	151.99	151.99
EFFLUENT	BREAK FLOW	0.00	535.38	535.38	686.23	926.25	1190.71	3062.01
	ECCS SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	535.38	535.38	686.23	926.25	1190.71	3062.01
*** TOTAL ACCOUNTABLE ***		733.31	733.30	733.30	838.22	1078.24	1342.70	3214.00

TABLE 14.3A-30a

DOUBLE ENDED PUMP SUCTION GUILLOTINE MAX SI

ENERGY BALANCE

ENERGY (MILLION BTU)

	TIME (SECONDS)	0.00	29.00	29.00	185.09	530.10	910.23	3600.00
INITIAL ENERGY	IN RCS,ACC,S GEN	774.97	774.97	774.97	774.97	774.97	774.97	774.97
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00	7.14	23.47	41.46	168.79
	DECAY HEAT	0.00	8.69	8.69	26.17	86.41	85.50	257.10
	HEAT FROM SECONDAR	0.00	-34.61	-34.61	-34.61	-30.74	-27.26	-27.26
	TOTAL ADDED	0.00	-25.92	-25.92	-1.30	49.14	99.70	398.63
*** TOTAL AVAILABLE ***		774.97	749.04	749.04	773.66	824.10	874.67	1173.59
DISTRIBUTION	REACTOR COOLANT	305.66	10.36	12.56	38.79	38.79	38.79	38.79
	ACCUMULATOR	12.20	9.10	6.91	0.00	0.00	0.00	0.00
	CORE STORED	30.94	13.65	13.65	3.83	3.78	3.62	2.56
	PRIMARY METAL	177.86	168.49	168.49	137.47	100.57	84.30	61.51
	SECONDARY METAL	62.90	59.46	59.46	53.67	43.10	34.02	25.17
	STEAM GENERATOR	185.41	176.40	176.40	156.17	125.27	101.52	76.35
	TOTAL CONTENTS	774.97	437.46	437.46	389.93	311.50	262.25	204.39
EFFLUENT	TOTAL CONTENTS	0.00	311.59	311.59	383.45	512.32	612.14	968.92
	BREAK FLOW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	311.59	311.59	383.45	512.32	612.14	968.92
*** TOTAL ACCOUNTABLE ***		774.97	749.05	749.05	773.38	823.82	874.39	1173.31

TABLE 14.3A-31

0.6 DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI

MASS BALANCE

	TIME (SECONDS)	0.00	30.00	30.00	202.92	568.00	954.11	3600.00
		MASS (THOUSAND LBM)						
INITIAL	IN RCS AND ACC	733.31	733.31	733.31	733.31	733.31	733.31	733.31
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00	93.17	297.71	514.07	1996.78
	TOTAL ADDED	0.00	0.00	0.00	93.17	297.71	514.07	1996.78
***	TOTAL AVAILABLE ***	733.31	733.31	733.31	826.48	1031.02	1247.39	2730.09
DISTRIBUTION	REACTOR COOLANT	528.74	42.98	81.42	148.44	148.44	148.44	148.44
	ACCUMULATOR	204.57	153.70	115.25	0.00	0.00	0.00	0.00
	TOTAL CONTENTS	733.31	196.67	196.67	148.44	148.44	148.44	148.44
EFFLUENT	BREAK FLOW	0.00	536.63	536.63	678.03	882.57	1098.94	2581.64
	ECCS SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	536.63	536.63	678.03	882.57	1098.94	2581.64
***	TOTAL ACCOUNTABLE ***	733.31	733.30	733.30	826.47	1031.01	1247.38	2730.08

TABLE 14.3A-31a

0.6 DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI

ENERGY BALANCE

	TIME (SECONDS)	0.00	30.00	30.00	202.92	568.00	954.11	3600.00
		ENERGY (MILLION BTU)						
INITIAL ENERGY	IN RCS,ACC,S GEN	774.97	774.97	774.97	774.97	774.97	774.97	774.97
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00	6.34	20.26	34.98	135.86
	DECAY HEAT	0.00	8.89	8.89	27.96	59.46	88.63	256.85
	HEAT FROM SECONDAR	0.00	-34.01	-34.01	-34.01	-29.92	-26.38	-26.38
	TOTAL ADDED	0.00	-25.12	-25.12	0.29	49.80	97.23	366.33
***	TOTAL AVAILABLE ***	774.97	749.85	749.85	775.25	824.77	872.20	1141.29
DISTRIBUTION	REACTOR COOLANT	305.66	9.98	12.28	37.97	37.97	37.97	37.97
	ACCUMULATOR	12.20	9.16	6.87	0.00	0.00	0.00	0.00
	CORE STORED	30.94	13.47	13.47	3.83	3.78	3.62	2.56
	PRIMARY METAL	177.86	168.74	168.74	139.42	100.75	84.47	61.73
	SECONDARY METAL	62.90	60.11	60.11	54.95	43.23	34.16	25.32
	STEAM GENERATOR	185.41	178.77	178.77	160.45	125.92	102.21	77.07
	TOTAL CONTENTS	774.97	440.22	440.22	396.62	311.64	262.43	204.65
EFFLUENT	TOTAL CONTENTS	0.00	309.63	309.63	378.34	512.84	609.47	936.35
	BREAK FLOW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	309.63	309.63	378.34	512.84	609.47	936.35
***	TOTAL ACCOUNTABLE ***	774.97	749.85	749.85	774.96	824.47	871.90	1141.00

TABLE 14.3A-32

DOUBLE ENDED COLD LEG MIN SI

MASS BALANCE

	TIME (SECONDS)	0.00	25.00	25.00	271.79
		MASS (THOUSAND LBM)			
INITIAL	IN RCS AND ACC	733.31	733.31	733.31	733.31
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00	137.74
	TOTAL ADDED	0.00	0.00	0.00	137.74
***	TOTAL AVAILABLE ***	733.31	733.31	733.31	871.06
DISTRIBUTION	REACTOR COOLANT	528.74	29.93	66.87	137.51
	ACCUMULATOR	204.57	126.92	89.88	0.00
	TOTAL CONTENTS	733.31	156.85	156.85	137.51
EFFLUENT	BREAK FLOW	0.00	539.99	539.99	647.87
	ECCS SPILL	0.00	36.47	36.47	85.53
	TOTAL EFFLUENT	0.00	576.46	576.46	733.40
***	TOTAL ACCOUNTABLE ***	733.31	733.31	733.31	870.91

TABLE 14.3A-32a

DOUBLE ENDED COLD LEG MIN SI

ENERGY BALANCE

	TIME (SECONDS)	0.00	25.00	25.00	271.79
	ENERGY (MILLION BTU)				
INITIAL ENERGY	IN RCS,ACC,S GEN	774.97	774.97	774.97	774.97
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00	9.37
	DECAY HEAT	0.00	6.82	6.82	33.08
	HEAT FROM SECONDAR	0.00	-34.19	-34.19	-34.19
	TOTAL ADDED	0.00	-27.37	-27.37	8.27
***	TOTAL AVAILABLE ***	774.97	747.60	747.60	783.23
DISTRIBUTION	REACTOR COOLANT	305.66	6.84	9.05	35.61
	ACCUMULATOR	12.20	7.57	5.36	0.00
	CORE STORED	30.94	17.39	17.39	3.83
	PRIMARY METAL	177.86	169.82	169.82	142.14
	SECONDARY METAL	62.90	59.91	59.91	57.29
	STEAM GENERATOR	185.41	178.04	178.04	168.47
	TOTAL CONTENTS	774.97	439.58	439.58	407.35
EFFLUENT	TOTAL CONTENTS	0.00	305.85	305.85	370.01
	BREAK FLOW	0.00	2.17	2.17	5.39
	TOTAL EFFLUENT	0.00	308.03	308.03	375.40
***	TOTAL ACCOUNTABLE ***	774.97	747.61	747.61	782.75

TABLE 14.3A-33

DOUBLE ENDED HOT LEG MIN SI

MASS BALANCE

	TIME (SECONDS)	0.00	36.64	36.64
	MASS (THOUSAND LBM)			
INITIAL	IN RCS AND ACC	733.31	733.31	733.31
ADDED MASS	PUMPED INJECTION	0.00	0.00	0.00
	TOTAL ADDED	0.00	0.00	0.00
***	TOTAL AVAILABLE ***	733.31	733.31	733.31
DISTRIBUTION	REACTOR COOLANT	528.74	130.74	130.77
	ACCUMULATOR	204.57	92.98	92.94
	TOTAL CONTENTS	733.31	223.71	223.71
EFFLUENT	BREAK FLOW	0.00	509.60	509.60
	ECCS SPILL	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	509.60	509.60
***	TOTAL ACCOUNTABLE ***	733.31	733.31	733.31

TABLE 14.3A-33a

DOUBLE ENDED HOT LEG MIN SI

ENERGY BALANCE

	TIME (SECONDS)	0.00	36.64	36.64
	ENERGY (MILLION BTU)			
INITIAL ENERGY	IN RCS,ACC,S GEN	774.97	774.97	774.97
ADDED ENERGY	PUMPED INJECTION	0.00	0.00	0.00
	DECAY HEAT	0.00	10.28	10.28
	HEAT FROM SECONDAR	0.00	-36.78	-36.78
	TOTAL ADDED	0.00	-26.50	-26.50
***	TOTAL AVAILABLE ***	774.97	748.46	748.46
DISTRIBUTION	REACTOR COOLANT	305.66	26.15	26.16
	ACCUMULATOR	12.20	5.54	5.54
	CORE STORED	30.94	9.19	9.19
	PRIMARY METAL	177.86	162.65	162.65
	SECONDARY METAL	62.90	57.00	57.00
	STEAM GENERATOR	185.41	167.71	167.71
	TOTAL CONTENTS	774.97	428.24	428.24
EFFLUENT	TOTAL CONTENTS	0.00	320.22	320.22
	BREAK FLOW	0.00	0.00	0.00
	TOTAL EFFLUENT	0.00	320.22	320.22
***	TOTAL ACCOUNTABLE ***	774.97	748.46	748.46

TABLE 14.3A-34

DOUBLE ENDED PUMP SUCTION GUILLOTINE MAX SI

TIME	FLOODING TEMP	FLOODING RATE	CARRYOVER FRACTION	CORE HEIGHT	DOWNCOMER HEIGHT	FLOW FRACTION	TOTAL	INJECTION ACCUMULATOR	INJECTION SPILL	ENTHALPY
SECONDS	DEGREE F	IN/SEC		FT	FT		(POUNDS MASS PER SECOND)			BTU/LBM
29.0	143.7	0.000	0.000	0.00	0.00	0.250	0.0	0.0	0.0	0.00
29.8	141.8	16.456	0.000	0.67	0.54	1.000	5918.2	5227.9	0.0	60.61
30.1	141.0	12.105	0.000	1.04	0.59	1.000	5868.3	5177.9	0.0	60.61
30.6	141.1	1.516	0.070	1.28	1.11	1.000	5787.7	5097.2	0.0	60.63
31.0	141.5	3.316	0.141	1.36	1.72	0.714	5699.9	5009.2	0.0	60.64
31.9	142.1	2.335	0.296	1.50	2.85	0.542	5571.3	4880.3	0.0	60.67
34.1	144.0	2.080	0.484	1.74	5.82	0.441	5279.2	4587.7	0.0	60.73
37.4	147.0	2.218	0.601	2.00	10.10	0.398	4904.3	4212.3	0.0	60.81
44.1	153.6	3.266	0.693	2.49	16.06	0.503	3955.4	3288.6	0.0	61.04
44.2	153.7	3.264	0.694	2.50	16.06	0.503	3946.1	3279.3	0.0	61.05
47.1	156.9	3.136	0.708	2.73	16.07	0.499	3754.1	3085.8	0.0	61.12
50.8	161.0	2.995	0.717	3.00	16.07	0.492	3552.1	2881.0	0.0	61.21
58.3	169.4	2.790	0.727	3.50	16.07	0.479	3204.3	2528.7	0.0	61.40
62.1	173.5	2.708	0.729	3.74	16.07	0.473	3051.6	2374.0	0.0	61.49
63.1	174.7	3.535	0.735	3.81	16.04	0.567	648.4	0.0	0.0	68.04
64.1	176.0	3.644	0.735	3.89	15.92	0.572	638.7	0.0	0.0	68.04
65.6	178.0	3.573	0.736	4.01	15.75	0.570	640.8	0.0	0.0	68.04
73.1	188.2	3.251	0.739	4.57	15.04	0.563	650.9	0.0	0.0	68.04
79.5	197.0	3.036	0.741	5.00	14.62	0.558	657.2	0.0	0.0	68.04
88.1	208.5	2.795	0.743	5.54	14.26	0.550	663.6	0.0	0.0	68.04
96.2	217.9	2.612	0.745	6.01	14.10	0.543	668.2	0.0	0.0	68.04
106.1	227.5	2.441	0.748	6.53	14.08	0.535	672.2	0.0	0.0	68.04
115.6	235.2	2.323	0.750	7.00	14.21	0.529	674.8	0.0	0.0	68.04
128.1	243.8	2.217	0.754	7.59	14.52	0.523	677.0	0.0	0.0	68.04
137.3	249.2	2.168	0.757	8.00	14.82	0.521	677.9	0.0	0.0	68.04
148.1	254.7	2.142	0.761	8.47	15.21	0.520	678.2	0.0	0.0	68.04
150.1	255.7	2.143	0.761	8.55	15.28	0.521	678.1	0.0	0.0	68.04
160.7	260.3	2.154	0.765	9.00	15.61	0.528	677.0	0.0	0.0	68.04
174.1	265.5	2.128	0.770	9.56	15.87	0.536	676.4	0.0	0.0	68.04
185.1	269.1	2.069	0.773	10.00	15.99	0.539	676.9	0.0	0.0	68.04

TABLE 14.3A-35

DOUBLE ENDED PUMP SUCTION GUILLOTINE MIN SI

TIME	FLOODING TEMP	FLOODING RATE	CARRYOVER FRACTION	CORE HEIGHT	DOWNCOMER HEIGHT	FLOW FRACTION	INJECTION TOTAL	INJECTION ACCUMULATOR	INJECTION SPILL	ENTHALPY
SECONDS	DEGREE F	IN/SEC		FT	FT		(POUNDS MASS PER SECOND)			BTU/LBM
29.0	143.6	0.000	0.000	0.00	0.00	0.250	0.0	0.0	0.0	0.00
29.7	142.1	16.129	0.000	0.52	0.52	1.000	5778.4	5223.1	0.0	60.43
30.1	140.9	11.822	0.000	1.01	0.58	1.000	5712.4	5156.9	0.0	60.44
30.7	141.1	1.639	0.067	1.28	1.20	1.000	5617.0	5061.4	0.0	60.46
31.1	141.5	3.259	0.148	1.36	1.78	0.672	5534.4	4978.6	0.0	60.47
32.0	142.1	2.306	0.284	1.50	2.84	0.537	5407.7	4851.6	0.0	60.49
34.1	143.9	2.051	0.476	1.72	5.58	0.441	5131.7	4575.3	0.0	60.54
37.6	147.2	2.188	0.600	2.00	9.95	0.396	4741.3	4184.2	0.0	60.61
44.6	154.1	3.192	0.694	2.51	16.06	0.496	3804.3	3269.7	0.0	60.81
48.2	158.2	3.047	0.710	2.79	16.07	0.491	3571.0	3034.7	0.0	60.89
51.3	161.6	2.936	0.717	3.01	16.07	0.485	3406.0	2867.6	0.0	60.95
58.9	170.1	2.735	0.726	3.50	16.07	0.471	3058.3	2515.6	0.0	61.12
61.2	172.7	2.686	0.728	3.65	16.07	0.467	2965.4	2421.6	0.0	61.17
63.2	175.2	3.904	0.734	3.79	15.89	0.590	493.2	0.0	0.0	68.04
65.7	178.7	3.746	0.736	4.00	15.41	0.589	497.4	0.0	0.0	68.04
72.2	187.7	3.339	0.738	4.50	14.38	0.582	510.4	0.0	0.0	68.04
79.5	197.8	2.972	0.739	5.01	13.52	0.575	521.4	0.0	0.0	68.04
88.2	209.1	2.518	0.740	5.53	12.83	0.565	530.6	0.0	0.0	68.04
97.0	218.6	2.345	0.741	6.00	12.42	0.554	537.1	0.0	0.0	68.04
108.2	228.4	2.094	0.741	6.54	12.20	0.542	542.5	0.0	0.0	68.04
118.9	236.1	1.933	0.742	7.00	12.21	0.532	545.7	0.0	0.0	68.04
132.2	243.9	1.809	0.745	7.53	12.43	0.523	547.8	0.0	0.0	68.04
144.7	250.2	1.743	0.748	8.00	12.75	0.517	549.0	0.0	0.0	68.04
160.2	256.8	1.700	0.752	8.56	13.23	0.515	549.6	0.0	0.0	68.04
173.1	261.5	1.685	0.757	9.00	13.66	0.514	549.7	0.0	0.0	68.04
188.2	266.3	1.678	0.762	9.51	14.19	0.515	549.6	0.0	0.0	68.04
194.2	268.0	1.677	0.765	9.71	14.40	0.515	549.5	0.0	0.0	68.04
203.2	270.4	1.678	0.768	10.00	14.72	0.516	549.4	0.0	0.0	68.04

TABLE 14.3A-36

SYSTEM PARAMETERS

	Design
Plant model	4 loop, 12.0 ft core
NSSS Power	3216 MWt
Core inlet temperature	543°F
Steam pressure	776 psig

TABLE 14.3A-37

CONTAINMENT PEAK PRESSURE AND TEMPERATURE

Break	Peak Pressure (psig)	Peak Temperature (°F)
Double-ended pump suction - Max SI	37.4	254
Double-ended pump suction - Min SI	40.5	259
0.6 double-ended pump suction	39.3	257
Double-ended hot leg	39.0	256
Double-ended cold leg	37.6	254

TABLE 14.3A-38

ASSUMPTIONS FOR CONTAINMENT ANALYSIS - PART 1

Service water temperature (°F)	85
Refueling water temperature (°F)	100
RWST available water volume (gal)	340,000
Initial containment temperature (°F)	120
Initial pressure (psia)	16.7
Initial relative humidity (%)	20
Net free volume (ft^3)	2.61×10^6

TABLE 14.3A-39

ASSUMPTIONS FOR CONTAINMENT ANALYSIS - PART 2

<u>Number of Fan Coolers</u>	
Total	5
Operating maximum	5
Operating minimum	3
<u>Number of spray pumps</u>	
Minimum safeguards spray flow (gpm)	2200

TABLE 14.3A-40

CONTAINMENT HEAT SINKS

No.	Material	Heat Transfer Area ft^2	Thickness in
1	Carbon Steel Concrete	41530	0.375 54.0
2	Carbon Steel Concrete	26012	0.5 42.0
3	Concrete	13636	12.0
4	Concrete	55454	12.0
5	Stainless Steel Concrete	9091	0.375 12.0
6	Carbon Steel	62538	0.5
7	Carbon Steel	74276	0.375
8	Carbon Steel	25407	0.25
9	Carbon Steel	63454	0.1875
10	Carbon Steel	2727	0.125
11	Carbon Steel	20000	0.138
12	Carbon Steel	9090	0.0625

TABLE 14.3A-40 (Continued)

CONTAINMENT HEAT SINKS

No.	Material	Heat Transfer Area ft^2	Thickness in
13	Stainless Steel	714	0.019
	PVC Insulation		1.25
	Carbon Steel		0.75
	Concrete		54.0
14	Stainless Steel	6226	0.019
	PVC Insulation		1.25
	Carbon Steel		0.5
	Concrete		54.0
15	Stainless Steel	3469	0.025
	Foam Insulation		1.5
	Carbon Steel		0.5
	Concrete		54.0
16	Stainless Steel	3965	0.025
	Foam Insulation		1.5
	Carbon Steel		0.375
	Concrete		54.0

NOTE:

All carbon steel exterior surfaces are modeled with a layer of paint with a thickness equaling 0.00033 ft. followeed by another paint layer of Carbozinc at a thickness of 0.000258 ft.

TABLE 14.3A-41

THERMOPHYSICAL PROPERTIES OF CONTAINMENT HEAT SINKS

Material	Thermal Conductivity (Btu/hr-ft - °F)	Volumetric Heat Capacity (Btu/ft^3 - °F)
Paint layer 1, Phenoline	0.08	28.8
Paint layer 2, Carbozinc	0.9	28.8
Carbon Steel	26.0	56.35
Stainless Steel	8.6	56.35
Concrete	0.8	28.8
PVC Insulation	0.0208	1.20
Foam Insulation	0.0417	1.53

TABLE 14.3A-42

DESIGN BASIS ACCIDENT CHRONOLOGY OF EVENTS

Time (Seconds)	Event
0.0	Start of accident
29.0	End of blowdown phase
60.0	Containment fan coolers start
75.0	Containment sprays start
203.2	End of reflood phase
525.0	Peak Pressure Reached
3006.0	RWST empties
3006.0	Sump recirculation starts

FIGURE 14.3A-105

FAN COOLER HEAT REMOVAL AS A
FUNCTION OF CONTAINMENT PRESSURE

Service Water Flow Rate = 1400 gpm
Service Water Temperature = 85°F

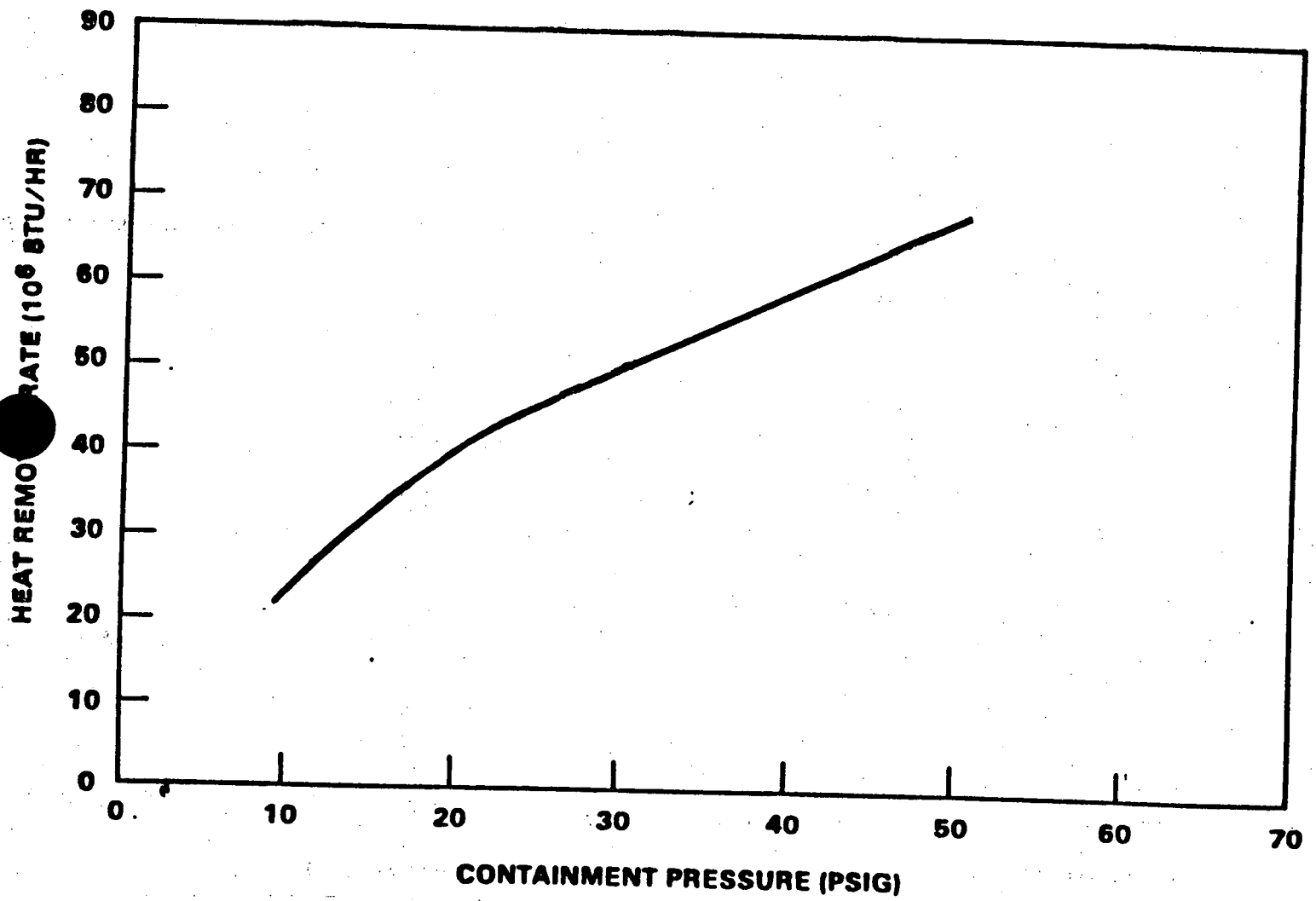


FIGURE 14.3A-106

CONTAINMENT HEAT ADDITION AND
HEAT ABSORPTION

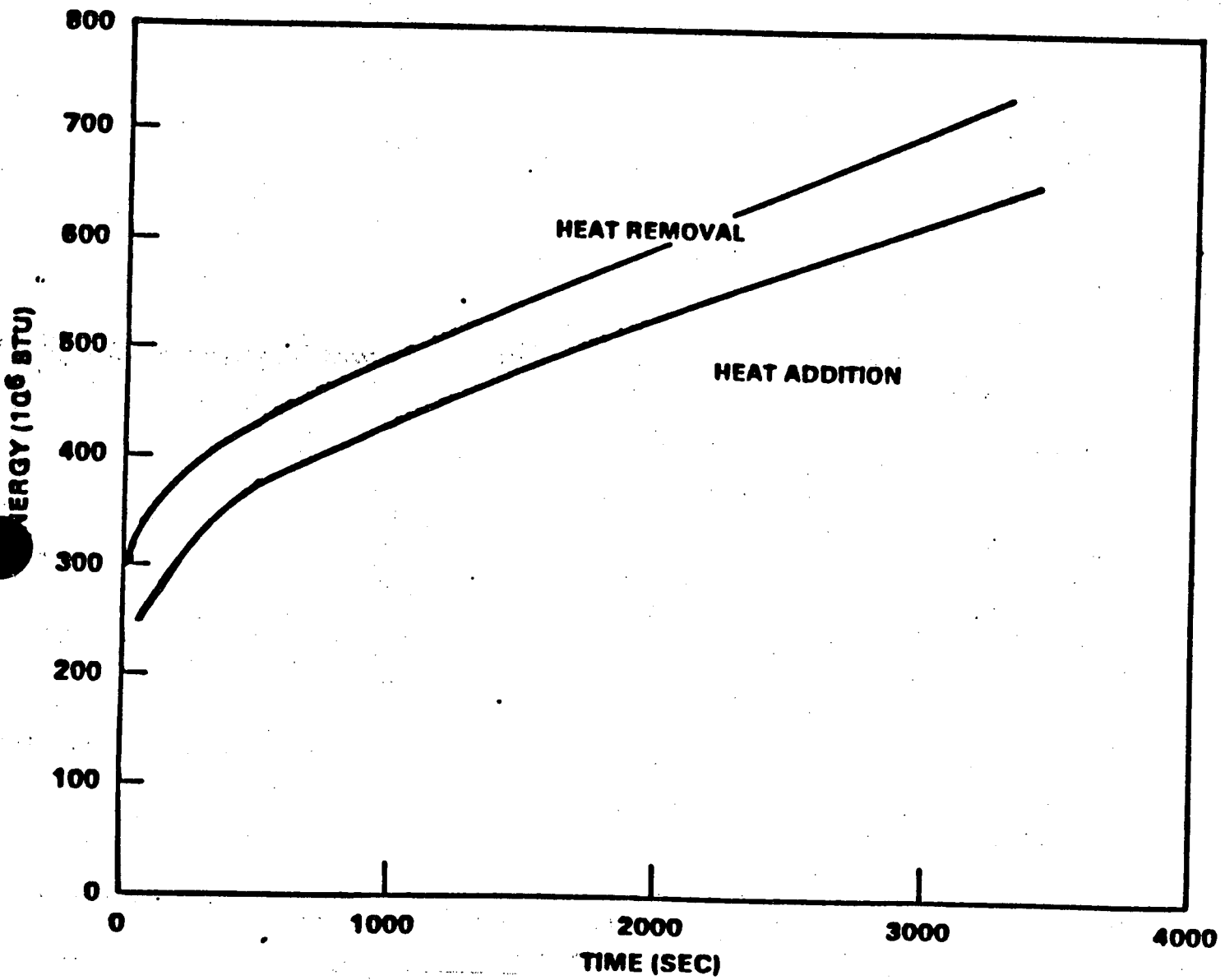


FIGURE 14.3A-107

DOUBLE ENDED PUMP SUCTION BREAK
CONTAINMENT HEAT REMOVAL

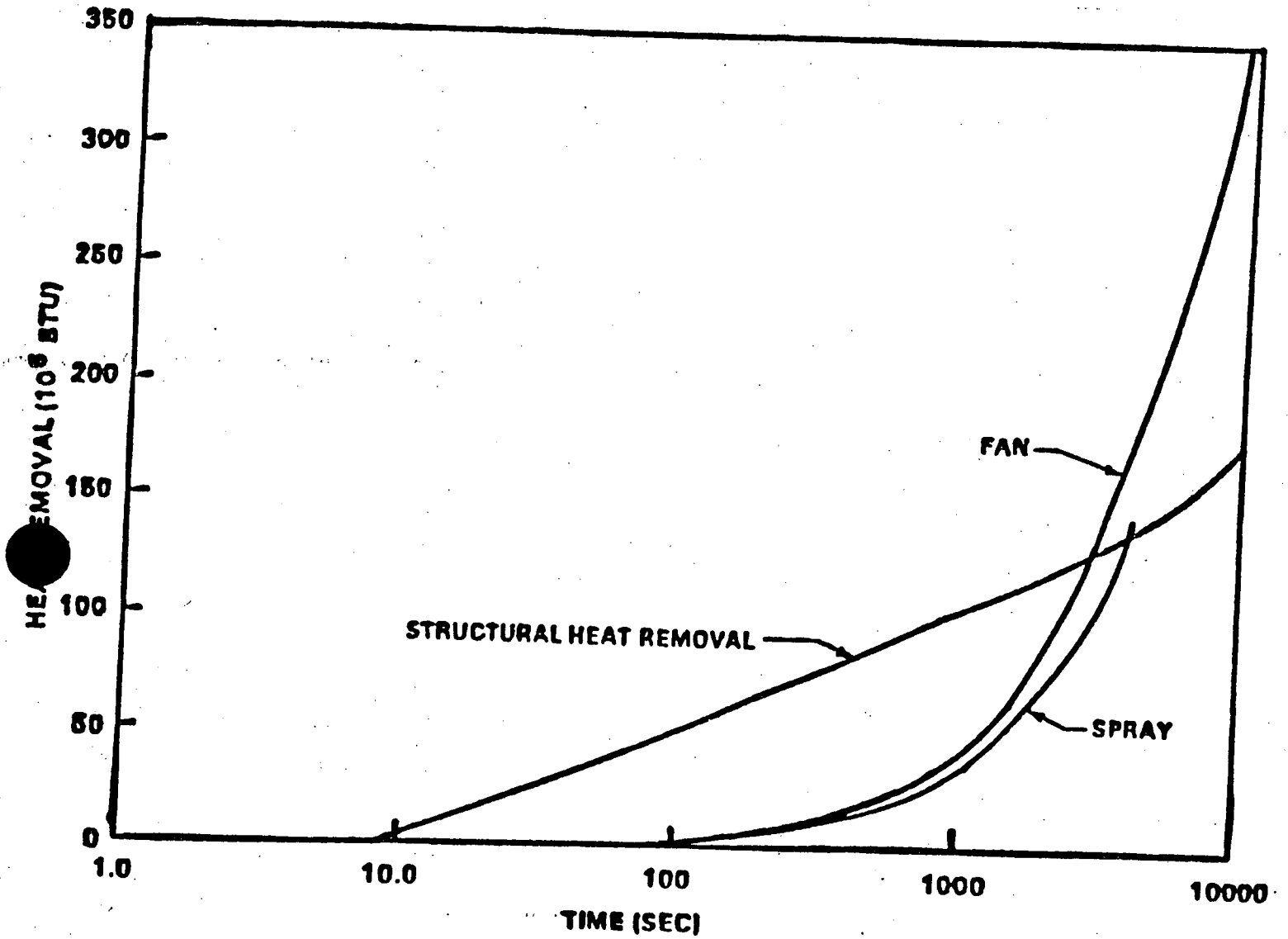


FIGURE 14.3A-108

STRUCTURAL HEAT TRANSFER
COEFFICIENTS,
PUMP SUCTION BREAKS

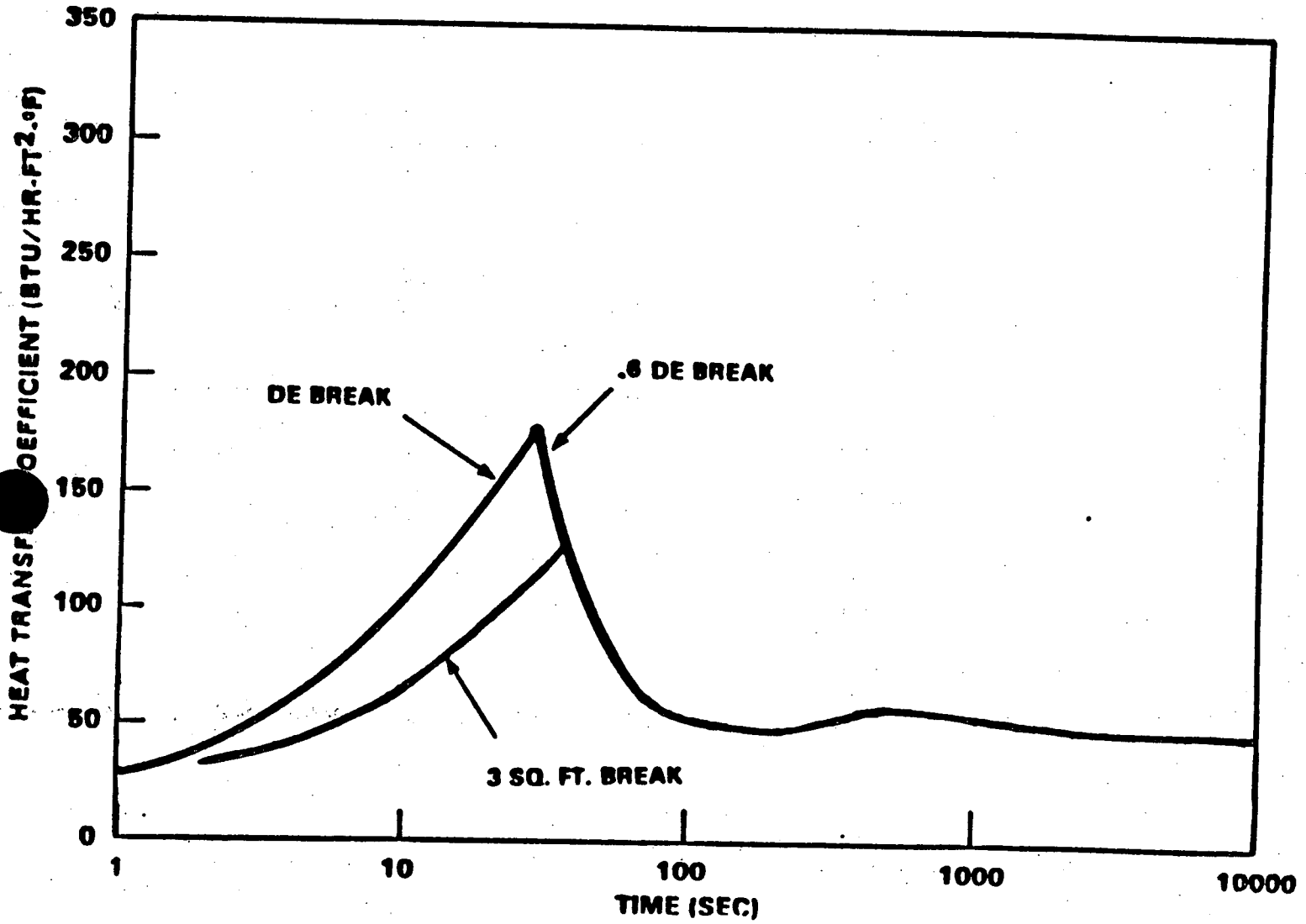


FIGURE 14.3A-109

CONTAINMENT CAPABILITY STUDY

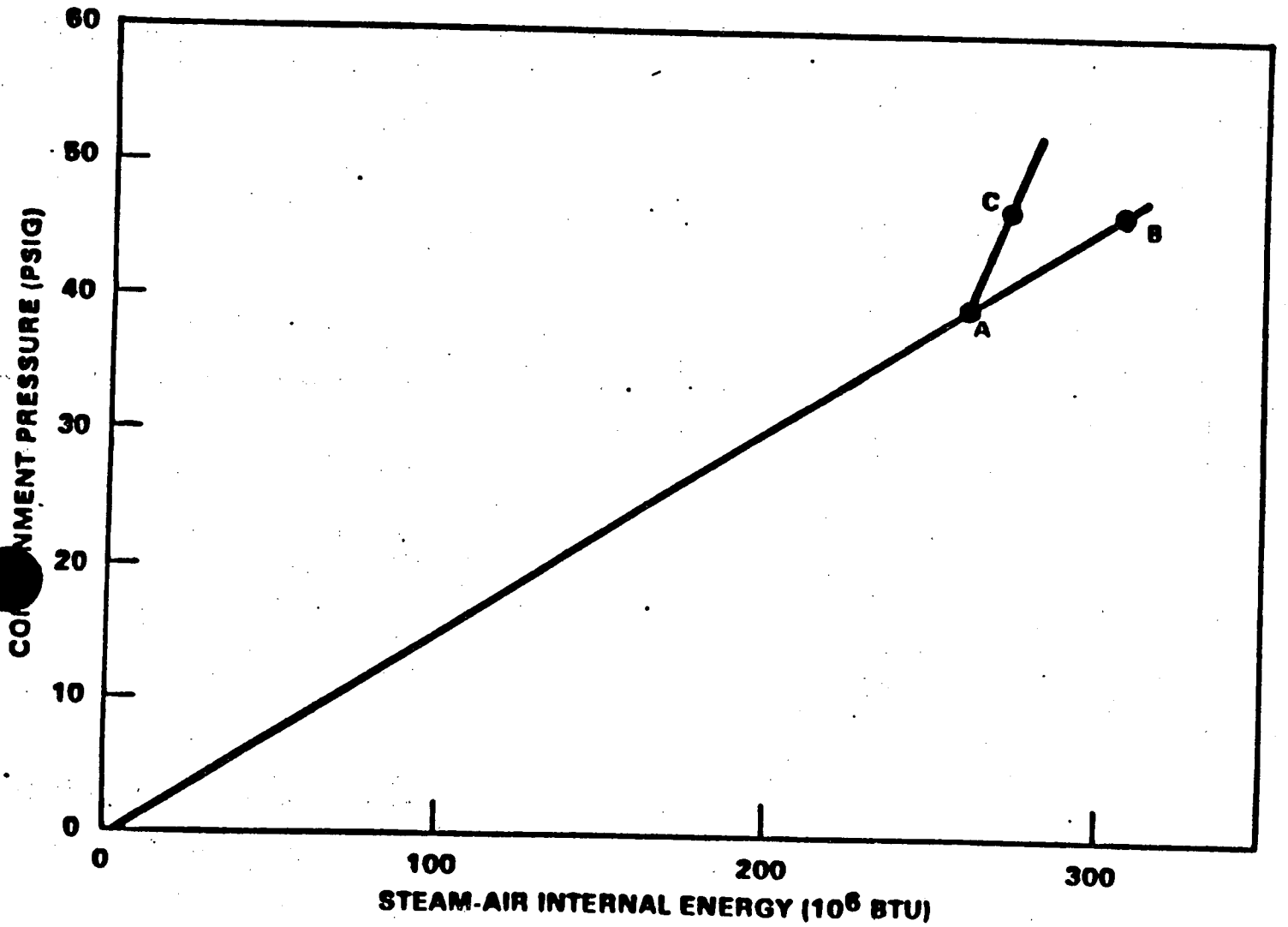


FIGURE 14.3A-110

DOUBLE ENDED PUMP SUCTION BREAK
MINIMUM SAFEGUARDS

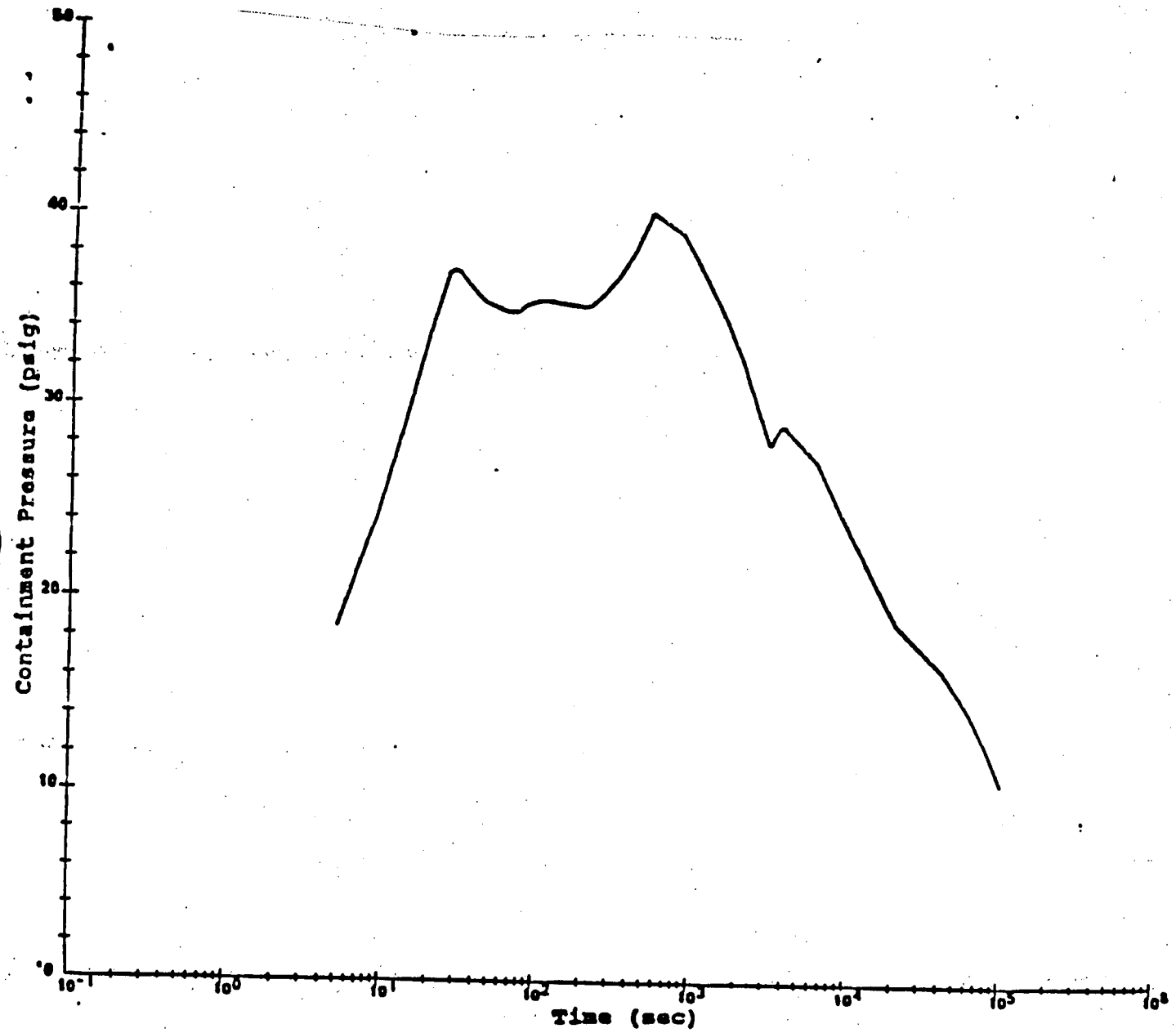


FIGURE 14.3A-111

DOUBLE ENDED PUMP SUCTION BREAK
MINIMUM SAFEGUARDS
RECIRCULATION SPRAY

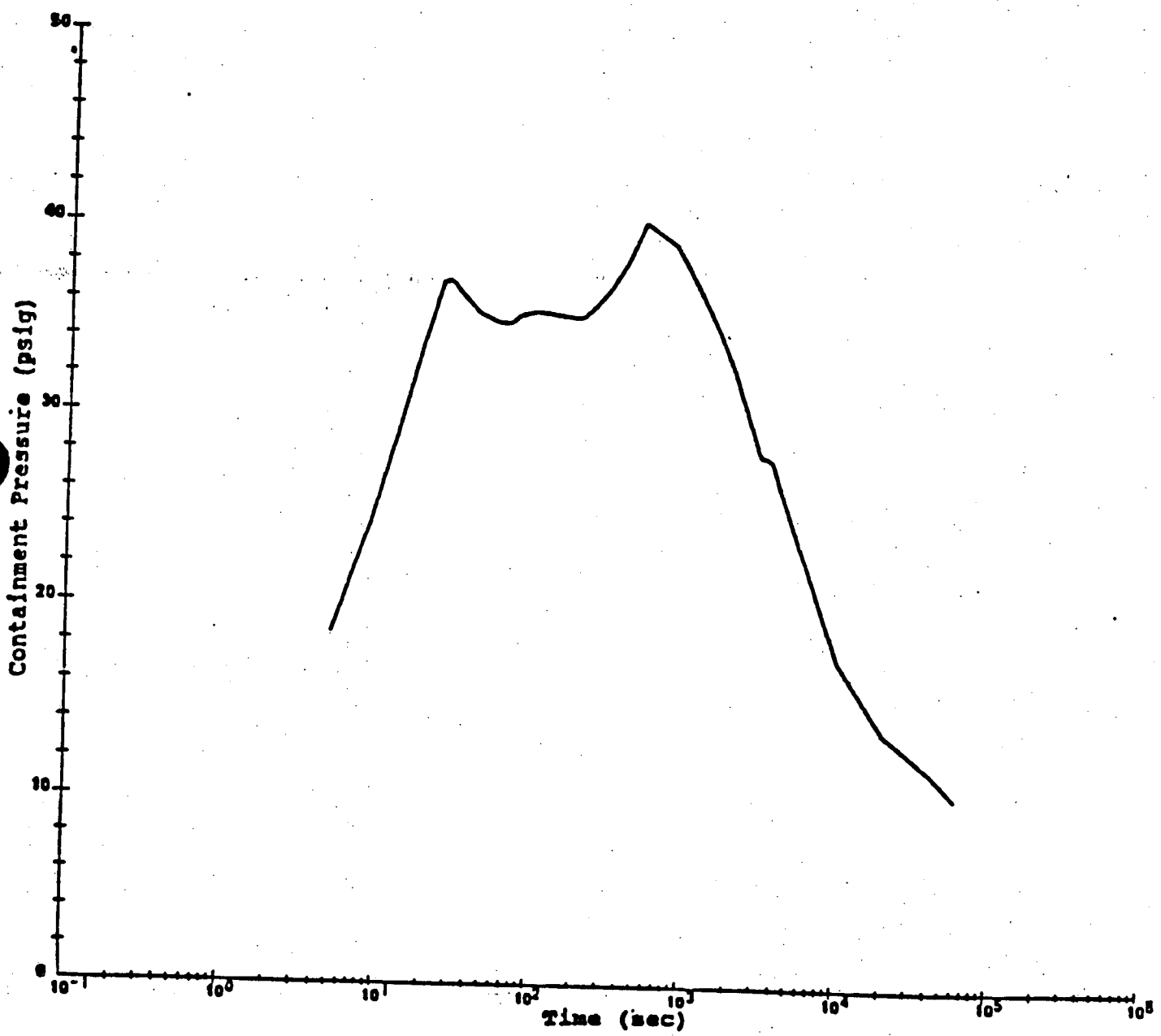


FIGURE 14.3A-112

DOUBLE ENDED PUMP SUCTION BREAK
MAXIMUM SAFEGUARDS

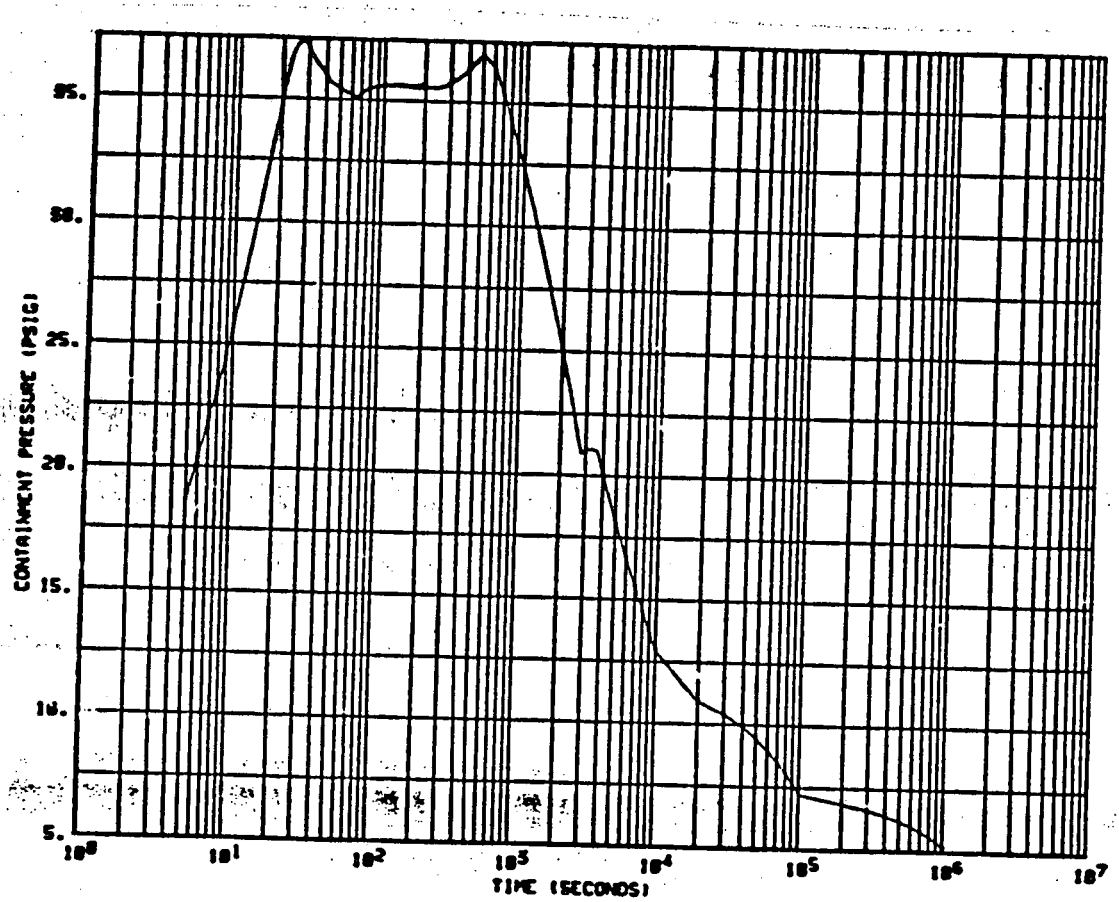


FIGURE 14.3A-113

C_D = 0.6 DOUBLE ENDED PUMP SUCTION BREAK
MINIMUM SAFEGUARDS

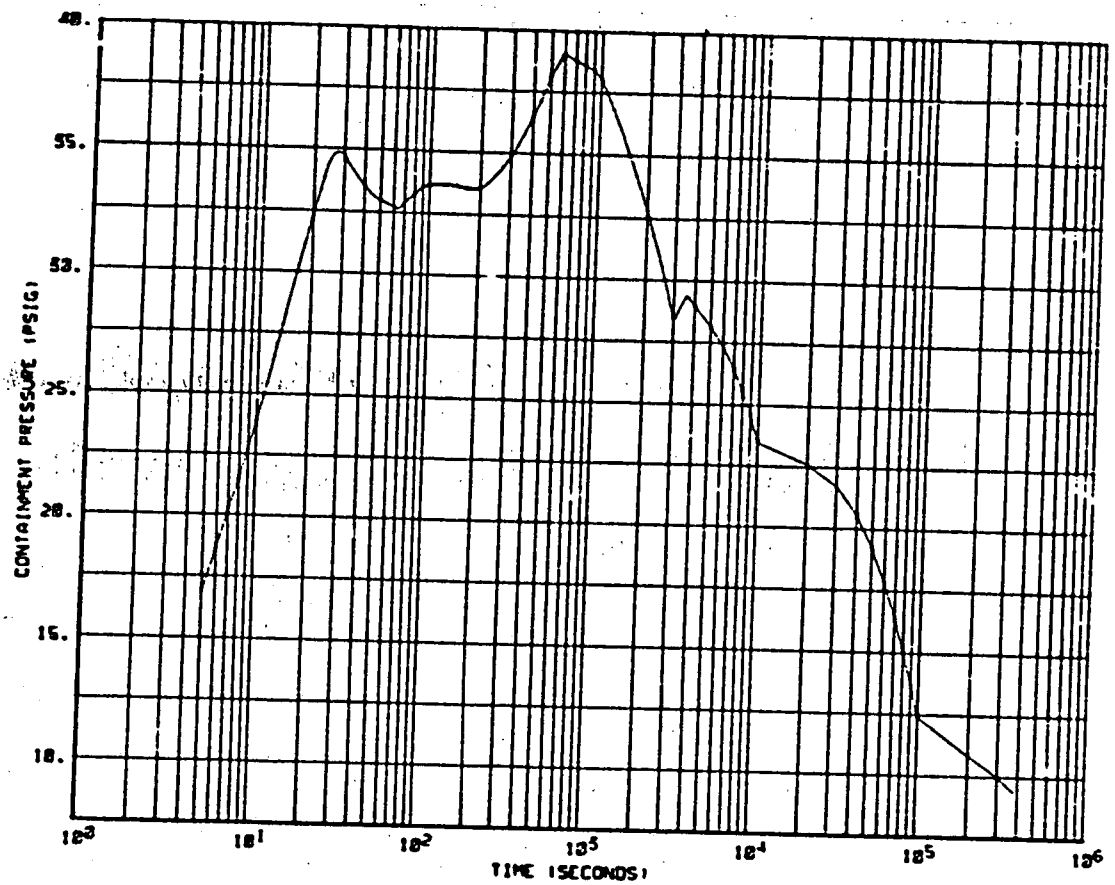


FIGURE 14.3A-114

3 FT^2 PUMP SUCTION SPLIT BREAK
MINIMUM SAFEGUARDS

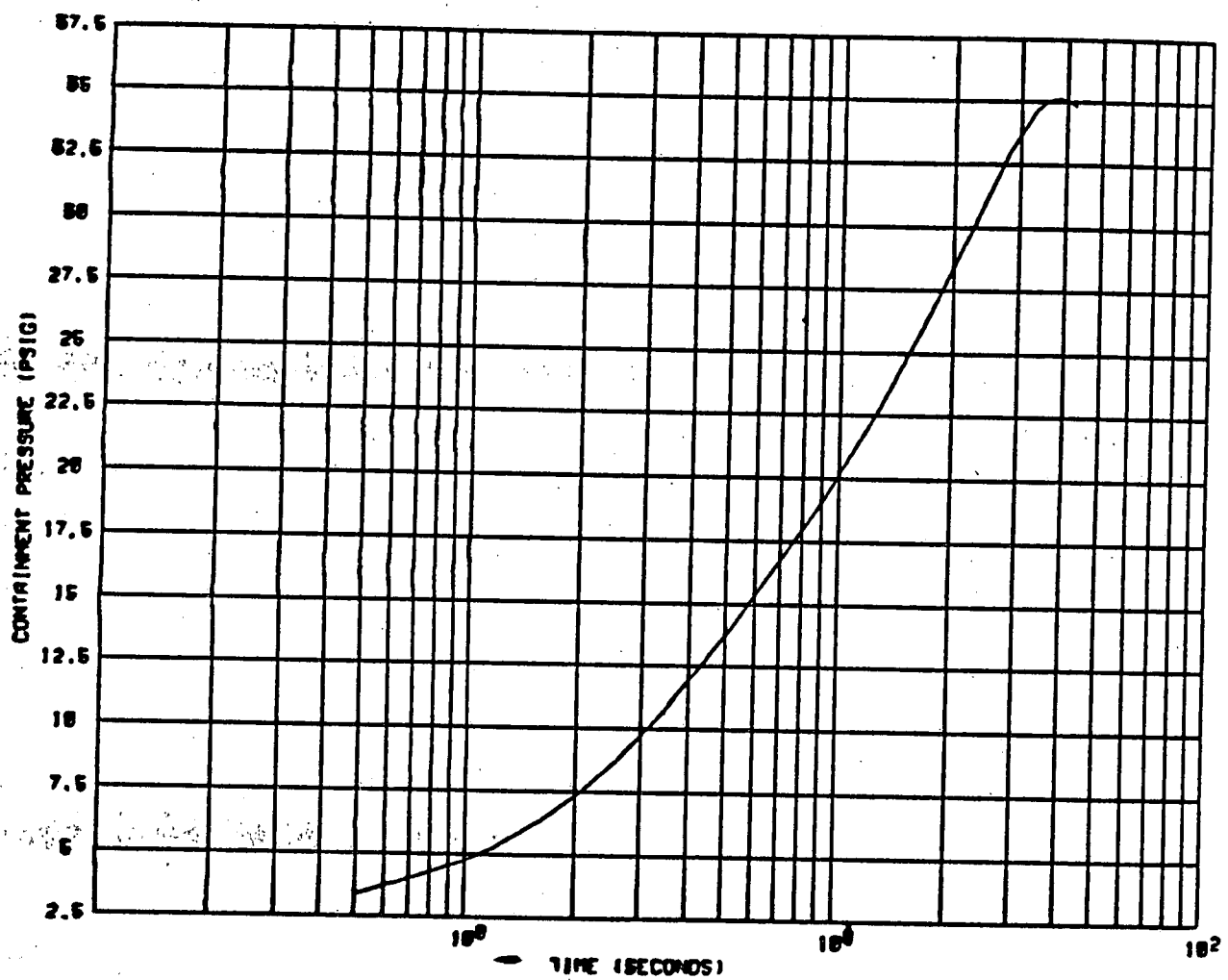


FIGURE 14.3A-115

DOUBLE ENDED COLD LEG BREAK
MINIMUM SAFEGUARDS

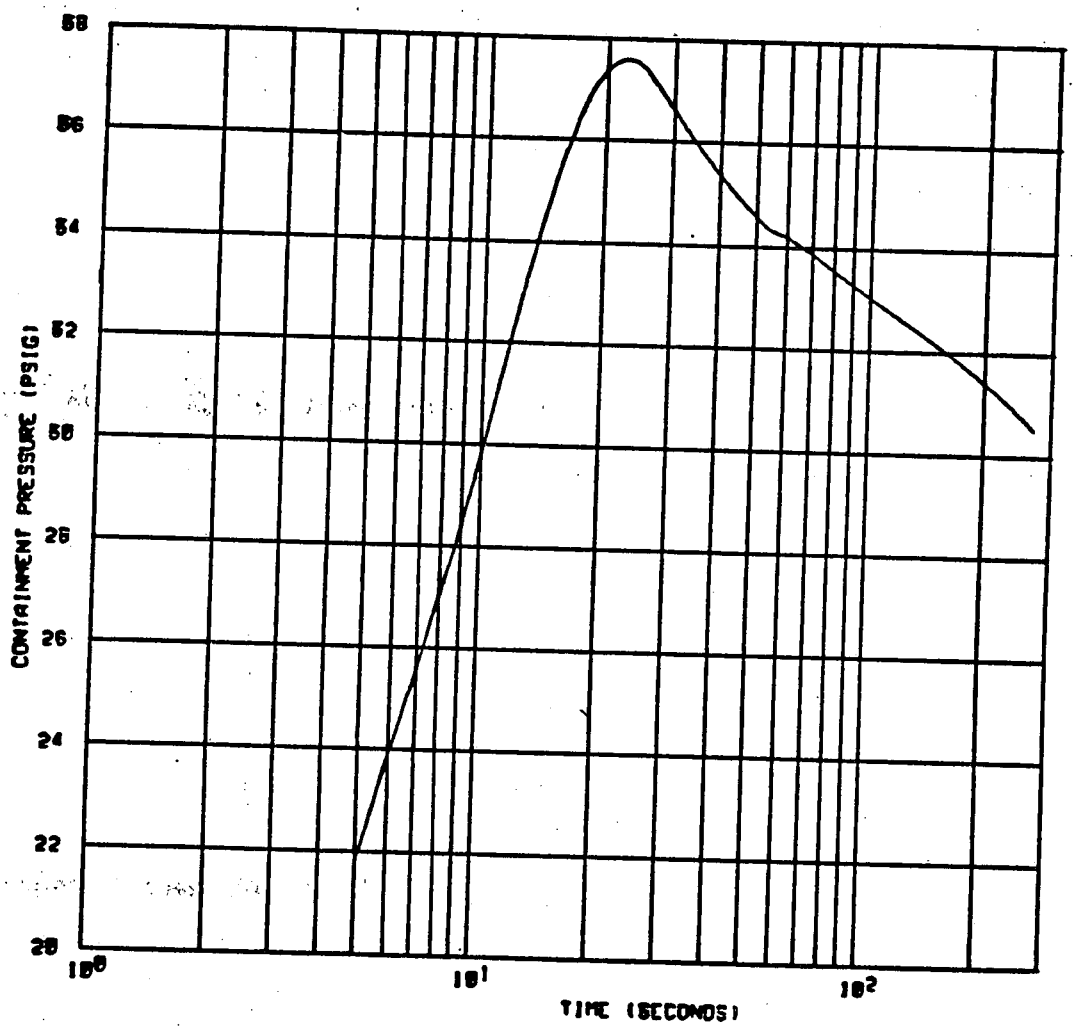
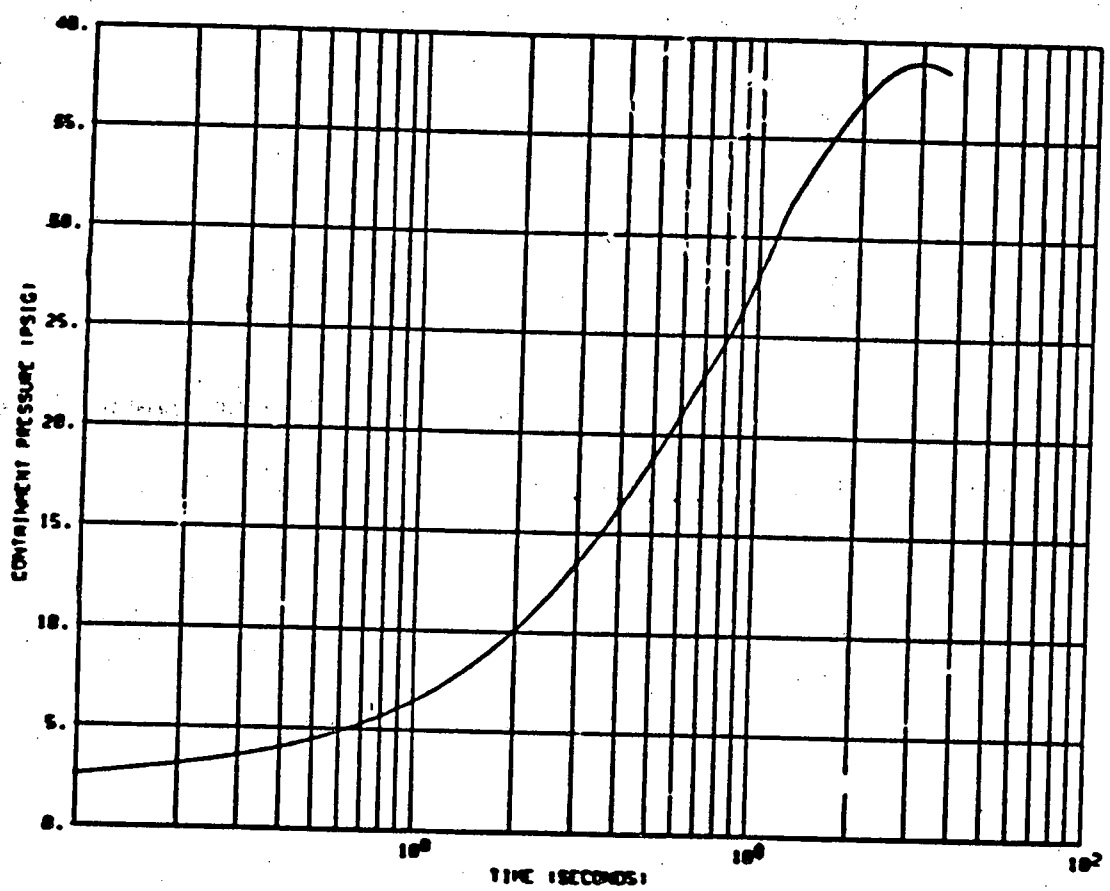


FIGURE 14.3A-116

DOUBLE ENDED HOT LEG BREAK
MINIMUM SAFEGUARDS