LOCA Mass and Energy Release Methodology for the APR1400

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ABSTRACT

This technical report describes the methodology of loss-of-coolant accident (LOCA) mass and energy(M/E) release analysis which is intended to be used for Nuclear Regulatory Commission (NRC) Design Certification (DC) Application of the Advanced Power Reactor 1400 (APR1400). The purpose of this report is to demonstrate the applicability of the methodology to APR1400 LOCA mass and energy release analysis.

An analysis of LOCA M/E release for APR1400 was performed using the above methodology. The system of advanced design features were reviewed and implemented into the analysis. The analysis methodology incorporates the advanced design features, 4 EDG for 4 train ECCS, fluidic device installed inside SIT and in-containment refueling water storage tank.

The mass and energy release analysis uses the acceptance criteria described in Standard Review Plan (SRP) 6.2.1.3 which ensures the meeting of General Design Criterion 50 and 10 CFR Part 50, Appendix K. The transient containment pressure is limited under the containment design pressure of 60 psig.

Analyses were performed for the spectrum of break location and SI flow :

- Double-ended suction leg slot break with maximum SI pump flow
- Double-ended suction leg slot break with minimum SI pump flow
- Double-ended discharge leg slot break with maximum SI pump flow
- Double-ended discharge leg slot break with minimum SI pump flow
- Double-ended hot leg slot break

The limiting case of the mass and energy release calculation was the case of double-ended discharge leg slot break with maximum SI pump flow. The analysis shows that the result including the effects of the advanced design features meets the acceptance criteria of Standard Review Plan(Reference 1).

The methodology as presented will be used when determining maximum containment pressure and temperature following a loss-of-coolant accident for the APR1400.

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LIST OF ACRONYMS

APR1400	Advanced Power Rector 1400
ASME	American Society of Mechanical Engineering
CEA	Control Element Assembly
CFR	Code of Federal Regulations
CFS	Cavity Flooding System
CS	Containment Spray
DC	Design Certification
DVI	Direct Vessel Injection
ECCS	Emergency Core Cooling System
ECSB	Emergency Containment Spray Backup
EDG	Emergency Diesel Generators
ESF	Engineered Safety Feature
FD	Fluidic Device
HVT	Holdup volume tank
ICI	In-Core Instrument
IRWST	In-containment Refueling Water Storage Tank
IWS	In-containment Water Storage
KEPCO	Korea Electric Power Corporation
KEPCO E&C	KEPCO Engineering & Construction Company
KEPCO NF	KEPCO Nuclear Fuel Company
KHNP	Korea Hydro and Nuclear Power, Co.
LBLOCA	Large Break Loss of Coolant Accident
LOCA	Loss of Coolant Accident
LPSIP	Low Pressure Safety Injection Pump
M/E	Mass and Energy
MSLB	Main Steam Line Break
US-NRC	United States Nuclear Regulatory Commission
PCT	Peak Cladding Temperature
POSRV	Pilot Operated Safety and Relief Valve
P/T	Pressure and Temperature
PWR	Pressurized Water Reactor
PZR	Pressurizer
RCGVS	Reactor Coolant Gas Vent System

RCS	Reactor Coolant System
RCP	Reactor Coolant Pump
RV	Reactor Vessel
SBLOCA	Small Break Loss of Coolant Accident
SC	Shutdown Cooling
SDVS	Safety Depressurization and Vent System
SG	Steam Generator
SI	Safety Injection
SIAS	Safety Injection Actuation Signal
SIP	Safety Injection Pump
SIS	Safety Injection System
SIT	Safety Injection Tank
SIT-FD	Safety Injection Tank with the Fluidic Device

1. INTRODUCTION

This technical report describes the methodology of loss-of-coolant accident (LOCA) mass and energy(M/E) release analysis which is intended to be used for Nuclear Regulatory Commission (NRC) Design Certification (DC) Application of the Advanced Power Reactor 1400 (APR1400). The purpose of this report is to demonstrate the applicability of the methodology to APR1400 LOCA mass and energy release analysis.

The APR1400 is an advanced PWR with improved design features to enhance reliability while retaining many basic features of the existing PWR. Therefore it is required for the APR1400 process that the result including the effects of the advanced design features on the mass and energy release analysis and containment pressure/temperature analysis meets the acceptance criteria of Standard Review Plan (Reference 1) for those analyses.

The method as presented are intended for use when determining maximum containment pressure and temperature following a LOCA.

Chapter 2 presents an overview of the APR1400 plant design features related to the LOCA analyses to assist in understanding applicability of the approved methodologies for current PWRs to the APR1400.

Chapter 3 addresses the codes and methodology used for the mass and energy release analysis. In this section, the mass and energy release model for the blowdown, reflood and the post-reflood phases are discussed. The modification of the methodology reflecting the advanced design features of the APR1400 are described.

Chapter 4 presents a sample mass and energy release calculation result performed by using the analytical models described above and its containment response.

Chapter 5 summarizes the version of the mass and energy release evaluation model with minor modifications, which is based on the approved methodology and discusses the conclusions.

2. DESIGN DESCRIPTION OF APR1400

2.1 RCS General Description

The RCS block diagram is shown in Figure 2-1. The major components of the system are a Reactor Vessel (RV), two parallel heat transfer loops, each containing one SG and two RCPs, and a pressurizer connected to the RV outlet pipe in RCS Loop 2. The two SGs and the four RCPs are symmetrically located on opposite sides of the reactor vessel. All components are located inside the containment building.

During normal operation, the reactor coolant is circulated through the reactor vessel and SGs by the RCPs. The reactor coolant is heated as it passes through the reactor vessel by energy produced by the fissioning fuel in the core and is cooled in the SGs as it gives up heat to the secondary system. Feedwater entering the shell side of the SGs absorbs the heat from the primary system forming steam.

The RCS pressure is maintained and controlled through the use of a pressurizer where steam and water are maintained in thermal equilibrium. During full load operation, the pressurizer volume is almost evenly divided between saturated water and saturated steam. Steam is formed by energizing immersion heaters in the pressurizer, or is condensed by a subcooled pressurizer spray as necessary to maintain operating pressure and limit pressure variations due to plant transients.

2.1.1 Reactor Vessel (RV)

The reactor vessel and internals are shown in Figure 2-2. The reactor vessel is essentially a vertical right cylinder with two hemispherical heads. The lower head is welded to the reactor vessel shell and contains [ ]TS incore instrumentation penetrations. The upper closure head can be removed to provide access to the reactor vessel internals. This head is penetrated by [ ]TS control element drive mechanism nozzles.

The reactor vessel contains the fuel bundles, the control rods and other internals necessary for support and flow direction. During normal operation, the reactor coolant enters the vessel through four inlet nozzles and flows downward through the RV annulus and turns and flows upward through the active core. The reactor coolant flows up parallel to the axis of the fuel bundles, removing the heat generated within the fuel as it passes through the core. The reactor coolant then turns and leaves the reactor vessel through two outlet nozzles to the RCS hot legs.

A small core bypass flow progresses from the four (4) inlet cold leg nozzles upward through the downcomer region where a small flow leaks across the alignment keyways between the core support barrel and the reactor vessel. In addition there is a small leakage through the outlet nozzle clearance with the core support barrel. The bypass flow enters and mixes with the fluid in the regions above the Inner Barrel Assembly, passes down through the Inner Barrel Assembly, and mixes with the flow exiting the core. Additional flow paths, which do not provide flow utilized directly in core heat transfer, are identified below:

1. through ICI guide tubes
2. through CEA guide tubes; and
3. through core support barrel annulus.

Four Direct Vessel Injection (DVI) nozzles are located above the centerline of the cold and hot legs nozzles, but below the upper vessel flange. These nozzles provide Safety Injection System (SIS) flow to the reactor vessel during abnormal operation and accident mitigation. The SIS fluid is injected directly into the reactor vessel downcomer above the elevation of the cold legs.

2.1.2 Steam Generators (SGs)

The steam generator shown in Figure 2-3 is a vertical U-tube heat exchanger which operates with the primary coolant on the tube side and secondary coolant on the shell side. Hot reactor coolant from the reactor vessel enters the SG through the inlet nozzle in the primary head. From here it flows through the U-tubes, where it gives up heat to the secondary coolant, to the outlet side of the primary head where the flow splits and leaves through the two outlet nozzles.

Feedwater flow enters into the section of integral economizer through two nozzles in the distribution box and is pre-heated before discharge into the evaporator section. Flow in the evaporator section passes upward through annuli formed by the tubes and baffle plate into the axial flow region. This region is basically a counterflow heat exchanger, with feedwater directed upward outside the tubes and primary flow directed downward inside the tubes. Feedwater then exits the economizer with a condition slightly subcooled and enters the boiling region of the SG. The flow after the boiling region is in the condition of steam-water mixture. The steam-water mixture becomes high quality steam by passing through the moisture separators and steam dryer. The steam exits the SG through the steam restrictor installed in steam nozzle. The restrictor is sized such that there is a [ ]TS percent reduction in

flow area enough to reduce containment peak pressure and temperature and to limit the return to power following a steam line break.

2.1.3 Reactor Coolant Pumps (RCPs)

The four identical RCPs are vertical single-stage, bottom suction, horizontal discharge, motor-driven centrifugal pumps designed to overcome the system flow resistances and circulate the reactor coolant at the flow rate required for design power operation. They are also used to heat up the reactor coolant during plant startup. The reactor coolant pump is shown in Figure 2-4.

Each RCP motor is provided with a flywheel to increase the rotating inertia of the RCP assembly. This inertia increases the RCP coastdown time and reduces the rate of decay of reactor coolant flow if electrical power to the RCP motors is lost thus ensuring that fuel design limits are not exceeded during the incident. An anti-reverse rotation device is provided in each RCP motor to prevent pump windmilling in the reverse direction and to limit backflow through a stopped RCP.

2.1.4 Pressurizer (PZR)

The pressurizer is shown in Figure 2-5. The pressurizer is designed to maintain RCS operating pressure and compensate for changes in reactor coolant volume during temperature/load changes. The pressurizer is connected to the hot leg in RCS Loop 2 via a surge line and to the cold leg in Loop 2A and 2B via spray lines. The pressurizer controls the RCS pressure by maintaining the temperature of the pressurizer liquid at the saturation temperature corresponding to the desired system pressure.

Pressurizer pressure is controlled by heaters and spray. The pressurizer heaters are sheath-type immersion heaters which protrude vertically into the pressurizer through sleeves welded in the lower head. The heaters consist of proportional heaters and backup heaters. The proportional heaters, a small portion of the pressurizer heaters is operated continuously to offset heat losses to ambient and to heat the continuous spray water from the cold leg to be in saturation. The proportional heater output varies between 0 and 100% and is automatically controlled by the Pressurizer Pressure Control System. The backup heaters, the remaining pressurizer heaters are automatically controlled by the PPCS. The backup heater output is not variable; on-off control is used. The backup heaters are normally deenergized but are turned on by a low pressurizer pressure signal or high level error signal.

The pressurizer heaters and their controls are non-class 1E, thus use normal power. A sufficient number of backup heaters are capable of being manually aligned to the emergency power supply in order to maintain natural circulation at hot standby conditions when normal power is not available.

The average reactor coolant temperature is programmed to vary as a function of load. A reduction in load causes the reduction of the average reactor coolant temperature to its programmed value for the lower power level. The resulting contraction of the reactor coolant lowers the pressurizer water level causing the RCS pressure to fall. The pressurizer water level error from the programmed level setpoint which is a function of T_{AVG} is controlled by the operation of the charging control valve and letdown orifice isolation valves.

An auxiliary spray line is provided from the charging pump to permit pressurizer spray during plant cooldown after the RCPs must be shut down due to low system pressure.

A vent line connection to the RCGVS is provided from the counter flange of each POSRV inlet nozzle. The vent line is used to vent air from the pressurizer prior to plant startup. In addition, the vent line allows non-condensible gases to be vented to the RCGVS during post-accident operations when these gases may collect in the pressurizer steam space. The vent connection also provides the capability of using the RCGVS for RCS pressure control during natural circulation cooldowns and after some accidents in which the use of pressurizer main and/or auxiliary spray is not possible.

The Safety Depressurization and Vent System (SDVS) provides the capability to initiate feed-and-bleed operation during the beyond design basis event of total loss of feedwater (TLOFW). The SIS provides a "feed" flow to the RCS while the "bleed" flow exits the RCS through the POSRVs to the IRWST. The combined feed-and-bleed operation would result in an adequate core cooling and safe shutdown for the beyond design basis event. The SDVS provides the capability to depressurize the RCS in response to a severe accident scenario. The POSRVs are designed and qualified in accordance with requirements associated with the RCS overpressure protection and rapid depressurization functions.

2.1.5 Reactor Coolant Piping

Each loop of an RCS contains five pipe assemblies; one [ ]^{TS} internal diameter pipe assembly between the reactor vessel outlet nozzle and SG inlet nozzle, two [ ]^{TS} internal diameter pipe assemblies from the SG's two outlet nozzles to the RCP suction nozzles, and two [ ]^{TS} internal

diameter pipe assemblies from the RCP discharge nozzles to the reactor vessel inlet nozzles. These pipe assemblies are referred to as the hot leg, the suction legs, and the pump discharge legs, respectively. The suction leg and pump discharge leg are also referred to as the cold leg. The other major section of reactor coolant piping, the surge line, is a [ ]TS pipe assembly between the pressurizer and the hot leg in Loop 2.

2.2 Safety Injection System (SIS)

SIS is designed to inject borated water into the RCS to flood and cool the core following a LOCA. SIS provides the feed function and restores the RCS liquid inventory when the RCS pressure decreases rapidly by opening pressurizer Pilot Operated Safety Relief Valves (POSRVs) during beyond design basis event of a total loss of feedwater to steam generators.

The SIS consists of four mechanically separated trains, four SITs, and associated valves, piping and instrumentation. Each train contains one SI pump, one SIT, and associated suction and discharge paths. The pumps take suction from the IRWST. Motor operated valves and pump in each train receive power from either the normal power source or the Emergency Diesel Generators (EDGs).

Normal power connections for Class 1E are through four independent electrical trains with each train providing power to each bus. In the event of a LOCA, in conjunction with a single failure in the electrical supply, the flow from at least three SI pumps is available for core protection. One independent electrical train, as described above, supplies power to each SI pump and associated valves.

2.2.1 SI Pumps

The four SI pumps are horizontal, multi-stage, and centrifugal pumps driven by induction motors. The SI pumps deliver water from the IRWST to the reactor vessel downcomer via DVI nozzles. Each SI pump discharge line is connected to the DVI nozzle or the DVI nozzle/hot leg. The SI lines 1 & 2 inject the borated water to RCS through the DVI nozzles and the SI lines 3 and 4 to the DVI nozzles or hot leg injection lines for the long-term mode. This is schematically illustrated in Figures 2-6 and 2-7.

2.2.2 Safety Injection Tanks (SITs)

The four safety injection tanks provide a means of rapidly reflooding the core following a large break LOCA, and keeping it covered until flow from the SI pumps becomes available (in the

event that offsite power is lost, there will be [ ]^{TS} for SI pumps delay time from safety injection setpoint reached to time when SI pumps deliver flow to RCS at full speed). For the purpose of safety analysis, water injected up until the end of RCS blowdown is disregarded and refill/reflood is initiated when the reactor vessel is empty.

Whenever pressurizer pressure is above [ ]^{TS}, the SITs are isolated from the RCS by only two check valves in series. If RCS pressure should fall below SIT pressure, the tanks will begin to discharge borated water into the RCS. Thus the tanks comprise an extremely reliable passive core flooding system.

2.2.3 Fluidic Devices (FDs)

A passive fluidic device, installed in the SITs, can provide two operation stages of a safety water injection into the RCS and allow more effective use of borated water in case of LOCA. Once LOCA occurs, the system will deliver a high flowrate of cooling water for the certain period of time, and thereafter, the flowrate is reduced to lower flowrate.

The fluidic device consists of vortex chamber, main(supply) port, control port, exit port, and standpipe. The vortex chamber is a shape of flat slice of cylinder and will be installed horizontally at the bottom of SIT inside, its axis overlapping with the centerline of SIT. The 4 main ports and 4 control ports are connected [ ]^{TS} symmetric manner to the vortex chamber with certain angle. The standpipe is connected to the main port and its axis is parallel with the centerline of SIT.

The time of flow switching is determined by the height of the standpipe. The water flows through both of main and control ports when the water level is above the top of the standpipe. In this case, the flow passage is almost straight and the flow resistance is minimum. On the other hand, when the water level is below the top of the standpipe, the water flows only through control port. SIT fluidic device is shown on Figure 2-8.

2.3 Containment

The containment building encloses the entire pressurized water reactor, steam generators, reactor coolant loops, and portions of the auxiliary and engineered safety features systems. It ensures that leakage of radioactive material to the environment does not exceed the acceptable dose limit as defined in 10 CFR 50.34 even if a Loss of Coolant Accident (LOCA) were to occur. Also, the containment must withstand the pressure and temperatures of the DBA without exceeding the design

leakage rate of [ ]TS for the first 24 hours and the limit thereafter is based on a leak rate associated with half of the design leak rate.

The containment structure consists of a reinforced concrete base slab, a prestressed concrete cylindrical shell and hemispherical dome, and a reinforced concrete internal structure. The inside face of the slab, shell, and dome of the containment interior boundary is lined with a leaktight carbon steel liner.

2.4 In-Containment Water Storage System

The In-containment Water Storage System (IWSS) performs water collection, delivery, storage and heat sink functions inside containment during normal operation and accident conditions. It consists of the in-containment refueling water storage tank (IRWST), the holdup volume tank (HVT), and the cavity flooding system (CFS). The IRWST and HVT are integral parts of the reactor containment building internal structures. Each is a reinforced concrete structure, and the inside surface is lined with stainless steel. The IWSS is shown in Figure 2-9. A plan view for IRWST and HVT is shown in Figure 2-10.

The IRWST in the containment provides a water source to fill the refueling pool during a refueling outage. Also, the IRWST provides a continuous suction source for the safety injection (SI), containment spray (CS) and shutdown cooling (SC) pumps, thus eliminating the operator actions to realign the suction in an emergency such as a loss-of coolant accident (LOCA), which improves reliability and reduces the complexity of the design. The HVT provides a low collection point in containment to collect water released from pipe breaks and containment sprays during design basis accident.

The IRWST is designed to have a sufficient inventory of boric acid water for refueling and long-term core cooling during a LOCA. The capacity of the IRWST water is in the range of [ ]TS and [ ]TS Sufficient submerged water level is maintained to secure the minimum NPSH for the SI pumps, SC pumps, and CS pumps.

Reactor coolant blown out through a break and water sprayed by the CS pumps during a LOCA is collected in the holdup volume tank (HVT). The accumulated water in the HVT overflows back into the IRWST, thereby the IRWST is replenished. The temperature in IRWST during operation is in the range of [ ]TS. The design temperature of IRWST is [ ]TS.

2.5 Containment Spray System

The CS system is an engineered safety feature (ESF) designed to reduce the containment atmosphere pressure and temperature below containment design limits with a margin in the event of a postulated LOCA or MSLB inside containment, by removing heat from the containment atmosphere. The function of CS system is accomplished by taking borated water from IRWST, pumping it to the containment atmosphere through a CS heat exchanger and spray nozzle. The schematic diagram of CS system is shown on Figure 2-11.

The containment spray (CS) system reduces the containment pressure and temperature inside containment and removes radioactive fission products from the containment atmosphere following a postulated LOCA or Main Steam Line Break (MSLB). The CS system consists of two redundant [ ]TS capacity trains. Each train includes a CS pump, a CS heat exchanger, a CS miniflow heat exchanger, a main spray header with nozzles, an auxiliary spray header with nozzles, and associated valves, piping and instrumentation.

The CS system has sufficient capacity to reduce containment pressure to less than 50 percent of design pressure within 24 hours after the design basis event and to maintain the bulk contents of the IRWST subcooled during the feed and bleed mode of core cooling. Each CS pump train is designed to deliver a minimum [ ]TS to the spray nozzles. CS pump flow to the SC heat exchanger during the SC backup operation is less than [ ]TS for each pump.

The CS system operation is automatically actuated by a containment high-high containment pressure signal (Containment Spray Actuation Signal). The minimum containment spray actuation setpoint is greater than [ ]TS. The actuation pressure is sufficiently high to prevent the system actuation due to a small leak. The minimum delay time for actuation of the CS system is greater than [ ]TS with offsite power available or with offsite power unavailable.

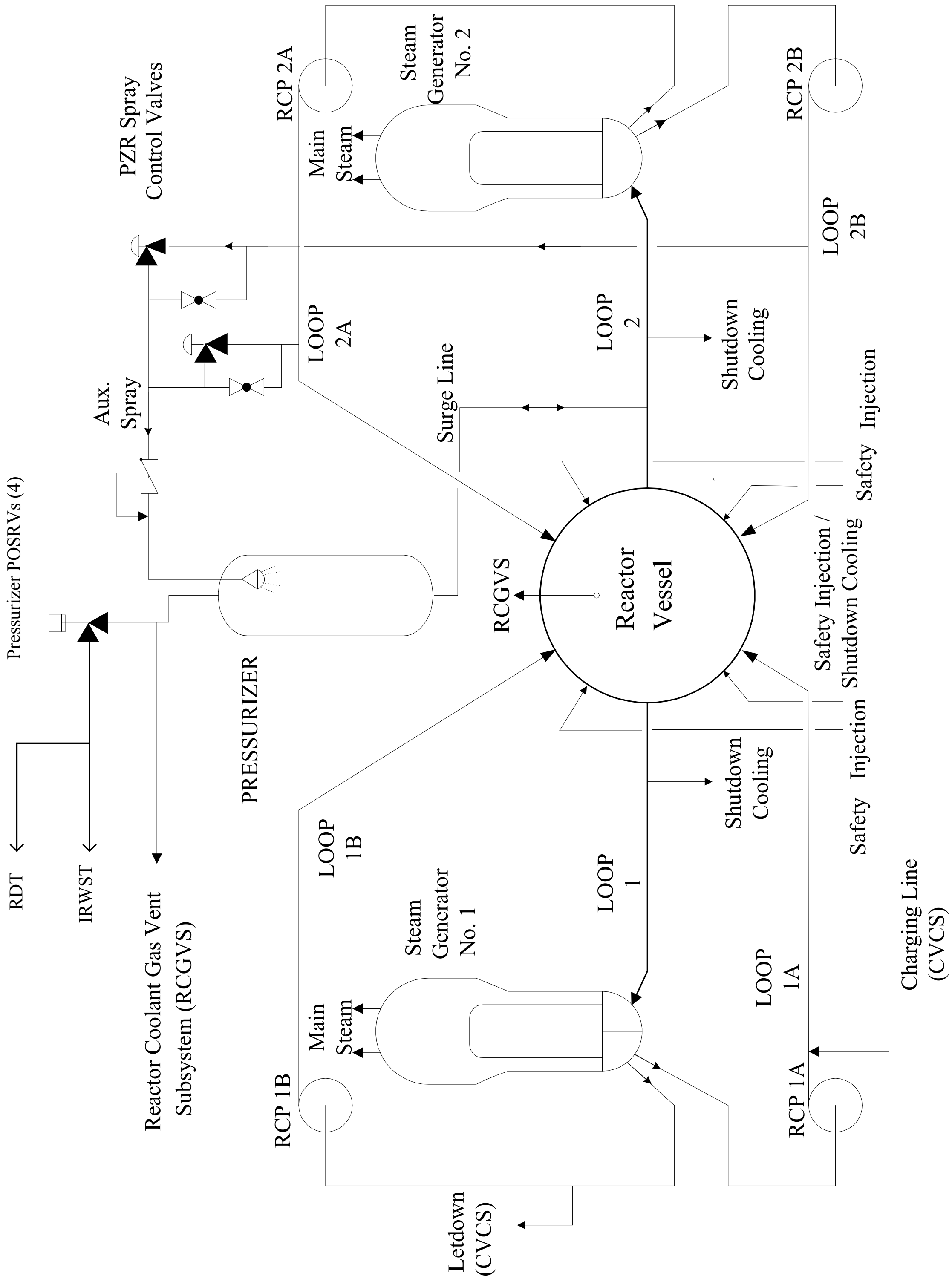

Figure 2-1 Reactor Coolant System Block Diagram

TS

Figure 2-2 Reactor Vessel and Internals

TS

Figure 2-3 Steam Generator

TS

Figure 2-4 Reactor Coolant Pump

TS

NOZZLE SCHEDULE		
NO.	SERVICE	NO. REQUIRED

Figure 2-5 Pressurizer

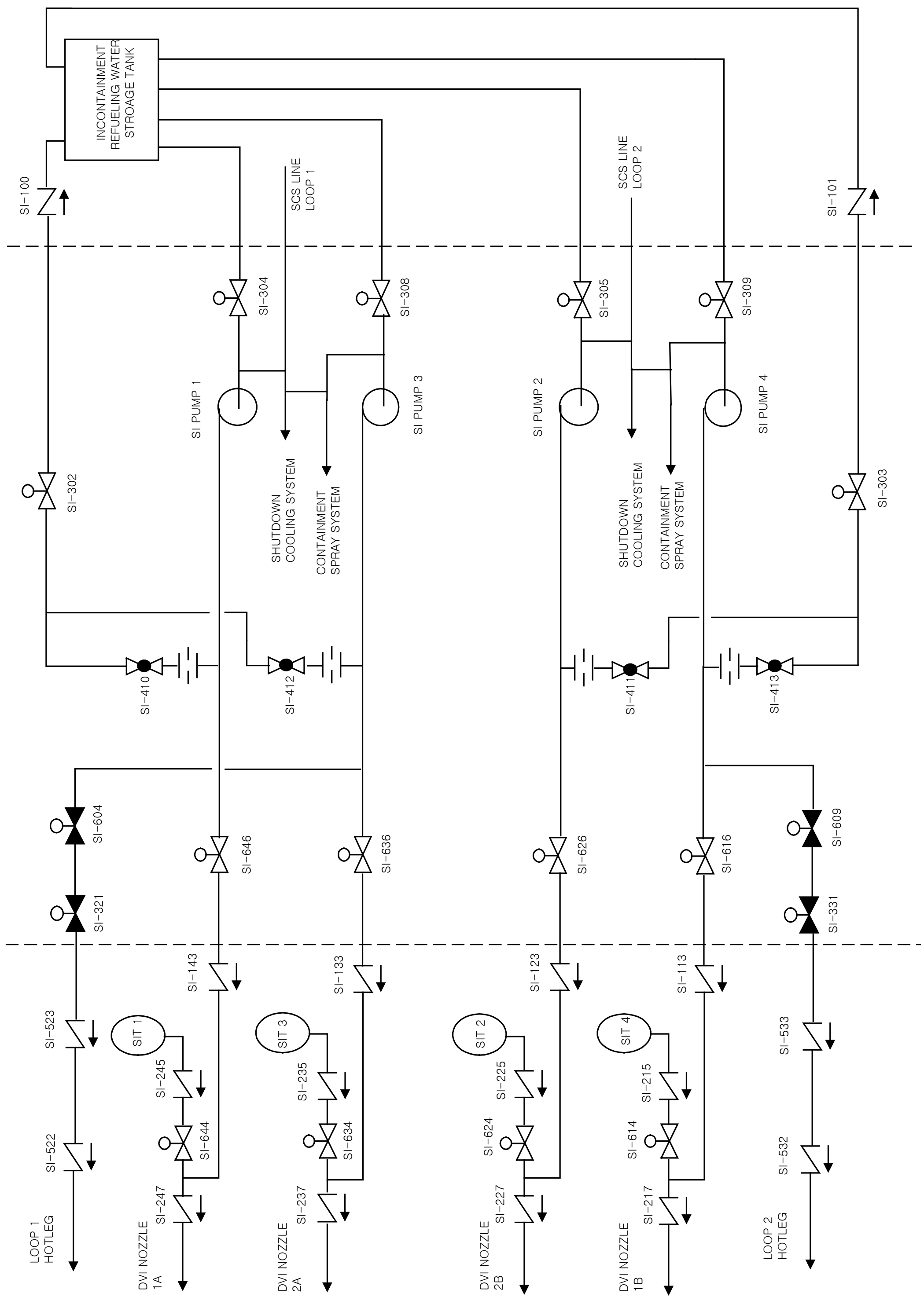

Figure 2-6 Safety Injection System (Short-Term Mode)

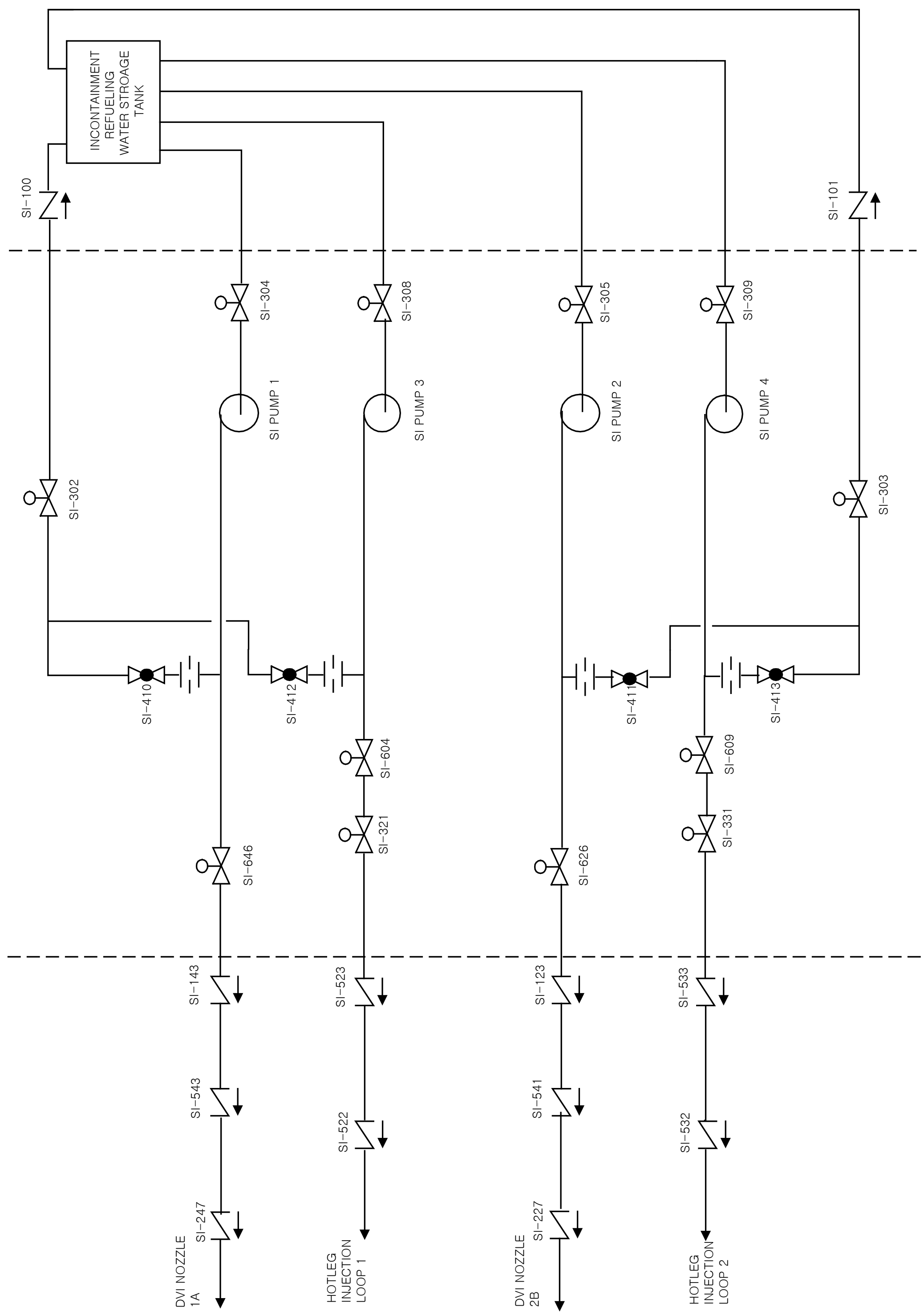

Figure 2-7 Safety Injection System (Long-Term Mode)

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Figure 2-8 Safety Injection Tank and Fluidic Device

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Figure 2-9 In-Containment Water Storage System (IWSS)

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Figure 2-10 IRWST and HVT Plan View

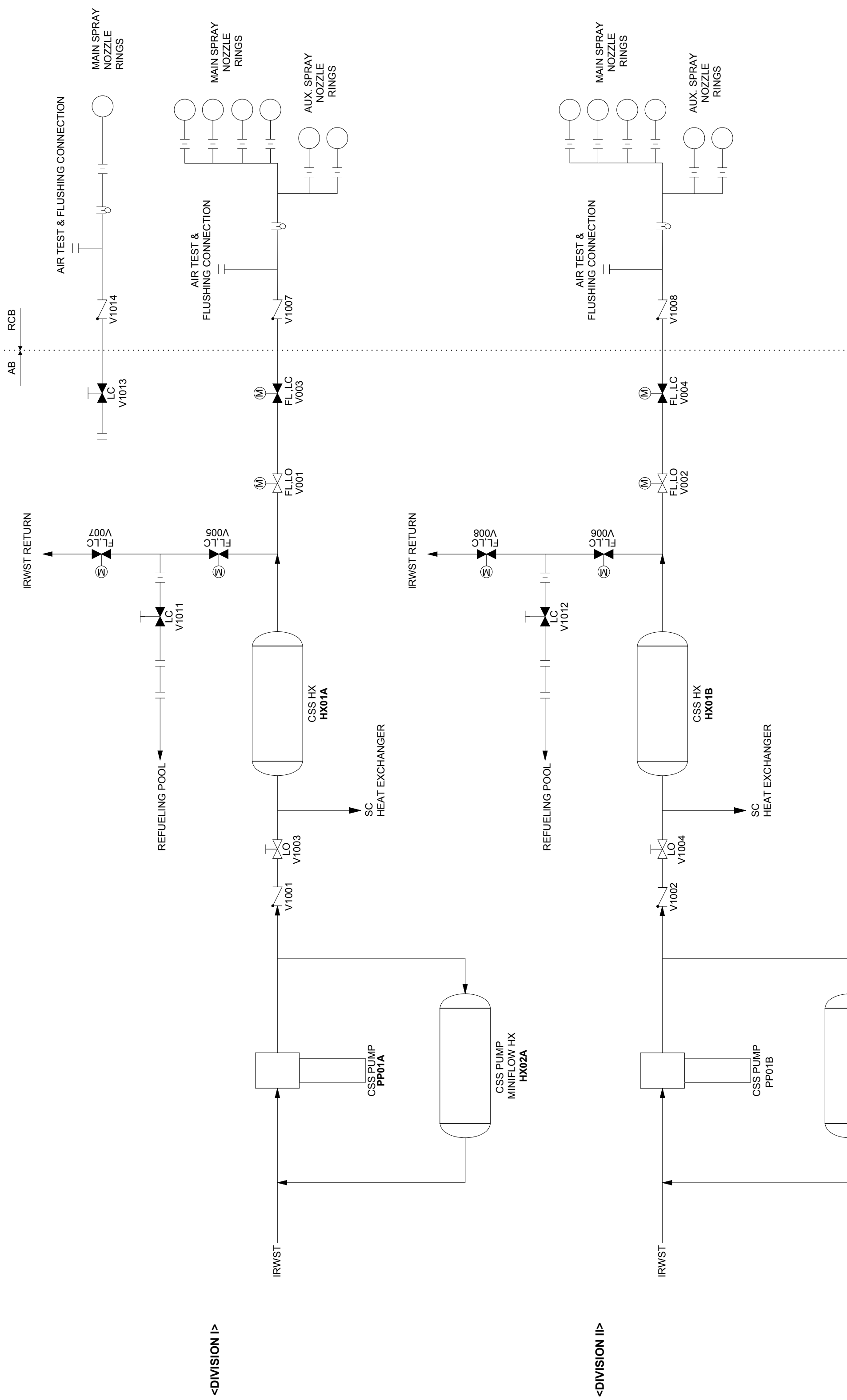

Figure 2-11 Containment Spray System (CSS)

3. METHODOLOGY DESCRIPTION FOR LOCA MASS AND ENERGY RELEASE

3.1 Acceptance Criteria

The methodology of the mass and energy release analysis incorporates the acceptance criteria described in Standard Review Plan (SRP) 6.2.1.3, “Mass and Energy Release Analysis for Postulated Loss-of-Coolant-Accident (LOCA)” (Reference 1). The SRP Acceptance criteria are based on meeting the relevant requirements of the following regulations:

1 General Design Criterion 50, as it relates to the containment and subcompartments being designed with sufficient margin, requires that the containment and its associated systems can accommodate, without exceeding the design leakage rate, and the containment and subcompartment design can withstand the calculated pressure and temperature conditions resulting from any LOCA.

2 10 CFR Part 50, Appendix K, as it relates to sources of energy during the LOCA, provides requirements to assure that all the energy sources have been considered.

The conservative assumptions for the input conditions based on the acceptance criteria are considered in the mass and energy release analysis. However, any specific limitation to the results based on the acceptance criteria is not applicable to the mass and energy release, since the mass and energy release results are the process parameters in the middle of the containment analysis.

The final results of the containment analysis are the behavior of the containment pressure and temperature. The limitation based on the acceptance criteria is applied to the calculated containment pressure as the containment design pressure of [ ]TS. The containment design pressure is calculated in accordance with the guideline of Reference 5.

3.2 Accident Description for LOCA Mass and Energy Release

LOCA mass and energy release analyses are categorized as the following phases: blowdown, refill, reflood, post reflood, and decay heat period.

a. The blowdown period extends from time zero until the primary system depressurizes and equalizes with the containment pressure. During blowdown, most of the initial primary coolant is

released to the containment as a two phase mixture. Following blowdown, the water for releases is supplied from the safety injection system (SIS).

There is an important distinction between hot leg breaks and cold leg breaks for LOCA post blowdown analyses. For a hot leg break, the majority of the SIS supplied water leaving the core can vent directly to the containment without passing through a steam generator. Therefore, there is no mechanism for releasing the steam generator energy to the containment for a hot leg break, and only the blowdown period is considered. On the other hand, for cold leg breaks like discharge leg break and suction leg break, the water passes through a steam generator before reaching the containment. So the post blowdown releases to the containment are considered for cold leg breaks.

b. The first post blowdown period is refill. During refill, the SIS water refills the bottom of the reactor vessel to the bottom of the core. This period is conservatively omitted from the analysis.

c. The second post blowdown period is the reflood period. During reflood, SIS water floods the core. Reflood is assumed to end when the liquid level in the core is [ ][TS] below the top of the active core. During reflood, a significant amount of the SIS water entering the core is postulated to be carried out of the core by the steaming action of the core to coolant heat transfer process. This fluid then passes through a steam generator where reverse (i.e., secondary to primary) heat transfer heats it before it reaches the containment. The residual steam generator secondary energy is sufficient to convert all of this fluid to superheated steam during the initial part of the reflood period. Subsequently, as the steam generators are cooled by this process, there is not enough heat transfer to boil all of the fluid passing through the tubes. This causes the break flow to change from pure steam to two phase.

As the entire NSSS cools, the flow to the containment becomes eventually subcooled because the safety injection water is subcooled. The onset of the two phase release to the containment may or may not occur before the end of reflood; typically, this occurs close to the end of reflood. The potential release of subcooled fluid to the containment does not occur during reflood when conservative system parameters are utilized.

d. The third post blowdown period is the post reflood period. During this period, the dominant process is the continued cooling of the steam generators by the SIS water leaving the core. The release to the containment during this period becomes generally two phase in the earlier stage of this period

as the cooling of the steam generators continues. The post-reflood ends when the affected steam generator has essentially reached the containment temperature.

e. The final post blowdown period is the decay heat period, which begins at the end of post-reflood. During decay heat period, the dominant mechanisms for release rates are the generation of the decay heat and the cooling of all NSSS metal. Decay heat period ends when the containment pressure and the environment pressure are essentially equal.

LOCA mass and energy release is analyzed using the computer codes, CEFLASH-4A, FLOOD3 for the categorized phases. CEFLASH-4A computer code is used for the analysis of the blowdown period and FLOOD3 computer code is used for the analysis of the reflood period. The detail descriptions of the codes are presented in the Reference 2 and 3, respectively.

The containment analysis is performed subsequent to the mass and energy analysis using the computer code, GOTHIC which calculates containment pressure and temperature during the whole period of LOCA transient. The detail descriptions of the codes are presented in appendix A.

3.3 Mass and Energy Release Data

The pipe break is assumed to occur at the one of the three locations as follows.

a. Double Ended Suction Leg Slot Break (DESLSB) in the suction leg of RCP.
b. Double Ended Discharge Leg Slot Break (DEDLSB) in the discharge leg of RCP.
c. Double Ended Hot Leg Slot Break (DEHLSB) in the Hot leg of RCS.

The break type is assumed to be slot break which has the break area equivalent to the double ended break. The largest break area, i.e. the double ended break area is limiting in large break LOCA.

There are five analysis cases for LOCA M/E analysis: for the suction leg break with maximum & minimum SI flow, discharge leg break with maximum & minimum SI flow, and hot leg break cases. Those cases are summarized in Table 4-1. In this report, the analysis result of the limiting case is provided. The limiting case is determined based on the containment peak pressure. Mass and energy release data for the limiting case is provided in Tables 4-2. For cold leg breaks (pump suction and discharge), some of the post blowdown SIS water is postulated to spill to the containment floor whenever the reactor vessel annulus is full. The vessel spillage data associated with these breaks are also given in Part A of Table 4-2.

3.4 Energy Sources

The following sources of generated and stored energy in the reactor coolant system and secondary coolant system are considered:

a. Primary coolant,
b. Secondary coolant,
c. Primary walls (including reactor internals),
d. Secondary walls,
e. Safety injection water,
f. Core power
g. Decay heat.

For the conservative analysis, the assumptions of the energy sources are biased to maximize the stored energy.

For considering the stored energy in the coolant, the initial reactor coolant system water volumes are conservatively calculated based on maximum manufacturing tolerances for the reactor vessel and steam generator tubes. Expansion of the loop components from cold to hot operating conditions is also considered for the coolant stored energy. The initial water volume of pressurizer includes an allowance for level instrumentation error. This makes the maximized pressurizer water volume which includes the maximized stored energy.

For considering the stored energy in the walls, the large specific heat and heat conductivity of carbon steel is conservatively assumed for the entire walls in RCS.

The core stored energy may be increased slightly by TCD. However, the effect of TCD on the mass and energy release is negligible. The details of the results are described in Reference 5.

For considering the energy in the safety injection water, the liquid break flow is assumed to be mixed with the water in In-containment Refueling Water Storage Tank (IRWST). The mixed water is taken and discharged into DVI by SI pumps. This increases the energy in the safety injection water.

The initial power level assumed in the analyses consists of the core power and an additional RCP power. The initial core power is assumed to be 102% of its normal power which

includes the instrumentation error. The higher power level is conservative for LOCA containment pressure calculations.

For the core decay heat curve as a fraction of the initial power level following the accident; a [ ]TS conservatism factor is used for the first [ ]TS, followed by a [ ]TS factor thereafter. The normalized decay heat curve is shown in Figure 4-1.

Initial conditions in the reactor coolant system are given in Table 4-3. It shows various stored energies in RCS at the initial time.

3.5 Description of Blowdown Model

Blowdown mass and energy release rates are calculated using the CEFLASH-4A computer code (Reference 2). The node diagram of this code is presented in Figure 3-1 for the blowdown analysis of LOCA discharge leg break. A description of the CEFLASH-4A code including the conservatisms in modeling is given below. This section includes justification of the heat transfer correlations. The following assumptions are made in selecting input data for the code.

a. The CEFLASH-4A code model of the heat transfer in a node allows only one wall per node. Accordingly, the thickness used for the "U" factor for each node wall is selected such that the energy released from the system is conservatively modeled.

b. The CEFLASH-4A wall representation uses the total heat capacitance of all the walls in the reactor coolant system that actually face a given node. This is conservative since, in reality, some of the walls will not participate as effectively as others in the heat transfer process. For example, the geometry of the flow path is such as to allow some components to partially shield others from the flow. This effect is conservatively omitted from the modeling.

c. Although much of the steel facing the coolant in the reactor coolant system is stainless cladding [ ]TS, a conservative carbon steel conductivity [ ]TS, is used for the entire wall. This conservatively overpredicts the energy released from all such walls.

d. Wall surface heat transfer coefficients are assumed to be infinite.

e. All primary water volumes are conservatively increased from their nominal design values in order to obtain an upper bound for the available mass and energy in the system prior to LOCA. The pressurizer water volume includes an allowance for level instrumentation error. Pressure and temperature expansion of the reactor coolant system and steam generator to the normal operating condition is included.

f. An accepted (Jens Lottes) two phase heat transfer correlation is used for the core to coolant heat transfer whenever the flow through the core is not pure steam.

g. Heat transfer across the steam generator tubes is modeled with the same heat transfer coefficient in both the forward and reverse directions. This is conservative since it maintains a nucleate boiling heat transfer coefficient on the secondary side during the LOCA blowdown. In reality, the reactor trip following the LOCA would result in a turbine trip which would close the turbine stop valves and then the heat transfer in the secondary side would be a natural convection, in which the heat transfer coefficient has a small value. However, in this analysis, it is conservative to assume the overall heat transfer coefficient in the initial steady state at full power operation since it maximizes the reverse heat transfer.

h. The turbine stop valves are assumed to close at [ ]TS. This is conservative since it keeps energy within the NSSS which in turn is a source of energy for containment pressurization.

i. The Main Feedwater Isolation Valves(MFIV) are assumed to close only after the generation of a Main Steam Isolation Signal (MSIS) of [ ]TS containment pressure. This signal occurs very rapidly (~1 second). MFIV closure is assumed to take [ ]TS, with an additional allowance of [ ]TS for the MSIS signal delay. Feedwater flow and enthalpy are kept at their normal values due to the short times involved. As an additional conservatism, the feedwater is assumed to be added at the end of blowdown, so that the steam generator secondary temperatures during the blowdown are not lowered by the relatively cold feedwater. Note that the feedwater is hot relative to potential peak LOCA containment temperatures so that feedwater addition at the end of blowdown is conservative both for blowdown and for reflood calculations.

j. Auxiliary feedwater flow is conservatively omitted since it is cold [ ]TS relative to both blowdown and reflood conditions.

3.6 Description of Core Reflood Model

Reflood mass and energy release rates are calculated using the FLOOD3 computer code (Reference 3). The hydraulic network of this code is presented in Figure 3-2 for the reflood analysis of LOCA discharge leg break. Heat transfer is conservatively modeled for core, vessel walls, vessel internals, loop metal, steam generator tubes, steam generator secondaries, and steam generator secondary walls. The FLOOD3 code hydraulics calculates flow rates and pressure. The heat transfer process predicts fluid enthalpies. Fluid densities are calculated as functions of pressures and enthalpies. The conservatisms in the model are as follows:

a. The containment backpressure during reflood is assumed to be [ ]TS and constant. It is given for the input of FLOOD3 code.

b. A one-dimensional heat transfer model is used for all wall heat transfer calculations. This is demonstrated in Reference 4 where comparisons of one-dimensional models and otherwise identical two-dimensional models show that one-dimensional modeling is more conservative.

c. A nucleate boiling heat transfer coefficient of [ ]TS is used to model the heat transfer from the steam generator tubes to the primary coolant. This coefficient represents an upper limit, and is conservatively used at all times throughout the tubes.

d. During reflood, the behavior of steam generator liquid level is calculated. The liquid level is predicted to be decreased due to the reversed heat transfer and a part of tube area is in contact with the secondary steam. The heat transfer coefficient of steam-to-tube area is Nusselt condensation heat transfer coefficient, and is much higher than that of liquid-to-tube, natural circulation heat transfer coefficient. Therefore, it is conservatively assumed that the whole tube heat transfer area is in contact with the secondary steam. A conservative Nusselt condensation heat transfer coefficient of [ ]TS is used in conjunction with the tube area.

e. The thermal resistance corresponding to the steam generator tubes is [ ]TS. This value is also used in calculating secondary to primary heat transfer.

f. The carryout rate fraction (CRF) used during reflood is constant 0.05 up to the 46 cm (18-inch) core level, and linearly increases to 0.8 up to the 61 cm (24-inch) core level, and is kept constant at 0.8 until the 3.2 m (10.5 feet) level is reached. 3.2 m (10.5 feet) is 0.6096 m (2 feet) below the top of the active core. Other variables, such as core inlet temperature, pressure, flow rate, linear heat rate, or other experimental data are not used to determine the CRF.

g. Reflood is assumed to terminate when the 3.2 m (10.5 feet) quench level in the core is reached.

h. [ ]TS of the standard decay heat (Figure 4-1) curve is used as a conservatism for the available energy sources.

i. During reflood, credit is taken for the condensation of steam in the annulus by the cold SIS water. As a conservatism, credit is not taken unless the reactor vessel annulus is full since the SI flow is injected directly into the annulus. Also, as an additional conservatism, credit is not taken when the SI flow rate is too low to thermodynamically condense all of the steam in the annulus. Thus, credit is not taken for the condensation after the SITs empty or the turndown to low SIT flow by the fluidic device. The percentage of the total steam flow condensed varies slightly with time for each case. For suction leg and discharge leg cases, credit is taken for the condensation of approximately [ ]TS of the total steam flow when the annulus is full and the thermodynamic criteria are simultaneously met.

3.7 Description of Post Reflood Model

The post reflood model is identical to the reflood model except that, at the end of reflood, the CRF is changed from [ ]TS to [ ]TS. This conservatively increases the system flow rates due to the increased CRF. The flow rates are further enhanced by the fact that the core liquid height is now constrained at the [ ]TS level, which maximizes the available driving head between the annulus level and the core in the flooding equation. All heat transfer coefficients are kept at the values used for the reflood analysis. Condensation is analyzed as previously described; however, there is insufficient spillage for complete thermodynamic condensation of the steam so that credit for condensation has not been taken.

3.8 Description of Decay Heat Phase Model

The final phase of the large break LOCA is a relatively stable period characterized by decay heat release and it extends from the end of the post-reflooed phase. The analysis method used to determine the mass and energy released during this period are described in Appendix A.2.4, “Decay Heat Phase M/E M/E Analysis Model”

3.9 Single Active Failure Analysis

Two possible failures are considered as single failure in LOCA mass and energy analysis, the failure of one SI pump and the failure of one emergency diesel generator (EDG). They have effects on the safety injection flow to be decreased and eventually degrades the ECCS performance to cool down core. In LOCA mass and energy analysis, the single failure is assumed for the minimum safety injection flow and no failure is assumed for the maximum safety injection flow.

Another failure in containment system is considered as single failure, the failure of one train of containment spray. The failure reduces the capability to suppress the containment pressure, which results in higher containment pressure during the LOCA transient. In the case with maximum safety injection, the failure of one train of containment spray system is assumed. In the case with minimum safety injection, the failure of one train of containment spray system is assumed too due to the failure of one emergency diesel generator.

The limiting case is determined by the case analyses with the maximum and minimum safety injection flow. This case analysis with the maximum and minimum safety injection flow is performed at the three break locations.

The cases presented in this analysis show the mass/energy source terms with maximum safety injection (no pump failure or no power source failure) and minimum safety injection (failure of one diesel generator). Since the peak containment pressure is a function of both the release rates and the containment parameters, the various type of single failure is estimated to find out the limiting single failure for the analysis.

3.10 Evaluation of Effect by the Advanced Design Features

3.10.1 Effect of Fluidic Device Controlled by K-factor

In APR1400 design, a fluidic device (FD) is employed for the control of safety injection tank (SIT) flow during the large break LOCA. The fluidic device is a safety-related equipment and is installed in the SIT as shown in Figure 2-8. It passively controls the SIT injection flow in two operation stages, initially high flow injection and then low flow injection, according to the SIT water level.

High flow : Be made when the SIT water level is above the entrance of stand pipe of the fluidic device and SIT inventory is supplied into both the main port and the four control ports. Condensing fraction is assumed to be [ ]TS during the period of high flow injection between the RV annulus full and SIT empty.

Low flow : Due to the sustained SIT injection, the SIT water level decreases below the entrance of the stand pipe. The inventory supply into the main port is lost. The inventory is supplied only into the four control ports thus the SIT fluidic device makes the low flow which is about one third of the high flow. This delays the SIT empty time and minimizes the spillage of the injected flow. Condensing fraction is assumed to be [ ]TS during the period of the low flow injection.

The fluidic device is considered in this analysis. The function of flow control is implemented in the computer code, FLOOD3 as in the flow diagram, Figure 3-3.

Although the fluidic device will improve the LOCA thermal margin for the fuel performance, it may have an adverse impact on the mass and energy release during the LOCA. In a conventional LOCA M/E analysis where the fluidic device is not considered, the SIT injection flow is high enough to condense the steam flows in the intact side during the period from the reactor downcomer full to the SIT empty. In APR1400, the SIT-FD low flow is so small that the flow is not credited to condense the steam flows in reactor vessel annulus. Thus the steam mass and energy release through the break is increased by the amount of the non-condensed steam. The increased mass and energy release can have a considerable impact on the peak pressure and temperature of the containment.

3.10.2 Effect of IRWST Water Temperature on Mass and Energy Release

The released mass through the break during LOCA is accumulated on the floor inside containment in hot liquid condition. This liquid flows into the IRWST via holdup tank and is mixed with the IRWST water inventory, which is the source water of safety injection pumps. Mixing with the hot liquid results the temperature increase of IRWST inventory and this yields the temperature increase of

SI water into RCS. Therefore the energy of the break flow may be higher due to the deteriorating circulation of the released mass.

In the LOCA M/E analysis, the effect of the IRWST water temperature was considered. The containment analysis based on the initial M/E data can provide the data of the sump water temperature. Taking the data of the sump water temperature as the input of SI water temperature during reflood stage, the reanalysis of LOCA M/E is performed for more conservative M/E data.

3.11 Description of Containment Pressure and Temperature Analysis

The methodology for the containment response analyses to LOCA and MSLB accidents are addressed in Appendix A in detail.

TS

Figure 3-1 CEFLASH-4A Node Diagram for LOCA Discharge Leg Break

TS

Figure 3-2 FLOOD3 Hydraulic Network Model for LOCA Discharge Leg Break

TS

Figure 3-3 Flow Diagram for Fluidic Device Implementation

4. LOCA M/E ANALYSIS FOR APR1400

4.1 M/E Data for the Analyzed Cases

Five cases are analyzed for full spectrum analysis of LOCA M/E: suction leg break with maximum and minimum SI flow, discharge leg break with maximum and minimum SI flow and hot leg break cases. Those cases are summarized in Table 4-1. In this report, the analysis result of the limiting case is provided. The limiting case is determined based on the containment peak pressure, which is the case of discharge leg break with maximum SI flow.

The mass and energy release data of the limiting case are given in Part A of Table 4-2. For cold leg breaks (pump suction and discharge), some of the post blowdown SIS water is postulated to spill to the containment floor whenever the reactor vessel annulus is full. The vessel spillage data associated with these breaks are also given in Part A of Table 4-2. In Part B and Part C of Table 4-2, the transient data of reactor vessel pressure and SI flow are provided, respectively. In Part D of Table 4-2, the chronology of events is provided.

Initial conditions in the reactor coolant system are given in Table 4-3. The ESF parameters and the analysis inputs conservatively assumed for analysis are presented in Table 4-4. The primary side resistance factors for the FLOOD3 code are shown in Table 4-5. The FLOOD3 code hydraulics calculates flow rates and pressure.

Figure 4-1 shows the normalized decay heat curve as a fraction of the initial power level.

Curves of Safety Injection Flow vs. time are provided in Figure 4-2. It shows the controlled SIT flow by fluidic device in SIT. There are two modes of the FD controlled flow. Those are roughly distinguished as follows: the full flow during blowdown stage and the low flow during post-blowdown stage. The low flow controlled by the fluidic device enables to maintain the safety injection flow from the SITs during the extended duration.

4.2 Containment Pressure and Temperature Results

The calculation results of the containment pressure and temperature response to LOCA events are described in Appendix B in detail.

TABLE 4-1

SPECTRUM OF POSTULATED LOCA

Loss of Coolant Accident (LOCA)	SIS Condition	Break Area, m^2 (ft^2)
Double-Ended Suction Leg Slot (DESLS)	Maximum SIS Flow	
	Minimum SIS Flow	
Double-Ended Discharge Leg Slot (DEDLS)	Maximum SIS Flow	
	Minimum SIS Flow	
Double-Ended Hot Leg Slot (DEHLS)	N/A	

TS

TABLE 4-2 (Sh. 1 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW
[ ]TS BREAK AREA)

TS

Part A. Mass and Energy Release Data (Blowdown Period)

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 2 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

TS

Part A. Mass and Energy Release Data (Blowdown Period)

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 3 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A. Mass and Energy Release Data (Blowdown Period)

TS

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

Integral Mass and Energy Release at End of Blowdown

Time (sec)	Integral Mass		Integral Energy	
	kg	lbm	Million kcal	Million Btu

TS

TABLE 4-2 (Sh. 4 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy Release Data (Reflood and Post-reflood Period) TS

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 5 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy Release Data (Reflood and Post-reflood Period)

TS

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 6 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy Release Data (Reflood and Post-reflood Period)

TS

Time (sec)	Break Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 7 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Integral Mass and Energy Release at the End of Reflood and Post-reflood

Time (sec)	Integral Mass		Integral Energy	
	kg	lbm	Million kcal	Million Btu

TS

Part A : Mass/Energy Release Data (Spillage)

Time (sec)	Integral Mass		Integral Energy	
	kg	lbm	Million kcal	Million Btu

TS

TABLE 4-2 (Sh. 8 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

TS

Part A: Mass and Energy (Steam) Release Data (Decay heat Period)

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 9 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Steam) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 10 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Steam) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 11 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Steam) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

Integral Mass and Energy Release (Vapor) at 24 hours and End of Analysis

TS

Time (sec)	Integral Mass		Integral Energy	
	kg	lbm	Million kcal	Million Btu

TABLE 4-2 (Sh. 12 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Spillage) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 13 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Spillage) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 14 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Spillage) Release Data (Decay heat Period)

TS

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TABLE 4-2 (Sh. 15 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part A: Mass and Energy (Spillage) Release Data (Decay heat Period)

Time (sec)	Mass Flow Rate		Break Enthalpy	
	kg/sec	lbm/sec	kcal/kg	Btu/lbm

TS

Integral Mass and Energy Release (Spillage) at 24 hours and End of Analysis

Time (sec)	Integral Mass		Integral Energy	
	kg	lbm	Million kcal	Million Btu

TS

TABLE 4-2 (Sh. 16 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Blowdown Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 17 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Blowdown Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 18 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Blowdown Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 19 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Reflood and Post-reflood Period)

TS

Time (sec)	Reactor Vessel Pressure	
	kg/cm^{2}A	psia

TABLE 4-2 (Sh. 20 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Reflood and Post-reflood Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 21 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Reflood and Post-reflood Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 22 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Decay heat Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 23 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Decay heat Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 24 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Decay heat Period)

TS

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TABLE 4-2 (Sh. 25 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part B : Reactor Vessel Pressure vs. Time (Decay heat Period)

Time (sec)	Reactor Vessel Pressure	
	kg/cm^2A	psia

TS

TABLE 4-2 (Sh. 26 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part C: Safety Injection Flow vs. Time (Blowdown Period)

Time (sec)	Safety Injection Tank Flow	
	kg/sec	lbm/sec

TS

TABLE 4-2 (Sh. 27 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part C: Safety Injection Flow vs. Time (Reflood and Post-reflood Period)

TS

Time (sec)	Safety Injection Tank Flow		Safety Injection Pump Flow	
	kg/sec	lbm/sec	kg/sec	lbm/sec

TABLE 4-2 (Sh. 28 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part C: Safety Injection Flow vs. Time (Reflood and Post-reflood Period)

Time (sec)	Safety Injection Tank Flow		Safety Injection Pump Flow	
	kg/sec	lbm/sec	kg/sec	lbm/sec

TS

TABLE 4-2 (Sh. 29 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part C: Safety Injection Flow vs. Time (Reflood and Post-reflood Period)

Time (sec)	Safety Injection Tank Flow		Safety Injection Pump Flow	
	kg/sec	lbm/sec	kg/sec	lbm/sec

TS

TABLE 4-2 (Sh. 30 of 30)

DOUBLE-ENDED DISCHARGE LEG SLOT BREAK - MAXIMUM SIS FLOW

Part D : Chronology of Events

TS

Time (sec)	Event	Values
	Break occurs	
	Containment pressure Hi-Hi setpoint	
	Start safety injection tank (SIT) injection	
	First peak containment pressure (Blowdown phase)	
	End of blowdown	
	Start SI pump injection	
	SIT flow is turned down to low flow by fluidic device in SIT	
	Start containment spray actuation	
	End of reflood	
	Peak containment temperature	
	Peak containment pressure	
	End of post-reflood	
	Safety injection tank empty	
	Time of depressurization of the containment at50 % of peak pressure	

TS

TABLE 4-3

INITIAL CONDITIONS FOR CONTAINMENT PEAK PRESSURE ANALYSIS

(Based on a nominal core power of 3983 MWt)

Parameter	Value
Reactor Coolant System	
- Reactor power level 1), MWt	
- Average coolant temperature, °C (°F)	
- Mass of reactor coolant system liquid, kg (lbm)	
- Mass of reactor coolant system steam, kg (lbm)	
- Energy in Reactor coolant system liquid plus steam 2), 10^6 kcal (10^6 Btu)	
- Energy from feedwater nozzle to MSIV per Steam Generator 2), 10^6 kcal (10^6 Btu)	

TS

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1) At full power plus 2% uncertainty plus max. RCP power [ ] TS
2) Energy is relative to 0 °C (32°F)

TABLE 4-4

ESF SYSTEMS PARAMETERS FOR CONTAINMENT PEAK PRESSURE ANALYSIS

System/Item	Full Capacity	Value Used for Peak Pressure Analyses 1)
Passive Safety Injection System		
Number of accumulators (safety injection tanks)		
Pressure setpoint, kg/cm^2G (psig)		
Volume per accumulator,		
Maximum, m^3 (ft^3)		
Minimum, m^3 (ft^3)		-
Active Safety Injection System		
Number of divisions		
Number of pumps/division		
Flow rate per pump at 0 psig,		
Maximum, L/min (gpm)		
Minimum, L/min (gpm)		

TS

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1)
2)

TS

TABLE 4-5

PRIMARY SIDE RESISTANCE FACTORS USED IN FLOOD3 CODE

Path	Resistance Factor, R′ SI unit[1] (British unit[2])
Core	
Lower Core	
Upper Core	
Upper Plenum to Steam Generator, Broken Side	
Upper Plenum to Tubes	
Tubes to Steam Generator Outlet	
Steam Generator Outlet in Broken Side of Annulus	
Forward Flow	
Reverse Flow	
Annulus to Break	
Suction Leg Break	
Discharge Leg	
Steam Generator Outlet in Broken Side to Break	
Suction Leg Break	
Discharge Leg Break	
Upper Plenum to Annulus, Intact Side	
Upper Plenum to Tubes	
Tubes to Annulus	
Break Resistances	
1.0 Break	

TS

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1) Units of R′ are $\dfrac{\dfrac{kg}{cm^2}}{\dfrac{kg^2}{sec^2}\,\dfrac{m^3}{kg}} \times 10^6$

2) Units of R′ are $\dfrac{psi}{\dfrac{lbm^2}{sec^2}\,\dfrac{ft^3}{sec}} \times 10^6$

TS

Figure 4-1 (Sheet 1 of 2) Normalized Decay Heat Curve (Early Period)

TS

Figure 4-1 (Sheet 2 of 2) Normalized Decay Heat Curve (Latter Period)

TS

Figure 4-2 Double-Ended Discharge Leg Slot Break(DEDLSB)
– Max. SI Pump Flow vs. Time

5. SUMMARY

An analysis of LOCA mass and energy release analysis for APR1400 performed in the application to the APR1400. The purpose of this report is to demonstrate the applicability of the methodology to APR1400 LOCA mass and energy release analysis.

The system of advanced design features were reviewed and implemented into the analysis. The analysis methodology incorporates the advanced design features, 4 EDG for 4 train ECCS, fluidic device installed inside SIT and in-containment refueling water storage tank.

The limiting case of the mass and energy release calculation was the case of double-ended discharge leg slot break with maximum SI pump flow.

The analysis shows that the result including the effects of the advanced design features meets the acceptance criteria of Standard Review Plan.

The methodology as presented will be used when determining maximum containment pressure and temperature following a loss-of-coolant accident for the APR1400.

6. REFERENCES

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APR1400 Containment Integrity Analysis Methodology

Revision 0

APPENDICES (A ~ G)

ABSTRACT

These appendices describe the methodology used to predict the containment maximum pressure and temperature response to a spectrum of high-energy line breaks in the containment building. The containment response calculations use plant-specific containment models developed using GOTHIC containment analysis code for the large dry containment design.

The plant-specific mass and energy (M&E) release calculations, which provide primary impact on containment peak pressure and temperature, are performed according to the CEFLASH-4A and FLOOD3 codes for loss-of-coolant accident (LOCA) events, and the SGN-III code for main steam line break (MSLB). The methodology for M&E release analysis is described in Section 3 of this report.

The successful application of the methodology described in these appendices demonstrates adherence to the following acceptance criteria:

- The containment design pressure should provide at least a 10 percent margin above the calculated peak containment pressure following LOCA or MSLB accidents.
- The containment pressure should be reduced to less than 50 percent of the peak calculated pressure for the design basis LOCA within 24 hours after the postulated accident.
- The maximum surface temperature of the structures within the containment is lowerthan the containment design temperature.
- The calculated external pressure load on the containment structure caused by inadvertent operation of containment heat removal systems is lower than the external design pressure with a 10 percent margin.

Appendix A describes the modeling approach and analysis flow for containment integrity analysis. It includes basic assumptions, key modeling characteristics, and analysis methods for containment response analyses to LOCA and MSLB. A description of the nodding structure with

the various GOTHIC components and models is presented in this section. A description of the M&E analysis model for the LOCA long-term phase is also included.

Appendix B provides application of the GOTHIC containment model described in Appendix A to the APR1400 containment integrity analyses. This section contains five subsections: LOCA peak pressure, MSLB peak temperature, MSLB peak pressure, maximum in-containment refueling water storage tank (IRWST) water temperature, and maximum passive heat sink temperature. All the results presented in this section are consistent with those described in APR1400 Design Control Document (DCD) Subsection 6.2.1.1.

Appendix C presents the results of various sensitivity studies to define the worst break condition and subsequently to determine the assumptions, initial conditions and modeling characteristics in view of containment peak pressure and temperature. It provides the bounding analyses to estimate the conservative initial conditions, nodding sensitivity of the containment model, determination of the droplet discharge duration for the break flow, and sensitivity analyses with respect to containment spray.

Appendices D present the containment external pressure loading analysis to demonstrate that the containment building and related structures are designed to accommodate the maximum external pressure load resulting from an inadvertent operation of containment heat removal systems such as the spray system, purge system, and fan cooler system.

Appendix E provides the conclusions of the containment integrity methodology described in the Appendix A through D.

Appendix F describes the APR1400 containment methodology corresponding to each requirement and the proposed analysis methodology that adheres to NUREG-0800 and ANSI/ANS-56.4 guidelines.

APPENDIX A

METHODOLOGY DESCRIPTION FOR CONTAINMENT RESPONSE ANALYSIS

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A. METHODOLOGY DESCRIPTION FOR CONTAINMENT RESPONSE ANALYSIS

A.1 APR1400 GOTHIC Containment Model

A.1.1 GOTHIC Code Description

GOTHIC is a general purpose thermal-hydraulic computer code used for the design, licensing, safety and operating analysis of nuclear power plant containments, which is developed by Numerical Applications Incorporated (NAI) with support from Electric Power Research Institute (EPRI). The GOTHIC computer code has been maintained under a 10 CFR Part 50 Appendix B, quality assurance program.

GOTHIC performs containment integrity analysis through solving the mass, energy and momentum conservation equations for the multi-component, multi-phase flow. Conservation equations are solved for three fields; vapor (steam/gases mixture), continuous liquid and continuous droplet. The vapor field is comprised of steam and non-condensable gases and is treated to be homogeneously mixed and thermal equilibrium in gaseous mixture (Reference G-6).

The phase balance equations are coupled by mechanistic models implementing phase interchange among vapor, continuous liquid and continuous droplet field. The phase interface models for the energy and momentum conservation equations allow each phase to leave on the possibility of thermal non-equilibrium and non-homogeneous fluid velocity.

GOTHIC solves the conservation equations of mass, energy, and momentum in lumped parameter and/or multi-dimensional geometries. The GOTHIC containment model described in here uses multiple lumped parameter volumes. The M&E balances are maintained among multiple lumped parameter volumes through the interconnecting flow paths, and a flow path models hydraulic connection between two volumes or a volume and boundary condition.

GOTHIC has a heat transfer model between solid structures and the liquid or steam/air mixture. Passive heat sinks, referred to as thermal conductors in GOTHIC, are modeled as one-dimensional heat structure. Nodalization of a conductor in the direction of heat transfer allows variation of material properties. Various boundary conditions may be specified for determining the heat transfer from/to the structure.

GOTHIC provides a variety of heat transfer correlations for a thermal conductor model. Condensation, natural convection and radiation are credited in calculating the heat transfer coefficient. Heat transfer coefficients are assigned to the thermal conductor surfaces exposed to the containment environment. These include the direct, film, Tagami, and user-specified heat transfer coefficients options. Uchida, Gido-Koestel, and diffusion layer model (DLM) are also included to represent condensing heat transfer on the conductor surface (Reference G-5).

GOTHIC also includes an extensive set of models for operating equipment. These items, collectively referred to components, include pumps and fans, valves and doors, heat exchangers, vacuum breakers, spray nozzles, coolers and heaters, hydrogen recombiners, igniters, etc. Additional resources available to expand the realm of situations that can be modeled by GOTHIC include functions, control variables and trips.

GOTHIC version 8.0 is used to perform all the calculations in this report. Each version of GOTHIC is qualified against a wide range of tests (both experimental and analytical) and the results are documented in the code Qualification Report (Reference G-7). The containment model and analysis methods used for the APR1400 containment response calculation are not restricted to a specific GOTHIC version. In use of future version of GOTHIC code, the containment model and analysis methods including code options described in this report will be revised accordingly.

A.1.2 Modeling Approach

In APR1400, the approach for containment integrity analysis utilizes GOTHIC containment model that computes containment pressure and temperature response to LOCA and MSLB accidents.

For LOCA containment analyses, the calculated M&E from the CEFLASH-4A and FLOOD3 during blowdown, reflood and post-reflood phases are provided to GOTHIC as an input for flow boundary condition. Figure A-1 shows the computer code used in each phase and the data interface between M&E calculation and the containment response. Until the end-of post reflood (EOPR) after accident initiation, the results of M&E calculation are provided to GOTHIC input. The containment pressure and in-containment refueling water storage tank (IRWST) water temperature results from the containment response analysis are used again for the LOCA M&E analysis to produce more accurate M&E release data. Feedback of the containment response data to M&E calculation is performed once since the computer code for M&E analysis are not time-dependently coupled with the GOTHIC that calculates the containment response.

After the EOPR, the GOTHIC model directly computes the M&E releases using its own reactor coolant system (RCS) model as well as containment pressure and temperature response during the remainder period of accident. During this decay heat phase, referred as the period that the RCS and SGs secondary side is essentially in thermal equilibrium, the decay heat and all of the residual energies stored in RCS and SGs metal and coolant are released to the containment building in the form of saturated steam through the coolant boil-off process.

For the MSLB containment analysis, the M&E releases from the break are calculated using SGN-III computer code, which are provided to the GOTHIC model as an input for flow boundary condition for containment response analysis. In the M&E analysis, there is no feedback of the containment pressure and temperature response to the M&E calculation for reflecting containment environment condition. Instead, conservative containment environmental condition is used for M&E release analyses. Figure A-2 shows the data interface between SGN-III computer code used for M&E release calculation and GOTHIC that performs containment response to MSLB accident. The M&E release continues until 1,800 seconds after accident initiation, which is assumed for the time when the auxiliary feedwater to the affected SG is terminated by the operator. After this time, the containment temperature and pressure is decreased in a rapid rate by continuous containment spray actuation and heat removal through the CS heat exchanger.

A.1.3 Analysis Approach

SRP 6.2.1.1.A describes the requirements regarding the containment peak pressure and temperature limitation. It addresses the peak calculated containment pressure following a LOCA or secondary system piping rupture should be less than the containment design pressure with at least a 10% margin. Also, in the long-term phase, the pressure at 24 hours after postulated accident should be less than one-half of calculated peak pressure.

In accordance with the regulatory requirements, the APR1400 LOCA containment analysis is categorized into two analysis phases: [ ]TS

Figure A-3 shows the analysis procedures for the containment response which are divided into short-term and long-term phase based on the EOPR.

During the short-term period in LOCA containment analysis, the principal parameters that impacts the containment peak pressure includes, M&E release from the RCS pipe rupture, containment free volume, heat sinks and containment initial conditions. The size of free volume and heat removal capacities of active and passive heat sinks in containment were determined from containment maximum pressure and temperature results to the design basis accidents with consideration of the acceptable margins (Reference G-1).

After the short-term requirement is satisfied, the long-term containment response analysis is performed simultaneously with the M&E release calculation using the core decay heat and residual metal and fluid energies in RCS and SGs which determines the long-term containment pressure temperature response. The calculation results are also used for EQ analyses of safety related equipment in the containment (Reference G-2).

In APR1400 MSLB containment analysis, similar to the LOCA containment analysis, the major parameters that impact the containment peak temperature and pressure are the M&E release from the secondary system pipe rupture, containment heat sinks, containment free volume and containment initial conditions. Unlike the LOCA containment analysis, the M&E releases from the

break terminate at the time when the SG secondary side inventory is depleted. Figure A-4 shows the flow diagram for the containment response analysis to an MSLB accident.

A.2 LOCA Containment Response Analysis

A.2.1 Assumptions

The containment pressure and temperature response analysis to a LOCA should be based on the assumption of loss of off-site power and the most severe single failure in the emergency power system, containment heat removal systems, or the core cooling systems (10CFR50, Appendix A, GDC 38 & 50 and SRP 6.2.1.1.A). In APR1400 containment system, an inherent assumption for the containment response analysis to LOCA events is the loss-of offsite power (LOOP) since it delays the actuation of CS system due to the time required to start the emergency diesel generator (EDG).

A single-failure assumed to occur in containment engineered safety feature (ESF) system is an EDG failure since loss of a CS pump takes place following an EDG failure. For the maximum SI following a LOCA, both CS pumps are available due to no EDG failure. However, loss of a CS pump is still assumed to occur to minimize the containment cooling. Consequently, only a CS pump is assumed to be available when performing LOCA containment response analyses without an EDG failure.

The major assumptions made in containment response analyses following a LOCA are listed below;

- It is assumed that the discharge fluid from the break during the blowdown phase is uniformly dispersed and mixed with the containment atmosphere and reaches thermal equilibrium with containment atmosphere.

- The IRWST pool surface area is assumed to be zero to isolate relatively cool IRWST water from the containment atmosphere. [

  ]TS

- The non-condensable gas in SI tanks is assumed to be released directly to the containment atmosphere [ ]TS

Input parameters are based on both plant specific values and the assumptions described above. A conservative prediction of containment response to a spectrum of LOCA events is made by considering the upper or lower bounding values of containment initial conditions, geometric parameters and thermodynamic properties to maximize the containment pressure. The initial conditions for LOCA containment peak pressure calculation are determined from results of the sensitivity study for bounding initial values used in LOCA containment analysis described in Appendix C.1.

A.2.2 Key Modeling Characteristics

The principal analyses models used in containment response analysis to LOCA include break fluid model for M&E release, heat transfer models applied to the surface of passive heat sinks and water pool surface. The followings describe the characteristics of these models with the explanation of the M&E release and (passive and active) heat sink models as the boundary conditions, and the conservatism of bounding initial conditions.

A.2.2.1 Break Flow Model

The phase separation condition to a LOCA break fluid may be treated differently depending upon the transient periods; blowdown phase and post-blowdown phases. During the blowdown phase, the break fluid is directly released to the containment atmosphere as superheated liquid and following blowdown, it is released to the containment in the form of vapor and spillage that go to the containment atmosphere and IRWST liquid region respectively.

For the break fluid during the blowdown phase, which is calculated from the CEFLASH-4A computer code, [ ]TS is used to produce a steaming rate at least as large as the steam addition rate which is assumed at the flash condition based on the containment temperature. The break fluid is assumed to release as TS

[ ]TS gives atmospheric heating due to liquid superheat relative to containment atmospheric conditions. This induces droplets evaporating through heat transfer between containment atmosphere and the break fluid, resulting in more steam in atmosphere and higher peak pressure.

The liquid droplets discharged to the containment are uniformly and instantaneously dispersed throughout the containment vapor region and rapidly evaporate based on the difference in steam partial pressure on the droplet surface and in the containment atmosphere, eventually coming to a thermal equilibrium with the containment atmosphere.

The break flow during the reflood and post-reflood phase, which is calculated by the FLOOD3 code, is discharged to the containment as vapor, cold spillage and hot spillage. The vapor discharged from the break goes to the containment vapor region and immediately mixes with containment atmosphere. [ ]TS The cold spillage is assumed to go directly to the IRWST liquid region.

For the droplets discharge during the blowdown phase, the break drop diameter is assumed to be 100 microns (0.003937 inches), based on guidance provided by the GOTHIC user manual (Reference G-5). This droplet size is validated from the GOTHIC qualification analyses based on the experimental data (Reference G-7). Applying mean droplet size of 100 microns to the break fluid is known to acceptable in the industry, and also accepted by NRC for use in GOTHIC containment analyses. (References G-9 and G-11).

The appropriate combination of droplet discharge and liquid discharge during blowdown and post-blowdown phases is used to obtain the worst containment response. Appendix C.3 describes the sensitivity analyses for determining the duration of droplet discharge. From the results of sensitivity study, the droplet discharge is assumed to be terminated at the EOB phase.

Figure A-5 shows discharge fluid phases applied to each break flow from a LOCA cold leg piping break.

A.2.2.2 Heat Transfer Model

Wall Heat Transfer Coefficients

GOTHIC heat transfer coefficients are assigned to thermal conductor surfaces that are in contact with the containment atmosphere. The direct heat transfer option with DLM is used to calculate condensation mass transfer on the surface of each heat structure. The use of Direct/DLM without considering the film roughness and mist generation in the boundary layer in determination of peak containment pressure and temperature to a LOCA and secondary system piping rupture was approved by NRC (References G-8 and G-9).

Natural convection option is chosen as heat transfer correlation for sensible heat transfer on containment passive heat sinks. Forced convection is not allowed in use for containment response analyses. In APR1400 GOTHIC containment model, the hydraulic diameter is used as a characteristic length for containment wall convection. The use of the containment hydraulic diameter in calculation of wall convection is usually conservative since the total surface area of all of the passive heat sinks, which is used to determine the hydraulic diameter, is estimated to be lower, consequently minimizing surface area of heat structures for heat absorption.

Radiation heat transfer to the containment structures from the containment atmosphere is conservatively excluded since the effects of radiation heat transfer have a negligible impact on the containment pressure calculation.

Liquid / Vapor Heat Transfer Coefficients

In the containment and IRWST volume, mass and heat transfer through the liquid and vapor interface area is not considered to ignore the cooling effect through the pool surface. The interface mass and heat transfer is assumed only between vapor and liquid droplets. This is a conservative assumption to obtain higher containment pressure and temperature unless the

IRWST water temperature is higher than the saturated temperature corresponding to the containment pressure.

A.2.2.3 Boundary Conditions

The boundary conditions for the LOCA containment model can be grouped into three categories as shown below.

- M&E releases through the break
- Containment Heat Structures (Passive Heat Sinks)
- Containment Spray Heat Exchangers (Containment Heat Removal System)

The approach use to model these boundary conditions are described as follows;

M&E Releases

LOCA M&E are released to the containment using the flow boundary conditions in the GOTHIC containment model until the EOPR. Thereafter, GOTHIC internally calculates the break flow from the RCS during the remainder period of the accident. Section 3 in this report describes the analysis method for the LOCA M&E calculation until the EOPR. The phase separation model applied to the break fluid is described in Subsection A.2.2.1.

Containment Thermal Structures

The boundary of control volume for LOCA containment analyses includes containment dome, cylinder wall and containment base floor. Typically, during a LOCA or secondary system pipe rupture, a large amount of energy is absorbed in these passive heat sinks and emitted to the outside of containment building. However, in APR1400 containment model, the outer surfaces of the containment shell (wall and dome) are modeled as adiabatic and the inner surface of base floor is excluded from passive heat sinks to prevent heat rejection to the outside of containment building. Subsection A.2.3.3 provides the detailed description of each type of passive heat sinks.

CS Heat Exchangers

As an ESF system that may establish heat removal to the outside of containment boundary, CS heat exchangers or containment fan coolers can be considered. In APR1400, the CS heat exchanger is assumed as the only active heat sink credited for containment response analyses. A CS heat exchanger is modeled using the GOTHIC heat exchanger component with the assumption of the shell side coolant inlet flow condition, without modeling the component cooling heat exchanger as an additional heat exchanger. Subsection A.2.3.4 details the design specification of the CS heat exchanger and the flow boundary condition.

A.2.2.4 Initial Conditions

Initial conditions for LOCA containment response analyses are selected to yield a conservatively high peak containment pressure and temperature. These include containment pressure, temperature, relative humidity and IRWST water volume. The outside ambient conditions are not relevant since the outside wall of containment building is assumed to be adiabatic.

The upper and lower bounding values used as the initial conditions for containment response analyses encompass the range of the limiting condition for operation (LCO) specified in Technical Specification. Table C-1A shows the upper and lower bounding values that are used for initial conditions of containment response analyses.

The upper bound pressure and temperature are chosen as the initial condition for containment response analyses to a LOCA. The lowest initial relative humidity (0%) is assumed to induce evaporation to the containment atmosphere. The largest IRWST water volume is chosen to minimize the containment initial free volume occupied by the vapor in containment. The lowest IRWST water volume as the initial value is used for the analysis that estimates the highest IRWST water temperature for the ECCS pump design.

A sensitivity analysis to estimate the conservative initial conditions for LOCA containment response is addressed in Appendix C.1.

A.2.3 LOCA Containment Modeling

The APR1400 GOTHIC containment nodding structure is built using lumped parameter volume model. The lumped parameter volume modeling for the containment structure is an acceptable approach for containment response analyses due to a large break LOCA and secondary system pipe rupture. This approach was verified through the simulation analysis for the purpose of comparison of 3-D model to the lumped parameter model for the Carolinas-Virginia Tube Reactor (CVTR) (References G-7 and G-10). The analyses using GOTHIC lumped parameter modeling for an extensive set of experiments have shown a good agreement between the GOTHIC calculation and the experimental data.

Figure A-6 and Table A-1 show the nodding diagram used for LOCA containment response analyses and summary of modeling descriptions, respectively.

[

]TS

Four boundary conditions (1F, 2F, 5F and 7F) are used to represent the discharge of M&E from the break. The CS system is modeled using the GOTHIC built-in components; pump, heat exchanger and spray nozzle to transport water from the IRWST to the containment atmosphere as liquid droplets. Eighteen (18) heat conductors are modeled to represent the passive heat sinks in the containment.

For the LOCA M&E release during the decay heat phase, the containment model described above is modified, primarily by adding RCS/SG model, to enable it to perform long-term M&E release as well as containment response calculations. [

]TS

The RCS with two SGs are modeled as an integrated single volume, and the stored energy in RCS and SG metal is modeled as [

]TS

The downcomer (node 4) is modeled to supply the minimum subcooled SI water to the reactor core needed for steaming of coolant boil-off, and to return the remainder water to the IRWST as spillage.

A pump and three valves are included to model the SI pump and flow control in RCS and downcomer volumes. Appropriate numbers of flow paths are used to represent the connection between two lumped parameter nodes or a node and a boundary condition.

Three boundary conditions (3F, 4P and 6F) are added to adjust the initial conditions of the decay heat phase in RCS/SG at the time when the post-reflood phase is completed.

APR1400 containment model requires the dimensional information regarding the control volumes and flow paths as the GOTHIC input data. Most of the inputs for the containment model are calculated from drawings. Some of the inputs are determined as appropriate values based on the conservatism from the standpoint of containment peak conditions. The determination of those values includes the following cases:

- Values that are expressed as a representative by its arbitrary geometry shape.
- Values that are not sensitive to the analysis results.
- Values that need to be biased to give conservative result.

A.2.3.1 Control Volumes

GOTHIC requires the volume, elevation, height and hydraulic diameter input values for each control volume. The net free volume is the volume that can be filled with steam or non-condensable gases including air and nitrogen gas. The reference elevation of the APR1400 containment is [ ]TS, which is the level of the upper slab of IRWST. The difference between the bottom and top elevations of the node is the height. The height of each control volume is calculated from the respective drawings. The hydraulic diameter is calculated as four times the free volume divided by the total wetted surface area parallel to the flow direction. The interface area of pool surface in each node is biased to yield conservative peak conditions.

For the containment response analysis to a LOCA, six (6) control volumes are modeled. Among them, three (3) control volumes representing RCS/SG, RV downcomer, and cold leg / hot leg piping are used to calculate M&E release during the decay heat phase.

<u>Volume 1</u>

Name	Description	Unit	Design Value	Value used for LOCA
Containment atmosphere	Volume	ft^3		
	Pool Area	ft^2		
	Height	ft		
	Hydraulic Diameter	ft		
	Water Volume	ft^3		

TS

This control volume represents the containment atmosphere region. The containment free volume is calculated by subtracting occupied volumes of equipment inside containment from the gross volume calculated based on dimensions of the containment building. Several internal structures/components have arbitrary shape and involve considerable uncertainty in the free volume calculation. Therefore, appropriate margins [ ]TS which include dimension uncertainties and tolerance caused by the arbitrary shape are considered to maximize the volume of each component and to minimize the containment free volume. The detailed

calculation to determine the containment net free volume is presented in calculation sheet for passive heat sink and free volume.

The bottom of the volume is located at the elevation of 100 ft, [

]TS The interface pool area was intentionally set to 0.0 ft^2 to prevent condensation on the water that settles to the bottom of the containment atmosphere volume. The heat transfer through the phase interface is assumed to occur only between vapor and droplet phases, as a conservative assumption to obtain higher containment pressure and temperature.

<u>Volume 2</u>

Name	Description	Unit	Design Value	Value used for LOCA
IRWST	Total Volume	ft^3		
	Pool Area	ft^2		
	Height	ft		
	Hydraulic Diameter	ft		
	Water Volume	ft^3		
	Water Level %	%		

TS

In APR1400 containment model, [

]TS The initial water level in IRWST could be assumed differently depending on the purpose of the containment response analysis. From the results of the sensitivity analyses for the containment peak pressure and IRWST maximum water temperature, larger amount of IRWST water volume makes lower vapor space resulting in higher peak containment pressure and temperature, whereas less IRWST water volume results in higher IRWST maximum water temperature in long-term analyses for LOCAs and MSLBs.

[

The IRWST is located at the bottom of the containment,

] TS The initial water level in IRWST is assumed at its maximum height since higher IRWST water level gives less containment free volume, resulting in higher peak containment pressure in LOCA events. The detailed description of the IRWST geometry and its function is presented in Section 2.4.

Volume 3

Name	Description	Unit	Design Value	Value used for LOCA
RCS/SG	Total Volume	ft^3		
	Pool Area	ft^2		
	Height	ft		
	Hydraulic Diameter	ft		

TS

This control volume represents the [ ] TS After the EOPR, GOTHIC model directly computes the M&E release as well as containment response. During the decay heat phase in a LOCA, there is no additional energy transfer to the break fluid from SG secondary side due to the temperature difference. [

] TS

The pool surface area is determined as sufficiently large to maximize the boil-off rate. The height and hydraulic diameter are determined as appropriate values. All the input values except the coolant volume do not affect the model sensitivity.

Volume 4

Name	Description	Unit	Design Value	Value used for LOCA
Downcomer	Total Volume	ft³		
	Pool Area	ft²		
	Height	ft		
	Hydraulic Diameter	ft		

TS

This control volume represents the RV downcomer. The downcomer receives the subcooled water from SIT (6F) or IRWST through the SIP and supplies it to the reactor core in the amount of water needed for steaming of core coolant and returns the remainder to the IRWST as spillage.[

]TS

For the subcooled safety injection, it is expected that a potential exists for the incomplete interaction between steam through the intact loop and SI water near the DVI nozzle in the downcomer. However, it is conservatively assumed that there is no mixing of steam and SI water to maximize the M&E release to the containment by closing the flow path to the downcomer from the intact SG (J16).

The total volume of downcomer is calculated from RV drawings. The pool area, height, and hydraulic diameter is appropriately adjusted to decrease the flow oscillation on the flow path (J10) caused by the water level unbalancing between RCS and downcomer. The steaming rate from the core during the decay heat phase is not sensitive to these input values.

Volume 5

This volume represents the piping of the RCS broken loop to check the flow condition as volume variables (pressure, temperature and void fraction, etc). The existence of this volume does not affect the model sensitivity.

Volume 6

Name	Description	Unit	Design Value	Value used for LOCA
SIT	Total volume of N_2 gas	ft³		
	Initial Pressure	psia		
	Initial Temperature	ºF		

TS

Four (4) SI tanks are modeled as a merged volume. In LOCA containment analysis, the nitrogen gas in SIT is assumed to release directly to the containment atmosphere. The volume is assumed to be filled with the nitrogen gas at the accident initiation, and starts discharging to the containment at a high rate after the EOB. The SIT dimension except its volume have no impact on the analysis result.

A.2.3.2 Flow Paths

Flow paths connect control volumes and boundary conditions to one another. APR1400 LOCA Containment model includes a total of sixteen (16) flow paths and the description of each flow path is described in Table A-2.

GOTHIC requires input values for the flow path that include elevation, height, flow area, hydraulic diameter, inertia length, and friction coefficient. These data are taken from the respective drawings or determined appropriately considering the impact to the model sensitivity and analysis results.

Standard values of 1 feet^2, 1 foot, 1 foot, 0 foot are used for the GOTHIC flow area, hydraulic diameter, inertia length, and friction length respectively for the flow paths through which liquid is passing. For the flow paths through which vapor, two-phase mixture, or unknown phase of fluid, standard values of 100 feet^2, 10 feet, 1 foot, 0 foot are used for the flow area, hydraulic diameter, inertia length, and friction length respectively. These standard values are chosen as the appropriate values that minimize the flow resistance through the flow path and do not affect the model sensitivity.

For the M&E release through the boundary condition, the flow rate through the flow paths J3, J5, J6, J13, J14 and J15 are specified, so most of the input parameters regarding that flow path are not important. Therefore, standard values mentioned above are used for the flow area, diameter, inertia length, and friction length of the flow path. The elevation of the end of the flow path connected to containment is set to [ ]TS with reference the elevation of the center line [ ]TS in primary system.

The flow path (J1) in the LOCA response containment model represents the recirculation line to supply the IRWST water to the containment atmosphere as subcooled water droplets. The fluid through the recirculation line is in liquid state, and the flow rate is also specified as fixed value for CS pump, thus all the input values regarding these flow path do not impact the model sensitivity. The flow path through the SIP is also specified in the same manner. The input parameters regarding the flow path (J4) are determined in a same manner. The [ ]TS

The APR1400 containment building is designed to allow the water released into the containment building to be accumulated in the holdup volume tank (HVT), then return to the IRWST. In containment building, four (4) vent stacks equipped with two swing panels are placed on the IRWST upper slab [ ]TS for overpressure protection of IRWST and/or containment. The swing panels have the vent area of totally [ ]TS, which maintains pressure balance between two volumes. The flow path (J2) between containment atmosphere and IRWST models these vent paths as well as the flow path for the water returning to the IRWST, and the pressure in the containment and the IRWST during the entire transient is equivalently maintained through the vent path connecting two volumes. Standard values of 10 feet, 1 foot, 0 foot, which are assumed for vapor or unknown phase of fluid, are used for the hydraulic diameter, inertia length, and friction length respectively, to minimize the pressure imbalance and flow resistance between two volumes. [ ]TS

Flow paths that connect to the RCS (J10) and to the containment (J9) from the downcomer represent the water supplying to make up the reduced coolant in the core, and the spillage returning to the containment volume. The vapor pressure in the RCS and the downcomer is almost equal and the fluid in all the flow paths (except J16, the intact loop) through the downcomer is subcooled liquid. [

]TS

[

]TS Standard values assumed for vapor are used for GOTHIC flow path inputs to minimize the flow resistance on the pipe, resulting in nearly the same pressure in both the containment atmosphere and the RCS.

A.2.3.3 Thermal Conductors

Passive Heat Sinks

During a LOCA or a secondary system pipe rupture, heat transfer takes place between the containment atmosphere and each surface of the passive heat sinks within the containment. Most of the structures exposed to the containment atmosphere are considered as passive heat sink and modeled as one-dimensional thermal conductor. The minimum surface area of each heat structure, which considers appropriate uncertainties caused by arbitrary shape, is used to maximize the containment pressure and temperature. The detailed calculation to determine the surface area of each passive heat sink is presented in calculation sheet for passive heat sink.

All the structures within the containment that can be considered as passive heat sink are tabulated in Table A-3. In APR1400 containment model, as shown in Figure A-6, total of eighteen (18) heat structures are considered as passive heat sink. Those structures that are located at a level lower than the elevation of the IRWST upper slab[ ]TS are excluded for conservatism. The upper surface of the containment floor is assumed to be insulated since it may be flooded during an accident. The conservative assumptions made for modeling heat structures within the containment building is described as follows:

- The outer surface of the containment shell (wall and dome) is modeled as adiabatic to ignore heat rejection through the outside of the containment building.

- Any internal structure which has two-sided surface exposed to containment atmosphere is modeled as a heat structure with full thickness and one-side surface exposed (the other side is assumed to be insulated).

- The internal surface of the base floor including basemat and IRWST outside upper slab is conservatively assumed to be insulated. (No heat transfer is assumed to the internal surface which may be flooded during an accident)

- All the structures which are not exposed to the containment atmosphere prior to the accident are excluded from passive heat sink modeling.

Each thermal conductor in the containment is comprised of multiple layers of different materials. The concrete, air gap, steel liner plate and painted surfaces are taken into account for the layers. The interface resistance between concrete and liner plate is set to be conservatively high by assuming conduction through the air gap to underestimate the heat absorption to the passive heat sinks.

In a GOTHIC thermal conductor, each individual layer is divided appropriately into multiple nodes using a feature named “auto divide” to calculate the temperature profile through the layers of the conductor. The mesh spacing determined by this feature is fine enough to represent accurate thermal gradient throughout the layers in each heat structure.

The heat sink material thermophysical data used in the analysis are given in Table A-4. Thermal properties of each material are minimum values considering the appropriate temperature expected during an accident.

Heat Transfer Coefficients

The heat transfer coefficients applied to each thermal conductor surface are described in Subsection A.2.2.2 in detail.

Thermal Conductor for Metal Sensible Energy Release

A thermal conductor (19) is included to model the release of sensible energy stored in RCS and SGs metal during decay heat phase. The conductor is assumed to be submerged in the RCS coolant and the initial temperature for the conductor is set to the RCS coolant temperature at EOPR (the initiation time of long-term phase). The related conductor input values for surface area, average thickness, mass and material density are appropriately [ ]TS

A.2.3.4 Components

GOTHIC components are used to model pumps, spray nozzles, heat exchangers, valves and heaters. All the component inputs are based on plant specific data. Among those components, valves are actually not installed on each flow path, however, GOTHIC valve components are only used to model the flow control where applicable.

Pumps

The APR1400 containment model has a CS system that transports water from the IRWST to the CS heat exchangers and delivers to the containment as liquid droplets. The CS pump which is connected to the CS heat exchanger and IRWST is modeled to specify the flow rate to the spray nozzle through the CS heat exchanger.

The CS pump draws the subcooled water from the IRWST and pumps to the containment spray heat exchange (CSHX) through the flow path (J1). A constant value [ ]TS is used for CS pump volumetric flow rate as described in Table A-5. This CS pump starts automatically from a high-high containment pressure setpoint with a time delay of 110 seconds needed for EDG start-up(20 seconds) and CS piping fill-up(90 seconds). The delay time for CS piping fill-up is

comprised of the durations needed for pump loading(20 seconds), pump startup(3 seconds), pipe filling with water (58 seconds), signal delay (2 seconds) and 7 seconds for contingency.

An SI pump is added to containment model only to simulate the SI to the RCS during decay heat phase. A constant volumetric flow rate [ ]TS, is used as an input value. There is no impact on the model sensitivity by the variation of the SI flow rate during the decay heat phase since the SI flow rate from one SI pump to the downcomer is enough to provide make up water for the core coolant boil-off. The SI pump is assumed to start at the beginning of decay heat phase.

<u>Spray Nozzles</u>

Spray nozzle component is used to model the discharge of liquid droplets to the containment atmosphere for containment atmosphere cooling. In lumped parameter modeling, the spray droplets immediately and uniformly fill the entire containment vapor region after spray initiation. The size of liquid droplets sprayed to the containment primarily influences heat transfer rate between droplets and vapor since smaller droplets have larger interfacial heat transfer area, thus reach thermal equilibrium with the containment vapor more quickly than larger droplets.

Spray nozzles typically deliver a wide spectrum of droplet sizes, however, GOTHIC spray model uses a single drop diameter. The mean drop diameter may be specified as the plant specific sauter mean diameter or as a conservative value for the analysis being performed (Reference G-5). The droplet size of the GOTHIC spray nozzle is conservatively assumed to be 1,000 microns (0.04 inch). In reality the diameter of liquid droplets from the CS nozzles are in the range of [ ]TS, and the mean drop diameter is estimated to be about 300 microns from the design specification sheet of the APR1400 CS nozzle. Appendix C.4 describes the sensitivity analysis to determine the impact of droplet sizes on the containment peak pressure and temperature.

<u>CS Heat Exchanger</u>

The APR1400 CS heat exchanger is modeled using the GOTHIC heat exchanger component. The CS heat exchanger model uses a flow boundary condition for the shell side inlet coolant flow instead of modeling the component cooling heat exchanger as a secondary heat exchanger. It uses a fixed UA value for the heat exchanger and assumes a conservative component cooling water flow rate and temperature. The CS heat exchanger input data were taken from the design specification sheets of the APR1400 CS heat exchanger. The design parameters of CS heat exchangers and the input values used for LOCA containment analyses are summarized in Table A-5.

Heater

The GOTHIC heater component is used to represent the decay energy directly to the coolant in the core during the long-term boil-off phase. The resulting heat rate can be modeled as RV internal heat generation to transfer the energy to the coolant and out to containment through the break flow path.

A heater for decay heat release can be modeled by specifying a positive flow rate through the heater.[

]TS

ANS 5.1/ 1979 decay heat curve with plus two sigma uncertainty is used for core decay heat power fraction and specified as a GOTHIC time-dependent forcing function as shown in Table A-6. The additional description of the decay heat release is presented in subsection A.2.4 "Decay heat phase M/E Analysis Model".

A.2.3.5 M&E Boundary Conditions Input

During a LOCA transient, M&E releases are calculated separately by other computer codes (CEFLASH-4A and FLOOD3) until the EOPR (or EOB for hot leg break) and provided to the GOTHIC containment model as boundary condition inputs. The mass flow rate and specific enthalpy are input to the containment model through time dependent forcing functions on each

flow boundary condition. The M&E release data used in the GOTHIC containment model are presented in Section 4 in this report.

During the LOCA transients, the break fluid, which is superheated liquid, is directly released to the containment atmosphere region. Thereafter, the fluid is continuously discharged to the containment as the separated form of vapor and liquid spillage. As shown in Figure A-6, the boundary condition (7F) in the nodding diagram is used to represent the M&E release during the blowdown phase. For the reflood and post-reflood phases, three boundary conditions (5F, 1F and 2F) are also added to the containment model to represent release of vapor, hot spillage and cold spillage respectively.

The liquid discharge through the flow path (J15) during the blowdown phase is assumed as droplets with a single diameter of 100 microns. [

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The vapor break flow from the boundary condition (5F) during the reflood and post-reflood phase is immediately mixed with the containment atmosphere, resulting in continuous increase of containment pressure and temperature.

Each of the four boundary conditions (1F, 2F, 5F and 7F) described above were assigned the appropriated mass and enthalpy functions as multipliers on the flow rate and temperature inputs in GOTHIC. As shown in Table A-6, the forcing functions (1T, 2T) and (11T through 16T) are assigned to flow boundary conditions to represent the M&E release during blowdown and post-blowdown phases, respectively.

The pressure value in the M&E release boundary conditions is used to determine the density and volume fraction of each phase, vapor and liquid (or droplet). For the flow boundary conditions, [

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The M&E release during the LOCA long-term boil-off phase (decay heat phase) are [

] TS

A boundary condition (6F) is added to the containment model to represent release of remaining SIT water which is not completely depleted until the EOPR. The remaining water in SIT at the EOPR is released to the downcomer and finally added to IRWST liquid. The total amount of SI from the boundary condition (6F) is relatively small and does not impact the containment response result.

Two boundary conditions (3F, 4P) are added to adjust initial conditions and water level of the RCS for the decay heat phase. These two boundary conditions are used until the EOPR and are disabled with the beginning of decay heat phase. Two valves (1V and 3V) are quickly opened at the same time with the beginning of decay heat phase. The fluid temperature from the boundary condition (3F) is the same as IRWST water, and the flow rate is assumed to be the same value as the SIP flow.

A.2.3.6 Forcing Functions

Tabulated forcing functions are used to provide input data for various boundary conditions or to control the GOTHIC components. There are 20 forcing function for the APR1400 LOCA containment model and each is briefly described in the Table A-6.

A.2.3.7 Control Variables

The APR1400 LOCA containment model has 79 control variables. The control variables are used to calculate the flow rates and accumulated mass and energy through each flow path, calculate the amount of mass and energy contained in each volume, determine the core heat rate, calculate CSHX heat removal rate, and calculate various values for plotting. Each of the control variable function is described briefly in Table A-7.

A.2.3.8 Other GOTHIC Modeling Parameters

Revaprozation Fraction

This is the fraction of the condensate that vaporizes from the surface of passive heat sinks. In APR1400, Direct/DLM is chosen as wall condensation heat transfer model. In use of DLM for wall condensation, the re-evaporation fraction is set to DEFAULT to allow GOTHIC to calculate the re-evaporation. The default re-evaporation option was used for all of the validation cases in the GOTHIC Qualification Report (References G-7 and G-8). The comparison of pressure and temperature results from the re-evaporation using DEFAULT and 8% are listed in Table B-2M and Table B-3B.

Minimum Heat Transfer Coefficient

The minimum heat transfer coefficient specifies the lower limit on convection heat transfer that applies to liquid-vapor interfacial heat transfer at the pool surface. It is set to the default value of 0.0 Btu/hr-ft^2-^{o}F to minimize the cooling effect by relatively cold IRWST water.

Reference Pressure

The reference pressure option is set to IGNORE (default) to use the local pressure and temperature to calculate density in the gravitational force term of the vapor momentum equation.

Forced Entrainment Drop Diameter

Diameter of entrained drops for specified entrainment modeling is in subdivided volumes. This parameter is set to DEFAULT (0.09996 inches) since the containment model is based on the lumped parameter approach.

Vapor Phase Head Correction

This option is set to INCLUDE. The static head of the pool liquid that is above the cell center line is subtracted from the vapor phase pressure, and the calculated results are physically more

realistic than results when this parameter is set to IGNORE. In APR1400 containment model, this parameter has no impact on the containment atmosphere volume since the liquid level is significantly lower than the volume center line.

Kinetic Energy

The kinetic energy transport and storage in the fluid energy equations is set to IGNORE. The kinetic energy in the break fluid is already included in the M&E release analysis. Thus, the selection is to set Kinetic energy to IGNORE.

Vapor, Liquid and Drop Phases

The vapor phase including non-condensable gases, liquid and droplet are all modeled in the APR1400 containment response analysis. Thus vapor, liquid and droplet conservation equations are solved for each fluid phase. The option is set to INCLUDE.

Force Equilibrium

This option is to allow or not the code to perform non-equilibrium calculations of interfacial heat transfer among the vapor, liquid and droplet phases. The selection for this option is set Force Equilibrium to IGNORE.

Drop-Liquid Conversion

The option “INCLUDE” enables the droplet phase to model entrainment, agglomeration and deposition into liquid phase. The value of Drop-Liquid conversion is set to INCLUDE.

Drop-Liquid Conversion

The option “INCLUDE” enables the droplet phase to model entrainment, agglomeration and deposition into liquid phase. The value of Drop-Liquid conversion is set to INCLUDE.

A.2.4 Decay heat phase M/E Analysis Model

GOTHIC computer code is employed to calculate M&E rates during long-term boil-off. The analysis for the decay heat phase utilizes a simplified RCS/SG model that calculates M&E release to the containment.

From the beginning of the decay heat phase, the RCS and SGs are in thermal equilibrium, thus there is no heat addition from SGs secondary side to RCS by temperature difference. The temperature of secondary side coolant and metal is maintained equal to the temperature of the RCS metal and coolant respectively, and the temperature gradually decreases during the remainder period of accident.

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The RCS/SGs is also modeled to calculate the maximum water boil-off from the decay heat being released to the containment by the path which results in the minimum amount of mixing with SI water.

A.2.4.1 Sources of Energies

Followings are accounted for in the decay heat phase M&E calculation:

- Core decay energy
- RCS and SGs fluid stored energy
- RCS and SGs metal stored energy

Core decay energy

Core decay heat is modeled using a GOTHIC heater component with a time dependent heat rate. The decay heat is calculated using ANSI/ANS 5.1-1979 with 2σ uncertainties for full reactor power (References G-3 and G-8). The full reactor power used for calculating decay heat rate during [

]TS Table A-8 represents the core power fraction as a function of time. The decay heat data are input to the forcing function (20T) as shown in Table A-6. The forcing function is multiplied by the full power core heat generation rate (plus uncertainty) to yield the decay heat power as a function of time. Figure A-7 shows the decay heat curves based on ANS 5.1/ 1979 with uncertainties.

<u>RCS and SG metal energy</u>

During the decay heat phase, the stored energy in RCS and SGs metal stored energy is taken into account as the energy source supplying to the coolant. The initial metal stored energy at the beginning of decay heat phase (EOPR) is determined from the total mass of RCS and SGs, heat capacity and the surface temperature. [

]TS

<u>RCS and SG fluid energy</u>

The water in the SGs secondary side is assumed to be incorporated to the RCS coolant during the decay heat phase, thus the RCS and SG fluid stored energy can be calculated by multiplying the total water mass to the saturated water enthalpy at the containment pressure.

A.2.4.2 M&E Release Calculation

During the decay heat phase, the amount of RCS water volume is maintained at saturated condition at containment pressure by the continuous SI water supply and coolant boiling by the decay heat and metal sensible energy. Since the water in the RCS/SG volume is saturated, boiling will occur even without heat addition from the decay energy as the containment pressure decreases. The spillage rate, which is calculated by subtracting the steaming rate from the safety injection system (SIS) injection rate, is automatically determined by the downcomer model that maintains the RCS and downcomer water level equally. The condensing of the steam from the intact loop by the SI water is not assumed to maximize the steaming rate conservatively. The equation for calculating steaming rate is as follows:

[ ]TS

Where

$\dot{m}_s$: Steaming rates, (lbm/sec)

$\dot{E}_d$: Decay energy release rates, (btu/sec)

$\dot{E}_m$: Metal sensible heat release rates, (btu/sec)

M: Total liquid mass in RCS and SGs, (lbm)

u_f: Specific internal energy of liquid, (btu/lbm)

h_g: Saturated steam enthalpy at containment pressure, (btu/lbm)

h_l: Safety Injection water enthalpy, (btu/lbm)

The water boil-off generated from the decay heat and metal stored energy is in saturation condition and released to containment through the break. The long-term energy release rate calculated from the GOTHIC code is given as follows:

$(\dot{m}_{steam} \cdot h_g)$: Energy release rate to the containment, (btu/sec)

A.3 MSLB Containment Response Analysis

This section describes major assumptions and key modeling characteristics applied to the containment response analyses to MSLB events. It also includes the description of nodding structure, component models and the other GOTHIC modeling parameters used in MSLB containment model in detail.

A.3.1 Assumptions

In general, the MSLB mass and energy release with the assumption of offsite power available leads to more severe than with LOOP. This causes peak containment pressure and temperature to exceed the same case with LOOP even considering a train of CS system failure by EDG single-failure and spray actuation delay caused by the EDG start-up. In APR1400, offsite power is assumed to be available in MSLB containment analyses to maximize heat transfer to secondary side of affected SG. Thus, there is no time delay needed for EDG start-up unlike LOCA with LOOP, which shift the CS initiation forward by 20 seconds. The single active failures assumed in MSLB containment analyses are loss of a train of CS system caused by a CS pump failure or an MSIV failure to close.

All the other assumptions made in the MSLB containment analyses are the same as discussed in Subsection A.2.1 for LOCA, except the nitrogen release from the SIT.

Input parameters are determined based on both plant specific values and the assumptions described above. The initial conditions for MSLB containment peak temperature calculation are determined from the result of sensitivity analysis for MSLB initial values described in Appendix C.1.

A.3.2 Key Modeling Characteristics

A.3.2.1 Break Flow Model

The break fluid from the affected SG is discharged to the containment atmosphere as superheated steam until the water in affected SG is depleted. The steam discharged from the break goes directly to the containment vapor region and immediately mixes with atmosphere, until it approaches thermal equilibrium.

A.3.2.2 Heat Transfer Model

The heat transfer model discussion provided in Subsection A.2.2.2 for LOCA also applies to MSLB containment analyses.

For the wall heat transfer coefficients, GOTHIC Direct/DLM is chosen as the condensation model on the surface of containment heat passive sinks, also natural convection is selected for sensible heat transfer on heat sinks. Radiation heat transfer to the containment structures is not modeled for conservatism.

For the liquid and vapor heat transfer, the interfacial area between liquid and vapor in containment and IRWST volumes are set to zero to eliminate the cooling effect through the pool surface.

A.3.2.3 Boundary Conditions

The boundary conditions considered in MSLB containment analysis includes M&E release to the containment, energy rejection through the outside surface of containment building and energy removal through the CS heat exchangers.

The mass and energy releases following an MSLB accident are introduced to the containment atmosphere using a flow boundary condition in the GOTHIC containment model. The

containment thermal structures and CS heat exchangers as boundary conditions, which are described in Subsection A.2.2.3, also apply to the MSLB containment analysis.

A.3.2.4 Initial Conditions

The break flow in MSLB accidents, which is discharged to the containment as superheated steam, mixes directly with containment atmosphere resulting in higher containment peak temperature rather than peak pressure.

Appendix B.3 demonstrates that all of the MSLB containment response calculations that use the initial conditions biased to lead peak pressure are bounded by maximum pressure determined in design basis LOCA containment analysis. Thus, the containment response analyses to MSLB accidents are performed in a manner that maximizes the containment temperature. The upper and lower bound values used as the initial conditions for MSLB containment analyses cover the entire range of the LCO specified in Technical Specification as presented in Table B-2A. The outside ambient conditions are not relevant due to the adiabatic assumption for the outside wall of containment building.

In order to maximize the containment peak temperature following MSLB, the lower bound estimate of pressure and upper bound value of temperature are chosen as the containment initial conditions. The initial relative humidity is assumed to have minimum value (0 %). The largest water volume in the IRWST, likewise with LOCA, is chosen to minimize the containment initial volume occupied by the vapor region.

A sensitivity analysis to estimate conservatism of the initial conditions used for an MSLB containment analysis is addressed in Appendix C.1.

A.3.3 MSLB Containment Modeling

[

.]TS The nodding structure

used in MSLB containment analyses is almost the same as that for the LOCA containment analyses, except the primary system for long-term M&E analysis.

As in LOCA containment model, the IRWST is [ ]TS The containment structure is modeled with passive heat sinks comprised of eighteen (18) heat structures and a CS system composed of GOTHIC CS pump, CS heat exchanger and spray nozzle.[ ]TS is used to represent the discharge of M&E from the secondary system piping rupture. Figure A-8 and Table A-9 show the nodding diagram used for the MSLB containment response analyses and summary of components modeling description, respectively.

A.3.3.1 Control Volumes

For the containment response analyses to MSLB accidents, containment atmosphere region (Volume 1) and IRWST (Volume 2) are modeled similarly to LOCA containment model. Nodding structure for those two volumes are the same as discussed in Subsection A.2.3.1 for LOCA.

A.3.3.2 Flow Paths

The MSLB containment model includes three (3) flow paths and the description for each flow path is as shown in Table A-10. The flow path (J13) represents the pipe that carries the pure steam discharged from the affected SG to the containment vapor region. All the GOTHIC parameters used for the flow paths are the same as discussed in Subsection A.2.3.2 for LOCA.

A.3.3.3 Thermal Conductors

The containment passive heat sinks and heat transfer coefficients discussion provided in Subsection A.2.3.3 for LOCA also applies to MSLB containment analyses.

A.3.3.4 Components

GOTHIC built-in components such as pump, spray nozzle and heat exchanger are used for MSLB containment analyses model. Input values for each component are based on plant specific data. For the CS pump, its operation starts automatically from a high containment pressure setpoint with a time delay of 90 seconds that is needed to fill up the CS piping. (The duration that is needed for EDG start-up, is additionally considered for CS system actuation for LOCA). All the other input parameters used for CS pump, spray nozzle and CS heat exchanger are exactly the same as discussed in Subsection A.2.3.4 for LOCA.

A.3.3.5 M&E Boundary Conditions Input

The break fluid from the secondary side of the affected SG is essentially superheated steam. Thus, the break fluid from the boundary condition (5F) is discharged to the containment as pure steam during the entire discharge period. The break fluid is immediately mixed with the containment atmosphere, and approaches the thermal equilibrium.

A.3.3.6 Forcing Functions

Tabulated forcing functions are used to provide input data for various boundary conditions or to control the GOTHIC components. There are three (3) forcing function tables in the APR1400 MSLB containment model and each is briefly described in the Table A-11.

A.3.3.7 Control Variables

The MSLB containment model has 27 control variables. The control variables are used to calculate the flow rates and accumulated mass and energy through each flow path, calculate the amount of mass and energy contained in each volume, calculate CSHX heat removal rate, and calculate various values for plotting. Each of the control variable function is described briefly in Table A-12.

A.3.3.8 Other GOTHIC Modeling Parameters

The GOTHIC modeling parameters discussion provided in Subsection A.2.3.8 for LOCA containment analyses also applies to secondary breaks.

Table A-1 Summary of LOCA Containment Model Description

Volumes	
1	Containment Building
2	IRWST
3	RCS / SGs (Integrated single node for calculating M&E release during the decay heat phase)
4	Downcomer, Provides minimum SI to the Core to makeup the reduced coolant by evaporation. The remaining SI water returns to IRWST as spillage.
5	Piping on the RCS broken loop
6	SIT (Nitrogen gas release only)

Heat Structures	
1~18	Conductors for Heat sink (Wall, dome & most of the internal structures in Containment)
19	A conductor that represents RCS/SG metal sensible energy. (Used only for decay heat phase) The initial temperature is adjusted to the RCS water condition at EOPR.

Components	
CSP	CS Pump (Start after Containment Hi-Hi setpoint with delay time (110sec. for LOCA)) Operation until the end of transient (10^6 seconds)
SIP	SI Pump (Start at EOPR), (Used only for the decay heat phase)
CS	Containment Spray Nozzle (Single droplet diameter (1,000 μm) is used)
CSHX	CS Heat Exchanger (CCHX is not modeled)
1H	Heater for decay heat release (Used only for the decay heat phase)
1V/3V	Valves, Start to open at EOPR (Remain open during the decay heat phase)
2V	Valve, Closed at EOPR (Remain closed during decay heat phase)
4V	Valve, Start to open at EOB for nitrogen release
5V	Valve, Remain closed to prevent mixing the steam and subcooled SI water.

Boundary Conditions (?F: flow boundary condition / ?P: Pressure boundary condition)	
1F	Hot Spillage release during reflood & post-reflood phase. (Results from FLOOD3), (No mixing with containment atmosphere)
2F	Cold Spillage release during reflood & post-reflood phase. (Results from FLOOD3), (No mixing with containment atmosphere)
3F/4P	B/Cs to adjust the RCS initial conditions (RCS pressure, coolant temp., water level) at EOPR. (Temporarily used to adjust RCS initial condition for decay heat phase),
5F	Vapor phase release during reflood & post-reflood phase. (Results from FLOOD3), (Go directly to the Containment Atmosphere)
6F	Remained liquid in SIT at EOPR (The SIT liquid released before EOPR is already reflected in the M/E release through flow BCs(1F/2F/5F/7F)
7F	Superheated liquid or two-phase mixture that is released during the blowdown phase (CEFLASH-4A), (The liquid after phase separation is discharged to containment as liquid droplets).

Table A-2 Description of LOCA Containment Flow Paths

No	Path	Description
J1	IRWST → Spray nozzle	CSP & CSHX are included on the flow path
J2	Containment Atmosphere → IRWST	Modeling four(4) vent paths to a junction(flow path)
J3	B/C 1F→ Containment atmosphere	Hot spillage releases during reflood/post-reflood.
J4	IRWST → Downcomer	Supplies SI water to downcomer through the SIP
J5	B/C 2F → Containment atmosphere	Cold spillage releases during reflood/post-reflood.
J6	B/C 3F → RCS (Virtually used)	Adjusting RCS initial conditions at EOPR with B/C 4P
J7	RCS → B/C 4P (Virtually used)	Adjusting RCS initial conditions at EOPR with B/C 3F
J8	RCS → Piping in broken loop	Path to the hotleg/coldleg piping from RCS
J9	Downcomer → Containment atmosphere	Path to return the spillage to IRWST
J10	Downcomer → RCS	Path to supply the subcooled SI to the Core
J11	Ruptured piping → Containment atmosphere	Pure saturated steam released
J12	SIT(N_2 gas) → Containment atmosphere	Path to transfer the pure N_2 gas to containment
J13	B/C 5F(vapor) → Containment atmosphere	Steam releases during reflood/post-reflood phases
J14	B/C 6F→ Containment atmosphere	SIT water remaining at EOPR releases
J15	B/C 7F→ Containment atmosphere	Superheated liquid releases during blowdown phase
J16	RCS → Downcomer (Intact loop)	Valve closed to prevent mixing of steam to SI water

Table A-3 Passive Heat Sink Data (1/2)

Passive Heat Sink	Material	Thickness [*ft*]			Surface Area [ft^2]			Boundary Condition
		Min.	Nom.	Max. (3)	Min. (3)	Nom.	Max.	
Containment Building								
1-1. Cylinder Wall (Above EL.100')	Epoxy In. Zinc CS Air Conc.	0.00025 0.00025 0.0288 - 4.4488	0.000333 0.000333 0.0288 0.000497 4.4488	**0.000417** **0.000417** **0.0288** **0.000497** **4.4488**	**72,077.9**	72,806.0	73,534.1	**(1)**
1-2.Cylinder Wall (EL.78' ~ 100')	Epoxy In. Zinc CS Air Conc.	0.00025 0.00025 0.0288 - 4.4488	0.000333 0.000333 0.0288 0.000497 4.4488	0.000417 0.000417 0.0288 0.000497 4.4488	10,263.6	10,367.3	10,470.9	(2)
2. Dome	Epoxy In. Zinc CS Air Conc.	0.00025 0.00025 0.0259 - 3.5	0.000333 0.000333 0.0259 0.000497 3.5	**0.000417** **0.000417** **0.0259** **0.000497** **3.5**	**34,989.6**	35,343.0	35,696.4	**(1)**
3. basemat	Epoxy Conc. Air CS Air Conc.	0.002192 3.0 - 0.020833 - 12.0	0.002596 3.0 0.000497 0.020833 0.000497 12.0	**0.00300** **3.0** **0.000497** **0.020833** **0.000497** **12.0**	**4,460.1**	4,598.0	15,186.3	**(1)**
Internal Concrete Structures								
4. Embedment Concrete	Epoxy In. Zinc CS Air Conc.	0.00025 0.00025 0.0864 - 2.5616	0.000333 0.000333 0.0864 0.000497 2.5616	**0.000417** **0.000417** **0.0864** **0.000497** **2.5616**	**5,210.4**	6,513.0	7,815.6	**(1)**
5. Unembedment Concrete	Epoxy Conc.	0.001275 2.534579	0.001679 2.534579	**0.002083** **2.534579**	**112,674.6**	116,188.5	119,702.4	**(1)**
6. Refueling Pool	SS	0.0172	0.0172	**0.0172**	**10,860.4**	11,432.0	12,417.7	**(1)**
7-1.IRWST Outside Upper Slab & HVT	Epoxy Conc.	0.002192 1.5	0.002596 1.5	**0.003** **1.5**	**8,364.3**	8,623.0	11,060.1	**(2)**
7-2.IRWST Outside Outer Wall	Epoxy Conc.	0.002192 1.5	0.002596 1.5	0.003 1.5	10,033.9	10,344.2	10654.5	(2)
8-1.IRWST Inside Upper Slab, Outer Wall, Inner Wall (Above EL.92.6')	SS Conc.	0.0208 1.5	0.0208 1.5	0.0208 1.5	10,530.3	10856.0	11,181.7	(2)
8-2.IRWST Inside Bottom Slab, Outer Wall, Inner Wall (Below EL.92.6')	SS Conc.	0.018209 1.5	0.018209 1.5	0.018209 1.5	17,268.9	17,803.0	18,337.1	(2)

Table A-3 Passive Heat Sink Data (2/2)

Passive Heat Sink	Material	Thickness [ft]			Surface Area [ft^2]			Boundary Condition
		Min.	Nom.	Max.	Min.	Nom.	Max.	
Lifting Devices								
9. Polar Crane & Bridge	Epoxy In. Zinc CS	0.00025 0.00025 0.04	0.000333 0.000333 0.04	**0.000417** **0.000417** **0.04**	**80,750.0**	85,000.0	89,250.0	**(1)**
Components								
10. SIT	Epoxy CS	0.0005 0.1601	0.000667 0.1601	**0.000833** **0.1601**	**5,130.0**	5,400.0	5,670.0	**(1)**
Internal Structural Steel, Supports, Ducts, Trays (4)								
11. Miscel. Steel - Group A	Epoxy In. Zinc CS	0.00025 0.00025 0.054831	0.000333 0.000333 0.054831	**0.000417** **0.000417** **0.054831**	**89,458.0**	99,690.0	109,922.0	**(1)**
12. Miscel. Steel - Group B	In. Zinc CS	0.00025 0.013698	0.000333 0.013698	**0.000417** **0.013698**	**62,194.5**	69,105.0	76,015.5	**(1)**
13. Miscel. Steel - Group C	Epoxy In. Zinc CS	0.00025 0.00025 0.016998	0.000333 0.000333 0.016998	**0.000417** **0.000417** **0.016998**	**24,819.3**	30,501.0	36,182.7	**(1)**
14. Miscel. Steel - Group D	In. Zinc CS	0.00025 0.013124	0.000333 0.013124	**0.000417** **0.013124**	**34,128.4**	36,784.0	39,439.6	**(1)**
15. Miscel. Steel - Group E	In. Zinc CS	0.00025 0.005393	0.000333 0.005393	**0.000417** **0.005393**	**158,512.1**	195,277	232,041.9	**(1)**
Uninsulated Piping (4)								
16. Miscel. Steel - Group F	Epoxy In. Zinc CS	0.00025 0.00025 0.022075	0.000333 0.000333 0.022075	**0.000417** **0.000417** **0.022075**	**13,462.4**	15,284.6	17,106.9	**(1)**
17. Miscel. Steel - Group G	SS	0.020600	0.020600	**0.020600**	**16,107.3**	18,128.4	20,149.6	**(1)**
Additional Item (Insulated) (4)								
18. Miscel. Steel - Group H	SS	0.086430	0.086430	0.086430	45,201.7	53,780.2	62,358.8	(2)
19. Miscel. Steel - Group I	In. Zinc CS	0.00025 0.22706	0.000333 0.22706	0.000417 0.22706	3,877.2	4,203.0	4,528.8	(2)
NSSS Items (4)								
20. Miscel. Steel - Group J	In. Zinc CS	0.00025 0.030235	0.000333 0.030235	**0.000417** **0.030235**	**16,258.7**	17,498.0	18,713.6	**(1)**
21. Miscel. Steel - Group K	SS	0.23805	0.23805	**0.23805**	**12,509.4**	13,086.1	13,662.7	**(1)**

Note:

(1) Left side (inner side): Containment Atmosphere / Right side (outer side): Adiabatic
(2) Left side & Right side: Insulated (Both sides are assumed to be insulated conservatively)
(3) The surface area and the thickness of each passive heat sink are biased to decrease heat absorption rate.
(4) Categorized heat structures which include structural steel, supports, ducts, trays, pipings and NSSS components. Followings are the detailed description of miscellaneous heat structures (Group A through K):

Group	Description	Providers(*)
A	Internal steel structures (Structural steel and PWR)	C
B	Grating and Metal decking	C
C	Piping supports and HVAC	P/C/M
D	Miscellaneous steel components	A/J/M
E	Electrical components	E
F	Miscellaneous steel components	P/A/J/N
G	Miscellaneous steel components	P/N/J
H	NSSS components in containment (Insulated)	P/CD
I	Supports for NSSS components (Insulated)	C/CD
J	NSSS components (carbon steel)	CD
K	NSSS components (stainless steel)	CD

(*) Providers of Heat structures data
C: Construction department
P: Piping design department
M: Mechanical engineering department
A: Architecture department
J: I&C department
E: Electric engineering department
N: Nuclear engineering department
CD: NSSS components provider (DOOSAN Heavy industries & Construction)

Table A-4 Material Properties of Passive Heat Sinks

Materials	Density		Specific Heat		Thermal Conductivity	
	kg/m^3	lbm/ft^3	J/kg-°C	Btu/lbm°F	W/m-°C	Btu/hr-ft-°F
Concrete	2,242.6	140	879.2	0.21	1.592	0.92
Carbon steel	7,817.0	488	460.5	0.11	46.383	26.8
Stainless steel	7,817.0	488	460.5	0.11	15.940	9.21
Inorganic zinc paint	5,462.3	341	891.8	0.213	1.004	0.58
Epoxy paint	1,417.6	88.5	1,272.8	0.304	0.277	0.16
Air	0.961	0.06	720.1	0.172	0.030	0.0174

Note:

The properties for each material are assumed constant at the specified values based on the temperature at the accident initiation to minimize heat transfer to the containment wall from the atmosphere.

Table A-5 Active Heat Sink Data

Component	Description	Unit	Design Value	Value for LOCA
CS System	No. of Trains (1)	EA		
	CSP flow/train	gpm		
		ft³/s		
CSHX Design Spec.	No. of Units (1)	EA		
	Heat Transf. Area	ft²/unit		
	Overall Heat Transf. Coeff.	btu/ft²-hr-°F		
CSHX (Tube side)	Temperature, Tube inlet (4)	°F		
	Volume Flowrate/line	gpm		
	Mass Flowrate @210°F	lbm/s		
CSHX (Shell side)	Temperature, Shell inlet (5)	°F		
	Flowrate/line (Shell), CCW	gpm		
	Mass Flowrate @110°F	lbm/s		

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Note:

(1) Single-failure of a train is assumed for LOCA and MSLB
(2) The CS flow is assumed to 90% of CS pump design flow conservatively.
(3) The Overall Heat Transfer Coefficient reflects the effect of fouling and tube plugging.
(4) The water temperature of CSHX tube side from the CS Pump varies with the IRWST water temperature.
(5) The CCHX (Component Cooling Heat Exchanger) is not modeled. Instead, the highest temperature of cooling water (110°F) that may appear during an entire accident transient is used for the CSHX shell side inlet temperature.

Table A-6 Forcing functions for LOCA Containment Analyses

No.	Description	Dependent Variable
1T	Mass release rate during the blowdown phase	lbm/s
2T	Enthalpy during the blowdown phase	Btu/lbm
3T	Heat Transfer Coefficient of the CS heat exchanger (Constant)	Btu/hr-ft^2-^{o}F
5T	Mass flow rate for the B/C (3F) to adjust the RV water level	lbm/s
6T	Atmosphere pressure (14.7 psia, Constant)	psia
7T	Atmosphere temperature (120 ^{o}F, Constant)	^{o}F
8T	Containment design pressure (60 psig, Constant)	psia
11T	Vapor mass release rate during the reflood and post-reflood phases	lbm/s
12T	Vapor enthalpy during the reflood and post-reflood phases	Btu/lbm
13T	Cold spillage mass release rate during the reflood and post-reflood phases	lbm/s
14T	Cold spillage enthalpy during the reflood and post-reflood phases	Btu/lbm
15T	Hot spillage mass release rate during the reflood and post-reflood phases	Btu/lbm
16T	Hot spillage enthalpy during the reflood and post-reflood phases	Btu/lbm
17T	Number of operating CS pumps, multiplier	1 or 2
18T	Number of operating SI pumps, multiplier	3 or 4
19T	Mass release rate of the remaining SIT water at EOPR	lbm/s
20T	Decay energy table (ANS 5.1/1979 + 2σ uncertainties)	decay rate

Note

Independent variable of each forcing function indicates time (seconds).
Forcing functions (4T,9T and 10T) are reserved, but not used.

Table A-7 Control Variables for LOCA Containment Analyses

No.	Description	No.	Description
1C	Break flow rate (J13), reflood/post-reflood	41C	Liquid mass in RCS/SG and Downcomer
2C	Accumulated vapor flow (J13)	42C	Liquid energy in RCS/SG and Downcomer
3C	SIP mass flow rate (J4)	43C	Decay energy release rate
4C	Accumulated SIP mass flow (J4)	44C	Accumulated decay energy
5C	Break flow(Cold spillage) rate (J5)	45C	Liquid energy in the Downcomer
6C	Accumulated cold spillage (J5)	46C	Total mass(L/V/D) in the entire volumes
7C	Containment Steam partial pressure	47C	Total energy(L/V/D) in the entire volumes
8C	Containment ralative humidity	48C	Accumulated nitrogen mass to containment
9C	Containment total pressure	49C	SIT nitrogen energy release rate (J12)
10C	IRWST liquid temperature	50C	Accumulated nitrogen energy to containment
11C	IRWST total pressure	51C	Break flow(Hot spillage) rate (J3)
12C	RCS/SG total pressure	52C	Accumulated hot spillage to containment(J3)
13C	RCS/SG total pressure (≥ 60.0psia)	53C	CSHX heat transfer rate (btu/s)
14C	Break flow rate (J11), long-term phase	54C	Accumulated heat to the HX shell side (btu)
15C	Accumulated break flow (J11)	55C	Spillage(hot+cold) flow rate (J3+J5)
16C	Spillage flow rate (J9), long-term phase	56C	Accumulated spillage (hot+cold) (J3+J5)
17C	Liquid mass in the IRWST	57C	Accumulated break flow (J11), (=15C)
18C	Vapor mass in the IRWST	58C	Vapor energy release rate from RCS (J11)
19C	Droplet mass in the IRWST	59C	Accumulated vapor energy from RCS(J11)
20C	Liquid mass in the Containment	60C	Spillage energy release rate (J9)
21C	Vapor mass in the Containment	61C	Accumulated spillage energy from RCS (J9)
22C	Droplet mass in the Containment	62C	SIP mass flow rate (J4) (=3C)
23C	Liquid energy in the IRWST	63C	Accumulated SIP mass flow (J4) (=4C)
24C	Vapor energy in the IRWST	64C	SIP energy flow rate (J4)
25C	Droplet energy in the IRWST	65C	Accumulated SIP energy flow (J4)
26C	Liquid energy in the Containment	66C	Mass flow rate (Downcomer→RCS) (J10)
27C	Vapor energy in the Containment	67C	Accumulated mass flow (Downcomer→RCS)
28C	Droplet energy in the Containment	68C	Energy flow rate (Downcomer→RCS) (J10)
29C	Total mass(L/V/D) in the Containment	69C	Accumulated energy flow (Downcomer→RCS)
30C	Total energy(L/V/D) in the Containment	70C	SIT liquid flow rate (J14) flow path (=37C)
31C	Total mass(L/V/D) in the IRWST	71C	Accumulated SIT liquid flow after EOPR
32C	Total energy(L/V/D) in the IRWST	72C	SIT liquid energy rate (J14) after EOPR
33C	Total mass in the Containment & IRWST	73C	Accumulated SIT liquid energy after EOPR
34C	Total energy in the Containment & IRWST	74C	SIT nitrogen mass release rate (J12)
35C	RCS/SG liquid temperature	75C	Break flow rate (J15) during blowdown phase
36C	Liquid Mass in the RCS/SG	76C	Accumulated break flow (J15)
37C	SIT liquid flow rate (J14) after EOPR	77C	Energy content of RCB atmosphere
38C	RCS/SG metal temperature	78C	Energy contents of Containment passive heat sinks
39C	Liquid mass in the Downcomer	79C	Energy contents of RCS metal
40C	Liquid energy in the RCS/SG		

Table A-8 Decay Heat Table used for Decay heat phase (ANS 5.1 1979 + 2σ)

Time (sec)	Decay heat rate	Time (sec)	Decay heat rate
10	0.0538760	12,000	0.0107960
12	0.0524860	15,000	0.0100970
15	0.0504010	20,000	0.0093500
20	0.0480180	30,000	0.0085640
30	0.0452095	40,000	0.0077780
40	0.0424010	60,000	0.0069580
60	0.0392440	80,000	0.0064240
80	0.0370650	100,000	0.0060210
100	0.0354660	120,000	0.0057418
120	0.0343692	150,000	0.0053230
150	0.0327240	200,000	0.0048470
200	0.0309360	300,000	0.0043085
300	0.0290070	400,000	0.0037700
400	0.0270780	600,000	0.0032010
600	0.0249310	800,000	0.0028340
800	0.0233890	1,000,000	0.0025800
1000	0.0221560	1,200,000	0.0024458
1200	0.0212620	1,500,000	0.0022445
1500	0.0199210	2,000,000	0.0019090
2000	0.0183150	3,000,000	0.0016320
3000	0.0165480	4,000,000	0.0013550
4000	0.0147810	6,000,000	0.0010910
6000	0.0130400	8,000,000	0.0009270
8000	0.0120000	10,000,000	0.0008080
10000	0.0112620	12,000,000	0.0006890

Table A-9 Summary of MSLB Containment Model Description

Volumes	
1	Containment Building
2	IRWST

Heat Structures	
1~18	Conductors for Heat sink (Wall, dome & all of the internal structures in Containment)

Components	
CSP	CS Pump (Start after Containment Hi-Hi setpoint with delay time [90sec. for MSLB]) Working until the end of transient (10^6 seconds)
CS	Containment Spray Nozzle (Single droplet diameter [1,000 μm] is used)
CSHX	CS Heat Exchanger (No CCHX is modeled for CSHX shell side)

Boundary Conditions (Flow boundary condition)	
5F	Vapor phase release during entire transient period. (Go directly to Containment atmosphere) (Results from SGN-III)

Table A-10 Description of MSLB Containment Flow Paths

No	Path	Description
J1	IRWST → Spray nozzle	CSP & CSHX are included on the flow path
J2	Containment Atmosphere → IRWST	Modeling four(4) vent paths as a junction (flow path)
J13	B/C 5F(vapor) → Containment atmosphere	M&E releases until water depletion of affected SG

Table A-11 Forcing functions for MSLB Containment Analyses

No.	Description	Dependent Variable
1T	Mass release rate during the discharge period.	lbm/s
2T	Enthalpy during the discharge period.	btu/lbm
17T	The number of operating CS pumps, multiplier	1 or 2

Note

Independent variable of each forcing function indicates time (seconds).

Table A-12 Control Variables for MSLB Containment Analyses

No.	Description	No.	Description
1C	Break flow rate (J13)	24C	Vapor energy in the IRWST
2C	Accumulated vapor flow (J13)	25C	Droplet energy in the IRWST
7C	Containment Steam partial pressure	26C	Liquid energy in the Containment
8C	Containment relative humidity	27C	Vapor energy in the Containment
9C	Containment total pressure	28C	Droplet energy in the Containment
10C	IRWST liquid temperature	29C	Total mass(L/V/D) in the Containment
11C	IRWST total pressure	30C	Total energy(L/V/D) in the Containment
17C	Liquid mass in the IRWST	31C	Total mass(L/V/D) in the IRWST
18C	Vapor mass in the IRWST	32C	Total energy(L/V/D) in the IRWST
19C	Droplet mass in the IRWST	33C	Total mass in the Containment & IRWST
20C	Liquid mass in the Containment	34C	Total energy in the Containment & IRWST
21C	Vapor mass in the Containment	53C	CSHX heat transfer rate (btu/s)
22C	Droplet mass in the Containment	54C	Accumulated heat to the HX shell side (btu)
23C	Liquid energy in the IRWST		

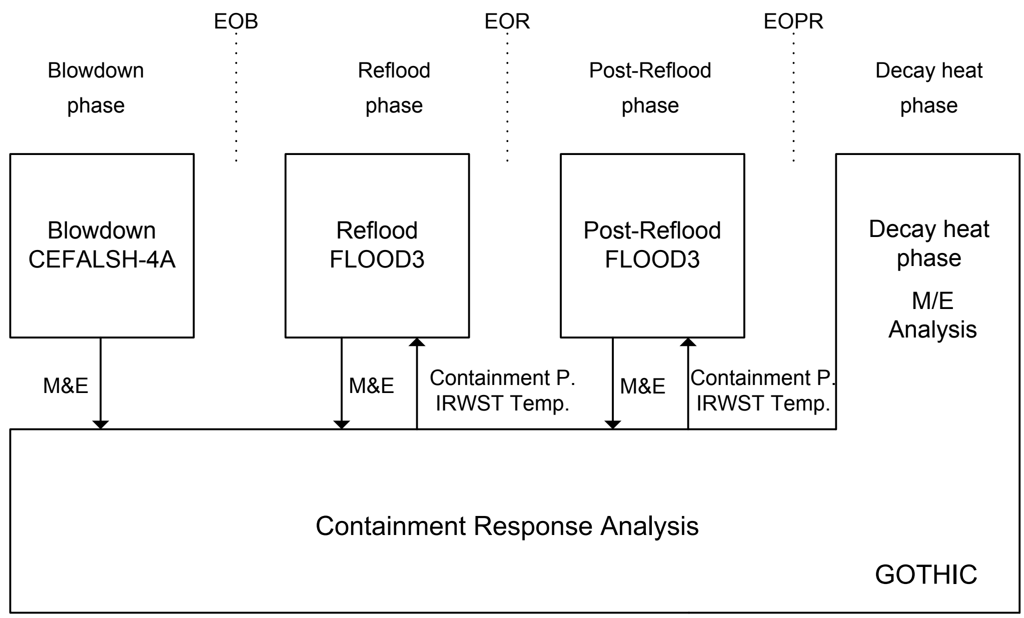

Figure A-1 Computer Codes Interface Diagram (LOCA)

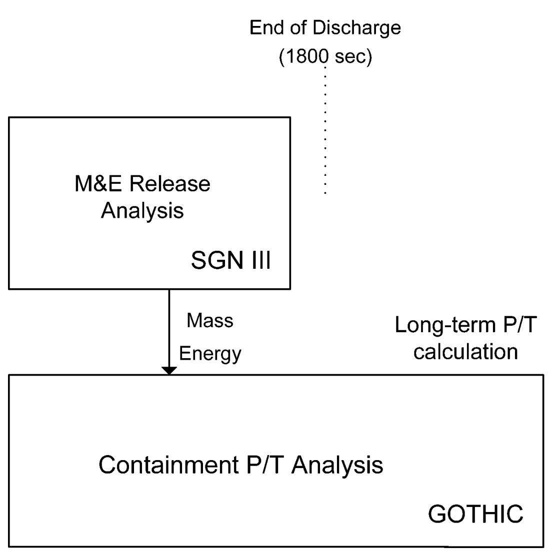

Figure A-2 Computer Codes Interface Diagram (MSLB)

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Figure A-3 LOCA Containment Response Analysis Flow Diagram

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Figure A-4 MSLB Containment Response Analysis Flow Diagram

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Figure A-5 Fluid phases of a LOCA discharge flow (Cold leg break)

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Figure A-6 Nodding Diagram for LOCA Containment Analyses

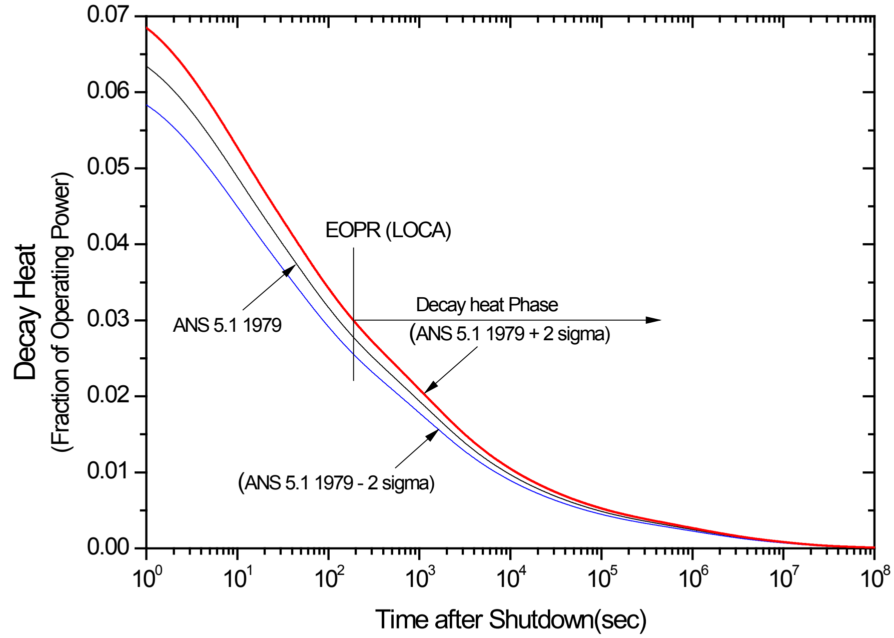

Figure A-7 Decay Heat Curve

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Figure A-8 Nodding Diagram for MSLB Containment Analyses

APPENDIX B

CALCULATIONS USING THE APR1400 CONTAINMENT MODEL

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B. CALCULATIONS USING APR1400 CONTAINMENT MODEL

This section provides application of the GOTHIC containment model described in Appendix A to the APR1400 containment integrity analyses. The purpose of this section is to demonstrate that the containment accommodates the pressure and temperature conditions resulting from high-energy pipe breaks of the primary or secondary system. This section contains five subsections: loss-of coolant accident (LOCA) peak pressure, MSLB peak temperature, MSLB peak pressure, maximum IRWST water temperature and maximum passive heat sink temperature.

LOCA containment analyses were performed for peak containment pressure; however, the MSLB containment analyses were performed to estimate peak temperature since the secondary system pipe breaks result in higher peak temperature rather than higher pressure. In addition, the maximum pressure estimated from MSLB analyses does not exceed the peak pressure in the design basis LOCA.

Sections B.1 and B.2 present the results of containment response calculations to LOCA and MSLB for peak pressure and peak temperature, respectively. Section B.3 demonstrates that all the results from MSLB pressure analyses, which were performed using the initial conditions biased to lead to maximum peak pressure, are bounded by the maximum peak pressure estimated in the containment response to the design basis LOCA. Calculations for maximum IRWST water temperature are presented in Section B.4. This section describes the conservatism of each initial condition used to maximize the IRWST water temperature. The calculation results are provided to estimate the minimum net positive suction head available (NPSHa) for the safety injection (SI) pumps or containment spray (CS) pumps. Section B.5 is presented to demonstrate that the highest surface temperature of heat structures in containment is lower than the containment temperature limit, providing reasonable assurance of the containment integrity.

The calculation results of containment response analyses to LOCA and MSLB presented in Sections B.1 and B.2 are consistent with those described in DCD Subsection 6.2.1.1.

B.1 LOCA Peak Pressure

This section addresses the containment responses subsequent to LOCA events with respect to peak containment pressure. All calculations were performed using the containment model that was developed based on the methodology described in Appendix A. The following subsection contains a description of LOCA accidents description, initial conditions and M&E data, and input parameters and calculations.

B.1.1 Description of Accident

In accordance with the LOCA M&E analyses described in Section 3, cold leg suction break, cold leg discharge break, and hot leg break are considered as large-break LOCA events for containment response analysis. The LOCA M&E release to the cold leg break is divided into four distinct phases: blowdown, reflood, post-reflood and decay heat phase. Followings are descriptions of each phase from the perspective of containment response.

Blowdown

The blowdown phase encompasses the rapid release of M&E into the containment and ends when the entire reactor coolant system (RCS) inventory has been released. The blowdown phase is usually completed within 20 seconds for a large-break LOCA. Typically, the initial containment peak pressure occurs toward the end of the blowdown phase.

Reflood

The reflood phase subsequently begins after the end of blowdown (EOB). The subcooled water from the SI tanks refills the reactor vessel until the liquid level in the core reaches the height to terminate liquid entrainment from the core. During the reflood phase, the active core is quenched as reactor vessel water level increases by SI flow, which leads to a large amount of steam and entrained water released to the containment through the break. For the reactor coolant pump (RCP) suction leg break in the APR1400 containment, containment peak pressure occurs before the end of the reflood phase since steam generator (SG) secondary energy is released to the containment at a higher rate compared to the RCP discharge leg break.

Post-reflood

The post-reflood phase begins after the end of the reflood phase and continues until the temperatures of the RCS and steam generators are essentially equal. The containment peak pressure occurs during the post-reflood period in the case of a LOCA with RCP discharge piping break, since the time required to exhaust the heat addition from the SG secondary side is usually longer than for an RCP suction piping break. After peak containment pressure is reached, continuous flow of subcooled water droplets through spray nozzles to the containment atmosphere gradually decreases containment pressure and temperature.

Decay Heat

The final post-blowdown phase, referred to as the decay heat phase, is a relatively stable period characterized by decay heat and RCS/SG metal sensible energy. During this period, M&E release to the containment continues through the boil-off of RCS coolant by heat addition from the remaining stored energy in RCS metal and coolant, as well as decay heat produced in the reactor. The heat removal system, including CS and CS heat exchangers, continues to condense the water vapor in the containment atmosphere and transfers the in-containment refueling water storage tank (IRWST) water energy to outside the containment building. Consequently, containment pressure and temperature monotonically decrease during this phase of the transient.

For the hot leg pipe break, flow is cut off to the steam generator in the broken loop and, therefore, it is assumed that there is no heat transfer between the primary and secondary sides of the affected steam generator. Hence, for the hot leg break, only the blowdown and decay heat phase, referred to as the long-term boil-off, are modeled.

B.1.2 Input Parameters

Initial Conditions

A sensitivity analysis for the initial conditions that affects peak pressure was performed to determine the upper or lower bounding initial values. As presented in Table B-1A, higher pressure and temperature and lower relative humidity were selected as the conservative initial values. For the IRWST water volume, greater initial water volume decreases the containment air space, resulting in higher peak pressure. Thus, the maximum water volume with higher water temperature is chosen for the calculation. The conservatism used in selecting initial values for the LOCA containment analysis is described in Section C.1.

M&E Release Data

As described in Appendix A, in the containment response analysis methodology, LOCA M&E release data until the end of post-reflood (EOPR) are used as flow boundary input for GOTHIC. Thereafter, GOTHIC directly calculates the M&E release from the RCS. The M&E release transients for each LOCA case are shown as a function of time in Figure B-1(A,B) through B-5(A,B). The analysis methods of LOCA M&E until the EOPR are described in Section 3 of this report. Additionally, Appendix A.2.4 presents the M&E analysis methodology during the decay heat phase.

B.1.3 Calculations

Containment response analyses to the five LOCA events are performed as follows: two cases of the RCP suction leg piping break with maximum and minimum SI, two cases of RCP discharge leg piping break with maximum and minimum SI flow, and one case of hot leg piping break with maximum SI. Containment response analyses are extended up to one million seconds to include all important aspects of the transient. The containment pressure and temperature and IRWST water temperature responses are graphically illustrated as a function of time in Figures B-1(C,D) through B-5(C,D).

Double-Ended Suction Leg Slot Break (DESLSB) with Maximum SI

This analysis assumes an RCP suction leg slot break coincident with a loss of offsite power (LOOP) that leads to CS actuation delay due to required diesel-startup time. No emergency

diesel generator (EDG) failure is assumed, and therefore all SI pumps are available. An additional single failure assumed in the containment engineered safety feature (ESF) system is the loss of a CS system train.

Figure B-1A shows the mass release transients until the EOPR after accident initiation. Figure B-1B represents the steaming and spillage flow rate from the break, which is calculated using GOTHIC RCS model during the decay heat phase. Figure B-1C shows the pressure and temperature transients of the containment atmosphere for the first 600 seconds. The IRWST water temperature as well as containment pressure and temperature during the entire transient, are shown in Figure B-1D.

The sequence of events is described in Table B-1B. Containment pressure and temperature increase rapidly due to the large release of break flow from the RCS. The containment pressure increase causes the generation of a containment pressure high-high signal at 4.41 seconds. Containment pressure continues to rise until the EOB phase. The SI tanks begin to inject water as RCS pressure decreases in the blowdown phase. Subsequently, SI pumps start water injection at the EOB. The initial containment peak pressure, 3.138 kg/cm^2 (44.64 psig) occurs at 19.19 seconds. Release of nitrogen gas from the SI tanks is assumed to begin at the EOB (19.2 seconds).

M&E release from the break is temporarily terminated at the EOB and begins again as the reactor core is recovering with SI water. This causes containment pressure to decrease for a moment in an earlier period of the reflood phase. The continuous M&E release from the break forces the SG secondary side energy to be released at a high rate. This causes heat addition from the SG secondary side to be exhausted relatively early in the post-blowdown phase, resulting in early occurrence of peak containment pressure. Containment pressure reaches an overall peak of 3.583 kg/cm^2 (50.96 psig) at 105.36 seconds and peak temperature reaches 134.53 °C (274.16 °F). This occurs before containment spray actuation in the reflood phase.

The CS pump begins to supply subcooled water to the CS nozzles with a time delay of 110 seconds after containment pressure reaches the pressure high-high setpoint. After CS actuation

at 114.41 seconds, liquid droplets sprayed from the CS nozzles transfer the energy of the containment atmosphere to the IRWST water pool through heat exchange between spray droplets and containment atmosphere. The residual SG secondary energy gradually decreases until SG pressure reaches thermal equilibrium with containment pressure. The continuous CS nozzle spray, along with the decrease of energy from the SG secondary side and core decay heat causes containment pressure to slowly decrease during the remainder of the post-reflood phase.

During the decay heat phase, referred to as the long-term cooling phase, all the energies contributing to water boil-off in the RCS are produced from core decay heat and stored energy in the RCS and SGs metal and coolant. The steaming rate during this period is determined by the boil-off of core coolant based on the containment pressure condition. The methodology for calculating M&E release during the decay heat phase is described in Appendix A.2.4.

The maximum IRWST water temperature is 100.2 °C (212.3 °F) at 30,442 seconds as shown in Figure B-1D. Containment pressure at 24 hours after the postulated accident is 28.65 percent of the peak calculated value.

Double-Ended Suction Leg Slot Break (DESLSB) with Minimum SI

The DESLSB with minimum SI flow has a transient history similar to the DESLSB with maximum SI case discussed above. This analysis also assumes a LOOP and associated single failure with a loss of one train of the SI system and one train of the CS system subsequent to an EDG failure.

Figures B-2A and B-2B show the mass release transients during the short-term period until the EOPR and the remainder of the transient period, respectively. Figures B-2C and B-2D show the pressure and temperature transient in the containment atmosphere and IRWST water.

The calculated containment peak pressure is 3.596 kg/cm^2 (51.14 psig) and the calculated peak temperature is 134.67 °C (274.40 °F). These occur in the reflood phase before containment spray actuation (114.4 seconds). The maximum IRWST water temperature is calculated to be

100.2 °C (212.4 °F) at 30,431 seconds as shown in Figure B-2D. Containment pressure at 24 hours is 28.54 percent of the peak calculated value. The event description is presented in Table B-1C.

Double-Ended Discharge Leg Slot Break (DEDLSB) with Maximum SI

This analysis assumes an RCP discharge leg slot break with LOOP. No EDG failure is assumed for maximum SI flow. The only single failure assumed in the containment ESF system is loss of a CS system train to decrease containment cooling ability.

The M&E release through the RCP discharge leg slot break during the blowdown phase is at a higher rate compared to the RCP suction leg break. Following the blowdown phase, however, the M&E discharge rate through the affected SG is relatively smaller in comparison to that of the RCP suction leg break, resulting in a slower increase in containment pressure. This, however, increases the time to approach thermal equilibrium between RCS and SG secondary side and delays the occurrence of peak containment pressure.

Figures B-3A and B-3B show the mass release transients of each break fluid before and after the EOPR, respectively. Figure B-3C shows the pressure and temperature responses of the containment atmosphere for the first 600 seconds after accident initiation. Figure B-3D shows IRWST water temperature as well as the containment atmosphere transient during the long-term period.

The containment pressure and temperature responses during the blowdown phase are similar to those of the RCP suction leg break. Pressure and temperature increase rapidly after accident initiation, causing generation of the containment pressure high-high signal at 3.78 seconds. The SI tanks begin to inject water as RCS pressure decreases and SI pumps start injection at the EOB (19.75 seconds). The initial containment peak pressure of 3.135 kg/cm^2 (44.59 psig) occurs at 17.89 seconds in the blowdown phase. Table B-1D provides a detailed description of event sequences.

As with the suction leg break described above, M&E release to the containment is terminated at the EOB due to depletion of core coolant inventory, causing containment pressure to temporarily decrease. Pressure begins to increase again, however, due to a large amount of steam generated by core quenching during reflooding. Containment pressure reaches an overall peak of 3.662 kg/cm² (52.09 psig) at 323.81 seconds and peak temperature reaches 135.27 °C (275.48 °F).

Nitrogen in the SI tanks begins to release directly to the containment at the EOB (19.75 seconds), which increases the containment pressure by approximately 0.042 kg/cm² (0.6 psi). The energy release rate from the SG secondary side gradually decreases and terminates at 360.25 seconds (EOPR).

The maximum IRWST water temperature is calculated to be 101.5 °C (214.7 °F) at 28,438 seconds as shown in Figure B-3D. Containment pressure at 24 hours is 28.52 percent of the calculated peak pressure.

Double-Ended Discharge Leg Slot Break (DEDLSB) with Minimum SI

The DEDLSB with minimum SI flow has a transient history similar to maximum SI case with DEDLSB described above. Figures B-4A through B-4D show the transients of mass release from the break as well as containment pressure and temperature.

As described in sequence of events in Table B-1E, the calculated peak pressure is 3.654 kg/cm² (51.97 psig) and the peak containment atmosphere temperature is 135.2 °C (275.35 °F). This occurs in the post-reflood phase after CS actuation (113.78 seconds). The maximum IRWST water temperature is 101.8 °C (215.22 °F) at 27,937 seconds as shown in Figure B-4D. The containment pressure at 24 hours is 28.44 percent of the calculated peak pressure.

Double-Ended Hot Leg Slot Break (DEHLSB)

This analysis assumes a hot leg piping slot break that has the same break area as that of the double-ended guillotine piping rupture. The M&E release rate is primarily dependent on the break size during blowdown; therefore, a hot leg break generally produces the maximum peak containment pressure at the EOB.

During the post-blowdown phase, most of the break fluid does not pass through the broken-loop SG before release to the containment. Thus, the M&E release after the EOB is calculated from the boil-off process in the reactor core. The SI flow rate to the RCS core does not affect the steam release during the decay heat phase since the steaming rate from the SI flow is determined from the core decay heat and RCS stored energy, and the remainder of the SI flow, regardless of the amount, returns to the containment as spillage without temperature increase.

The transients of mass release and the containment pressure and temperature responses are illustrated in Figures B-5A through B-5D. The postulated hot leg piping break results in a large amount of M&E release to the containment with a rapid increase in both containment pressure and temperature during the blowdown phase. This rapid increase in containment pressure results in the generation of a containment high-high pressure signal at 2.52 seconds, relatively earlier than during a cold leg piping breaks. The SI pumps start injection at 6.8 seconds and containment pressure continues to rise rapidly in response to the release of M&E until the EOB. Table B-1F presents the chronology of events.

The containment peak temperature is 133.11 °C (271.6 °F) and peak pressure is calculated to be 3.441 kg/cm^2 (48.94 psig) near the EOB (13.4 seconds) as shown in Figure B-5C. The maximum IRWST water temperature is calculated to be 98.0 °C (208.4 °F) at 34,451 seconds. Containment pressure at 24 hours is 29.75 percent of the calculated peak pressure.

B.1.4 Results

The containment pressure and temperature responses to LOCAs have been estimated to determine the design basis accident. The summary of all the results of postulated LOCA events are tabulated in Table B-1G. The results show that the “double-ended discharge leg slot break

(DEDLSB) with maximum SI flow" case is the limiting case in containment pressure response. Thus, DEDLSB with maximum SI system capabilities without an EDG single failure is determined as the design basis LOCA. The calculated peak pressure is 3.662 kg/cm^2 (52.09 psig). This limiting peak pressure also bounds all the containment peak pressures in secondary system piping breaks addressed in Sections B.2 and B.3.

In conclusion, it was demonstrated that APR1400 containment design pressure provides more than a 10 percent margin (13.2 percent) above the peak calculated pressure of the design basis LOCA, and the requirement that limits the maximum pressure at 24 hours to less than half of peak calculated pressure is also satisfied.

B.2 MSLB Peak Temperature

This section addresses the containment temperature and pressure responses subsequent to main steam line break (MSLB) events in the APR1400. It discusses the containment response to accidents from the peak temperature standpoint. The MSLB containment analysis model described in Section A.3 was used for this calculation.

B.2.1 Description of Accident

Following a postulated MSLB inside containment, steam and water contents in the affected SG shell side will be released to the containment. Steam line ruptures occurring inside the containment building may result in significant release of high-energy fluid to the containment environment that could produce high temperature and pressure conditions.

Most of the contents in the unaffected SG will be isolated by the main steam isolation valves (MSIVs). Containment pressurization subsequent to a secondary side piping break depends on how much of the break fluid enters the containment atmosphere as steam. The objective of the spectrum of break sizes is to find the largest break size that results in pure steam discharge. The quantitative nature of the releases following a steam line rupture is dependent upon possible configurations of plant steam systems and containment design as well as plant operating conditions and size of the rupture.

B.2.2 Input Parameters

Initial Conditions

The discharge fluid in MSLB accidents is nearly pure steam, which has relatively higher energy than LOCA break fluid. For that reason, it results in more impact on containment peak temperature rather than pressure. The description in Section B.3 demonstrates that all the MSLB containment analysis results, which are based on initial conditions biased for maximizing peak pressure, are bounded by the maximum peak pressure determined in design basis LOCA containment analysis. Thus, the initial conditions for MSLB containment analysis were estimated

in view of peak temperature. Section C.1 presents the sensitivity analysis for the initial bounding values used in the MSLB peak temperature calculation.

The maximum or minimum values for the bounding initial conditions are chosen as the same values applied to LOCA except for atmosphere pressure. As shown in Table B-2A, the minimum initial pressure value is determined because lower pressure decreases the initial cold air mass, causing rapid increase in containment temperature, and delays the time to reach the setpoint pressure for initiating containment spray. The conservatism used in selecting initial bounding values in the MSLB containment calculation is described in Section C.1.

M&E Release Data

The M&E release data, which are calculated using the SGN-III computer code, are provided to the flow boundary input of the GOTHIC containment model. The M&E release from the affected steam generator continues until the affected SG is depleted; thereafter, GOTHIC calculates the containment temperature and pressure transients without additional M&E release. The M&E release transients for each MSLB are shown as a function of time in Figures B-6 through B-15.

B.2.3 Calculations

A total of 10 MSLB cases covering various power levels and break sizes were postulated. The M&E releases from the break continue until the operator manually terminates flow to the affected SG from the auxiliary feedwater system. All the MSLB containment response analyses are performed for 1 million seconds.

Containment temperature and pressure rise rapidly due to the large steam release from the break. The break flow abruptly drops around 10 seconds after accident initiation since the steam release from the intact SG is terminated by MSIV closure. The CS pump begins to deliver subcooled water to the spray nozzle with a time delay of 90 seconds after containment high-high setpoint initiation. The liquid droplets from the CS nozzles rapidly condense the containment atmosphere, which is in superheated condition, resulting in a large reduction in containment atmosphere temperature. The highest temperature occurs at this time. After CS initiation, the

containment atmosphere is maintained in a saturated condition at the transient steam partial pressure.

Operator action to terminate the supply of auxiliary feedwater to the affected SG occurs at 1,800 seconds after accident initiation, subsequently causing the containment pressure and temperature to decrease at a higher rate during the extended period of the transient.

B.2.4 Results

The containment responses to MSLB accidents have been analyzed to determine the containment maximum temperature and pressure. The sequence of events for each analysis case is presented in Tables B-2B through B-2K, and the analysis results are summarized in Table B-2L. Table B-2M presents the re-evaporation effect that influences maximum temperature and saturated temperature. The containment pressure and temperature transients are illustrated as a function of time in Figures B-6(C,D) through B-15(C,D).

The results show that the most restrictive secondary system piping rupture with respect to maximum temperature is the double-ended rupture of a main steam line (break area 0.849 m^2 [9.134 ft^2]) at 102 percent power level, concurrent with an MSIV single failure. The calculated peak temperature and pressure in the containment associated with this worst case are 170.32 °C (338.58°F) and 3.196 kg/cm^2 (45.46 psig), respectively.

Each containment maximum temperature estimated from the MSLB accidents exceeds the saturation temperature for a while before CS actuation, as shown in Figures B-6(B) through B-15(B). This superheated condition has an insignificant impact on containment integrity, however, since the superheated steam condenses rapidly after contacting the subcooled surfaces of structures in containment. Furthermore, it lasts only a short time (less than 2 minutes). Thus, the temperature of the exposed structure surfaces does not exceed the saturation temperature corresponding to the steam partial pressure. Figure B-19(A,B) shows the temperature transients of structure surfaces in containment compared with the saturation temperature.

In accordance with Appendix B of Reference G-2, the equipment environmental qualification (EQ) methodology takes credit for up to 8 percent re-evaporation when the atmosphere is superheated. Thus, the re-evaporation effects on containment peak temperature and pressure are estimated. Figures B-16(A,B) and B-17(A,B) show the pressure and temperature transient curves produced from results of all the MSLB peak temperature analyses. Figures B-16A and B-17A show the pressure and temperature transients resulting from use of the GOTHIC default re-evaporation option, respectively. From comparison with results of the 8 percent re-evaporation shown in Figures B-16B and B-17B, increasing the re-evaporation rate in MSLB accidents has little effect on containment peak pressure, whereas temperature decreases significantly due to the evaporative latent heat of increased condensate. As shown in Table B-2M, the case (102 percent power with MSIV single failure) that considers 8 percents of re-evaporation shows a small increase in pressure (0.002 kg/cm^2 [0.03 psi]) and decreases peak temperature by 8.33 °C (15 °F) in comparison to the same case using the GOTHIC default option.

As presented in Table B-2M, the highest saturation temperature calculated using 8 percent re-evaporation, 134.42 °C (273.95 °F), is no higher than the maximum saturated temperature determined from the design basis LOCA (DEDLSB with maximum SI), shown in Table B-1G.

B.3 MSLB Peak Pressure

In general, the maximum peak pressure and temperature in containment occur in LOCA and MSLB accidents, respectively. For that reason, the LOCA containment response analyses were performed to determine the maximum containment peak pressure and the maximum peak temperature was estimated from MSLB peak temperature analyses. Hence, it is necessary to demonstrate that the maximum peak pressure in MSLB accidents is no higher than the peak pressure determined from the design basis LOCA. The same cases that are chosen for MSLB peak temperature calculation described in Section B.2 are also taken into account for the peak pressure estimation.

B.3.1 Input Parameters

Table B-3A presents the representative initial values used for the calculation. Each of the initial values is biased to maximize peak pressure. All of the bounding initial values are exactly the same as those for LOCA analyses described in Section B.1, except the values with respect to the safety injection tank safety injection tank (SIT).

The M&E release data used for this calculation are the same as those for the MSLB peak temperature calculation described in Subsection B.2. Figures B-6(A) through B-15(A) show the MSLB M&E release transients as a function of time.

B.3.2 Calculation and Results

The MSLB peak pressure results are summarized in Table B-3B. The MSLB at 75 percent power with a train of CS system failure produces the highest peak containment pressure 4.558 kg/cm^{2}A (64.83 psia) among all MSLB accident cases. The case considering 8 percent re-evaporation shows slightly higher pressure (0.001 kg/cm^2 [0.02 psi]) and lower temperature than the same case that uses the GOTHIC default option for re-evaporation. This calculated peak pressure is lower than the highest pressure determined in the design basis LOCA by (0.127 kg/cm^2 [1.8

psi]). The saturated temperature, which is used as the reference temperature of structure surfaces, rises as the steam contents in atmosphere increases due to the higher re-evaporation rate; however, the increased temperature value is negligible (less than 0.056 °C [0.1 °F]).

B.4 IRWST Maximum Water Temperature

This section provides the calculation of the maximum IRWST water temperature during LOCA and MSLB accidents. The results of this calculation are used as input to the minimum net positive suction head available (NPSHa) estimation for the pumps that use IRWST water as the upstream working fluid.

From the sensitivity analysis for IRWST water temperature described in Section C.4, one of the primary parameters that affect the maximum IRWST water temperature is initial water volume in the IRWST. Lower initial water volume in the IRWST leads to higher water temperature in the long-term cooling phase. Estimation of each initial value with respect to maximum IRWST water temperature is described in Section C.1. Table B-4A lists the initial bounding values chosen for the analysis of maximum IRWST water temperature. The same assumptions and M&E release data used for LOCA peak pressure described in Section B.1 are applied to the calculation.

Calculation and Results

IRWST water temperature transients during LOCA and MSLB accidents are shown in Figure B-18A. As shown in the figure, the worst-case accident that produces maximum water temperature is estimated to be the double-ended discharge leg slot break (DEDLSB) with minimum SI flow.

For water temperature transients during MSLB accidents, there are no additional M&E sources added to the containment volume after depletion of the affected SG, which occurs at 1,800 seconds after the postulated accident. For that reason, all the maximum water temperatures in MSLB accidents are lower than those of the limiting LOCA by more than 11.1 °C (20 ^{o}F).

Figure B-18B shows the containment pressure and saturation pressure corresponding to the water temperature at the time of highest IRWST water temperature. Containment pressure at the maximum IRWST water temperature is 1.055 kg/cm^2 (15 psi) higher than saturation pressure, which provides reasonable assurance that water temperature will not exceed the saturation temperature in the range of containment pressures analyzed.

B.5 Maximum Passive Heat Sink Temperature

This section describes the analyses that demonstrate that maximum surface temperatures of structures in containment, including wall and liner plate, do not exceed the design temperature limit for containment integrity during the entire range of transients for the anlayzed accidents.

The LOCA (DEDLSB with maximum SI) and MSLB (75 percent power with loss of a CSS train) that produce highest saturated temperatures are chosen for the calculation of maximum surface temperature of structures in containment. Table B-5A and Table B-5B present the highest temperature of each passive heat sink for the selected LOCA and MSLB, respectively.

In the LOCA case, the containment atmosphere is maintained at a saturated condition corresponding to the steam partial pressure. Figure B-19A shows that the highest surface temperatures of all the passive heat sinks are, without exception, lower than the maximum saturated temperature of 135.28 ^{o}C (275.5 ^{o}F).

For the MSLB, as shown in Figure B-19B, the highest surface temperature of structures is no higher than the maximum saturated temperature even though the containment atmosphere is maintained at a superheated state since the super heated vapor condenses rapidly after contacting the subcooled surfaces of structures in containment. The maximum saturated temperature of the MSLB case is 134.39 ^{o}C (273.9 ^{o}F).

It is demonstrated that the highest surface temperature of containment structures is no higher than the maximum saturation temperature corresponding to the steam partial pressure and the maximum saturated temperature is also lower than the containment design temperature of 143.33 ^{o}C (290 °F).

B.6 Conclusions

Appendix B describes the calculations using the APR1400 GOTHIC containment model presented in Appendix A. The containment pressure and temperature response to LOCA and MSLB events have been calculated to determine the limiting cases of accidents that produce not only the highest peak containment pressure and temperature, but also the maximum IRWST water temperature. All the results from the containment analyses are summarized in Table B-6.

The results show that the double-ended discharge leg slot break (DEDLSB) with maximum SI flow is estimated as the limiting case for peak containment pressure. The maximum atmosphere temperature of 170.32 ^oC (338.6 ^oF) is lower than the design temperature for EQ (182.22 ^oC [360 ^oF]). The maximum saturated temperature (135.28 ^oC [275.5 ^oF]), which limits the highest surface temperature of structures, is also no higher than the containment design temperature (143.33 ^oC [290 ^oF]). The maximum IRWST water temperature occurs in the LOCA case (DEDLSB with minimum SI). IRWST water is maintained in a subcooled state below the saturation condition corresponding to the containment pressure during all transients of an accident.

In conclusion, it was demonstrated that APR1400 containment design pressure provides more than a 10 percent margin above the maximum peak pressure in accordance with the requirements of General Design Criteria (GDC) 16 and 50. The maximum pressure at 24 hours satisfies the requirements of GDC 38 that containment pressure be less than one-half peak calculated pressure within 24 hours after accident initiation. With respect to containment temperature, reasonable assurance is provided that the maximum saturation temperature in a design basis LOCA, which is higher than the maximum surface temperature of structures in containment, is lower than the containment design limit.

Table B-1A Initial Conditions - LOCA Peak Pressure

Initial Conditions	Values	
	Design	LOCA
Containment building		
Atmosphere Pressure, psia	14.18~16.12	**16.12** (1)
Atmosphere Temperature, °F	50 ~ 120	120
Atmosphere Relative humidity (%)	0 ~ 100	0.0
Component Cooling Water Temperature, ℉	110 (2)	110
IRWST Water Temperature, ℉	50~120	120
Outside Air Temperature, ℉	50~120	N/A(3)
Containment Inner Wall Temperature, ℉	50~120	120
Water & N_2 gas in IRWST and SITs		
IRWST water Volume, ft³	83,818~89,721	89,721
N_2 gas in SI Tanks, lbm	7,106	7,106

Note

(1) The maximum initial pressure is determined based on LCO described in TS 3.6.4 with uncertainty, (14.7 + 1.0 [LCO max. value] + 0.42 [pressure indicator uncertainty]) psia.

(2) The CCW system and Service Water systems are not explicitly modeled. A conservatively high CCW water temperature of 110°F was used for the containment peak pressure and temperature analysis during the entire transient.

(3) Heat transfer to the outside of the containment is conservatively not modeled.

Table B-1B Sequence of Events – LOCA (DESLSB with Maximum SI Flow)

Time (sec)	Event	Values
0.00	Break occurs	—
4.41	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
14.01	Start safety injection tank (SIT) injection	—
19.19	First peak containment pressure (Blowdown phase)	3.138 kg/cm² (44.64 psig)
19.20	End of blowdown	—
	Start SI pump injection	—
63.80	SIT flow is turned down to low flow by fluidic device in SIT	—
104.76	Peak containment temperature	134.53 °C (274.16 °F)
105.36	Peak containment pressure	3.583 kg/cm² (50.96 psig)
110.20	End of reflood	
114.41	Start containment spray actuation	
125.0	End of post reflood	—
368.10	Safety injection tank empty	—
6,150.1	Time of depressurization of the containment at 50% of peak pressure	1.791 kg/cm² (25.48 psig)

Table B-1C Sequence of Events – LOCA (DESLSB with Minimum SI Flow)

Time (sec)	Event	Values
0.00	Break occurs	
4.41	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
14.01	Start safety injection tank (SIT) injection	—
19.19	First peak containment pressure (Blowdown phase)	3.138 kg/cm² (44.64 psig)
19.20	End of blowdown	—
	Start SI pump injection	
63.70	SIT flow is turned down to low flow by fluidic device in SIT	—
106.66	Peak containment temperature	134.67 °C (274.40 °F)
107.26	Peak containment pressure	3.596 kg/cm² (51.14 psig)
114.41	Start containment spray actuation	—
117.10	End of reflood	—
127.60	End of post reflood	—
368.30	Safety injection tank empty	—
6,078.7	Time of depressurization of the containment at 50% of peak pressure	1.798 kg/cm² (25.57 psig)

Table B-1D Sequence of Events – LOCA (DEDLSB with Maximum SI Flow)

Time (sec)	Event	Values
0.0	Break occurs	—
3.78	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
12.01	Start safety injection tank (SIT) injection	—
17.89	First peak containment pressure (Blowdown phase)	3.135 kg/cm² (44.59 psig)
19.75	End of blowdown	—
	Start SI pump injection	—
49.35	SIT flow is turned down to low flow by fluidic device in SIT	—
113.78	Start containment spray actuation	—
199.75	End of reflood	—
322.91	Peak containment temperature	135.27 °C (275.48 °F)
323.81	Peak containment pressure	3.662 kg/cm² (52.09 psig)
360.25	End of post-reflood	—
372.05	Safety injection tank empty	
7,542.8	Time of depressurization of the containment at50 % of peak pressure	1.831 kg/cm² (26.04 psig)

Table B-1E Sequence of Events – LOCA (DEDLSB with Minimum SI Flow)

Time (sec)	Event	Values
0.0	Break occurs	—
3.78	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
12.01	Start safety injection tank (SIT) injection	—
17.89	First peak containment pressure (Blowdown phase)	3.135 kg/cm² (44.59 psig)
19.75	End of blowdown	—
	Start SI pump injection	—
49.35	SIT flow is turned down to low flow by fluidic device in SIT	—
113.78	Start containment spray actuation	—
200.05	End of reflood	—
317.71	Peak containment temperature	135.19 °C (275.35 °F)
319.51	Peak containment pressure	3.654 kg/cm² (51.97 psig)
369.65	Safety injection tank empty	—
549.15	End of post-reflood	—
7,889.9	Time of depressurization of the containment at 50 % of peak pressure	1.826 kg/cm² (25.97 psig)

Table B-1F Sequence of Events – LOCA (DEHLSB with Maximum SI Flow)

Time (sec)	Event	Values
0.0	Break occurs	—
2.52	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
6.80	Start SI pump injection	—
13.09	Peak containment temperature	133.11 °C (271.60 °F)
13.40	End of blowdown	—
13.59	Peak containment pressure	3.441 kg/cm² (48.94 psig)
4,189.6	Time of depressurization of the containment at 50% of peak pressure	1.720 kg/cm² (24.47 psig)

Table B-1G Summary of LOCA Peak Pressure

Break Location	DESLSB[(1)] Maximum SI Flow	DESLSB Minimum SI Flow	DEDLSB[(2)] Maximum SI Flow	DEDLSB Minimum SI Flow	DEHLSB[(3)] Maximum SI Flow
Total Break Area, $m^2(ft^2)$	0.9121 (9.813)	0.9121 (9.813)	0.9121 (9.813)	0.9121 (9.813)	1.7877 (19.234)
Peak Pressure, kg/cm^2A (psia) [psig]	4.617 (65.66) [50.96]	4.629 (65.84) [51.14]	**4.696 (66.79) [52.09]**	4.687 (66.67) [51.97]	4.474 (63.64) [48.94]
Time of Peak Pressure (sec)	105.4	107.3	323.8	319.5	13.6
Peak Temperature, ℃(°F)	134.53 (274.16)	134.67 (274.40)	135.27 (275.48)	135.19 (275.35)	133.11 (271.60)
Time of Peak Temperature (sec)	104.8	106.7	322.9	317.7	13.1
Max. Saturated Temperature, ℃(°F)	134.54 (274.17)	134.67 (274.41)	**135.27 (275.49)**	135.20 (275.36)	133.04 (271.47)
Design Margin (%)	15.1	14.8	13.2	13.4	18.4

Note
(1) DESLSB: double-ended suction leg slot break
(2) DEDLSB: double-ended discharge leg slot break
(3) DEHLSB: double-ended hot leg slot break

Table B-2A Initial Conditions - MSLB Peak Temperature

Initial Conditions	Values	
	Design	MSLB
Containment building		
Atmosphere Pressure, psia	14.18~16.12	**14.18** [(1)]
Atmosphere Temperature, ℉	50 ~ 120	120
Atmosphere Relative humidity (%)	0 ~ 100	0.0
Component Cooling Water Temperature, ℉	110	110
IRWST Water Temperature, ℉	50~120	120
Outside Air Temperature, ℉	50~120	N/A
Containment Inner Wall Temperature, ℉	50~120	120
IRWST water Volume, ft^3	83,818~89,721	89,721

Note

The MSLB limiting temperature case conservatively uses the minimum initial pressure, (14.7-0.1[LCO min. value] - 0.42[indicator uncertainty]) psia.

Table B-2B Sequence of Events – MSLB (102% Power, Loss of a CSS train)

Time (sec)	Events	Values
0.0	Break occurs	—
3.89	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.20	High containment pressure reactor trip signal	—
5.30	Reactor trip breakers open, turbine admission valves	—
10.40	Main steam isolation valves closed	—
15.40	Main feedwater isolation valves closed	—
34.59	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
124.59	Start containment spray injection	—
125.19	Peak containment temperature	167.66 °C (333.80 °F)
344.89	Peak containment pressure	3.210 kg/cm² (45.66 psig)
1,800.0	End of blowdown	—
3,147.0	Time of depressurization of the containment at 50% of peak pressure	1.602 kg/cm² (22.79 psig)

Table B-2C Sequence of Events – MSLB (102% Power, MSIV single failure)

Time (sec)	Events	Values
0.0	Break occurs	—
3.89	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.20	High containment pressure reactor trip signal	—
5.30	Reactor trip breakers open, turbine admission valves	—
10.40	Main steam isolation valves closed	—
15.40	Main feedwater isolation valves closed	—
21.19	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
111.19	Start containment spray injection	—
111.79	Peak containment temperature	170.32 °C (338.58 °F)
321.19	Peak containment pressure	3.196 kg/cm² (45.46 psig)
1,800.0	End of blowdown	—
2,236.3	Time of depressurization of the containment at 50% of peak pressure	1.593 kg/cm² (22.66 psig)

Table B-2D Sequence of Events – MSLB (75% Power, Loss of a CSS train)

Time (sec)	Events	Values
0.0	Break occurs	—
3.72	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.00	High containment pressure reactor trip signal	—
5.10	Reactor trip breakers open, turbine admission valves	—
10.20	Main steam isolation valves closed	—
15.20	Main feedwater isolation valves closed	—
35.29	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
125.29	Start containment spray injection	—
125.79	Peak containment temperature	166.33 °C (331.40 °F)
436.29	Peak containment pressure	3.352 kg/cm² (47.67 psig)
1,800.0	End of blowdown	—
3,227.3	Time of depressurization of the containment at 50% of peak pressure	1.676 kg/cm² (23.83 psig)

Table B-2E Sequence of Events – MSLB (75% Power, MSIV single failure)

Time (sec)	Events	Values
0.0	Break occurs	—
3.72	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.00	High containment pressure reactor trip signal	—
5.10	Reactor trip breakers open, turbine admission valves	—
10.20	Main steam isolation valves closed	—
15.20	Main feedwater isolation valves closed	—
21.69	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
111.69	Start containment spray injection	—
112.19	Peak containment temperature	168.13°C (334.64 °F)
392.89	Peak containment pressure	3.256 kg/cm² (46.31 psig)
1,800.0	End of blowdown	—
2,316.7	Time of depressurization of the containment at 50% of peak pressure	1.625 kg/cm² (23.12 psig)

Table B-2F Sequence of Events – MSLB (50% Power, Loss of a CSS train)

Time (sec)	Events	Values
0.0	Break occurs	—
3.92	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
4.90	High containment pressure reactor trip signal	—
5.00	Reactor trip breakers open, turbine admission valves	—
10.10	Main steam isolation valves closed	—
15.10	Main feedwater isolation valves closed	—
34.49	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
124.49	Start containment spray injection	—
125.19	Peak containment temperature	168.37 °C (335.06 °F)
345.39	Peak containment pressure	3.212 kg/cm² (45.68 psig)
1,800.0	End of blowdown	—
3,167.2	Time of depressurization of the containment at 50% of peak pressure	1.602 kg/cm² (22.79 psig)

Table B-2G Sequence of Events – MSLB (50% Power, MSIV single failure)

Time (sec)	Events	Values
0.0	Break occurs	—
3.62	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
4.90	High containment pressure reactor trip signal	—
5.00	Reactor trip breakers open, turbine admission valves	—
10.10	Main steam isolation valves closed	—
15.10	Main feedwater isolation valves closed	—
21.99	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
111.99	Start containment spray injection	—
112.29	Peak containment temperature	166.24 °C (331.24 °F)
400.19	Peak containment pressure	3.083 kg/cm² (43.85 psig)
1,800.0	End of blowdown	—
2,336.5	Time of depressurization of the containment at 50% of peak pressure	1.536 kg/cm² (21.84 psig)

Table B-2H Sequence of Events – MSLB (20% Power, Loss of a CSS train)

Time (sec)	Events	Values
0.0	Break occurs	—
3.57	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.20	High containment pressure reactor trip signal	—
5.30	Reactor trip breakers open, turbine admission valves	—
10.40	Main steam isolation valves closed	—
15.40	Main feedwater isolation valves closed	—
41.59	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
131.29	Peak containment temperature	159.98 °C (319.96 °F)
131.59	Start containment spray injection	—
767.70	Peak containment pressure	3.046 kg/cm² (43.33 psig)
1,800.0	End of blowdown	—
3,367.7	Time of depressurization of the containment at 50% of peak pressure	1.521 kg/cm² (21.63 psig)

Table B-2I Sequence of Events – MSLB (20% Power, MSIV single failure)

Time (sec)	Events	Values
0.0	Break occurs	—
3.57	Containment pressure reaches reactor trip analysis setp. and main steam isolation signal analysis setpoint.	0.422 kg/cm² (6.0 psig)
4.85	High containment pressure reactor trip signal	—
4.95	Reactor trip breakers open, turbine admission valves	—
10.05	Main steam isolation valves closed	—
15.05	Main feedwater isolation valves closed	—
24.69	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
24.79	Peak containment temperature	163.53 °C (326.35 °F)
114.69	Start containment spray injection	—
544.19	Peak containment pressure	2.815 kg/cm² (40.04 psig)
1,800.0	End of blowdown	—
2,497.6	Time of depressurization of the containment at 50% of peak pressure	1.403 kg/cm² (19.96 psig)

Table B-2J Sequence of Events – MSLB (0% Power, Loss of a CSS train)

Time (sec)	Events	Values
0.0	Break occurs	—
4.54	Containment pressure reaches reactor trip analysis setpoint and main steam isolation signal analysis setpoint	0.422 kg/cm² (6.0 psig)
5.20	High containment pressure reactor trip signal	—
5.30	Reactor trip breakers open, turbine admission valves	—
10.40	Main steam isolation valves closed	—
15.40	Main feedwater isolation valves closed	—
41.89	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
131.89	Start containment spray injection	—
132.49	Peak containment temperature	164.59 °C (328.26 °F)
767.24	Peak containment pressure	3.278 kg/cm² (46.62 psig)
1,800.0	End of blowdown	—
3,407.8	Time of depressurization of the containment at 50% of peak pressure	1.635 kg/cm² (23.25 psig)

Table B-2K Sequence of Events – MSLB (0% Power, MSIV single failure)

Time (sec)	Events	Values
0.0	Break occurs	—
4.54	Containment pressure reaches reactor trip analysis setp. and main steam isolation signal analysis setp.	0.422 kg/cm² (6.0 psig)
5.80	High containment pressure reactor trip signal	—
5.90	Reactor trip breakers open, turbine admission valves	—
11.00	Main steam isolation valves closed	—
16.00	Main feedwater isolation valves closed	—
28.29	Containment pressure Hi-Hi setpoint	1.547 kg/cm² (22.0 psig)
118.29	Start containment spray injection	—
118.89	Peak containment temperature	166.03 °C (330.85 °F)
379.39	Peak containment pressure	3.103 kg/cm² (44.13 psig)
1,800.0	End of blowdown	—
2,497.8	Time of depressurization of the containment at 50% of peak pressure	1.544 kg/cm² (21.97 psig)

Table B-2L Summary of MSLB Peak Temperature

Break Location	102% Power		75% Power		50% Power
	CSS Failure	MSIV Failure	CSS Failure	MSIV Failure	CSS Failure
Total Break Area, m^2(ft^2)	0.849 (9.134)	0.849 (9.134)	0.849 (9.134)	0.849 (9.134)	0.849 (9.134)
Peak Pressure, kg/cm^2A (psia) [psig]	4.244 (60.36) [45.66]	4.230 (60.16) [45.46]	4.385 (62.37) [47.67]	4.289 (61.01) [46.31]	4.245 (60.38) [45.68]
Time of Peak Pressure (sec)	344.9	321.2	436.3	392.9	345.4
Peak Temperature, ℃(°F)	167.66 (333.80)	170.32 (338.58)	166.33 (331.40)	168.13 (334.64)	168.37 (335.06)
Time of Peak Temperature (sec)	125.2	111.8	125.8	112.2	125.2
Max. Saturated Temperature, ℃(°F)	132.84 (271.12)	132.70 (270.87)	134.38 (273.88)	133.36 (272.05)	132.86 (271.15)
Design Margin (%)	23.90	24.24	20.54	22.82	23.87

Break Location	50% Power	20% Power		0% Power	
	MSIV Failure	CSS Failure	MSIV Failure	CSS Failure	MSIV Failure
Total Break Area, m^2(ft^2)	0.849 (9.134)	0.818 (8.801)	0.818 (8.801)	0.381 (4.099)	0.381 (4.099)
Peak Pressure, kg/cm^2A (psia) [psig]	4.116 (58.55) [43.85]	4.080 (58.03) [43.33]	3.849 (54.74) [40.04]	4.312 (61.32) [46.62]	4.136 (58.83) [44.13]
Time of Peak Pressure (sec)	400.2	767.7	544.2	767.2	379.4
Peak Temperature, ℃(°F)	166.24 (331.24)	159.98 (319.96)	163.53 (326.35)	164.59 (328.26)	166.03 (330.85)
Time of Peak Temperature (sec)	112.3	131.3	24.8	132.5	118.9
Max. Saturated Temperature, ℃(°F)	131.44 (268.59)	131.01 (267.83)	128.29 (262.91)	133.58 (272.45)	131.66 (268.99)
Design Margin (%)	26.92	27.79	33.27	22.29	26.45

Table B-2M Comparison of Re-vaporization for MSLB Peak Temperature

ID	Accidents	Description	Re-evaporation	
			Default	8.0 %
1	102% Power CSS single-failure	Peak pressure, psia	60.36	60.38
		Peak temperature, °F	333.80	309.77
		Sat. temperature, °F	271.12	271.18
2	102% Power MSIV single-failure	Peak pressure, psia	60.16	60.19
		Peak temperature, °F	**338.58**	**323.20**
		Sat. temperature, °F	270.87	270.93
3	75% Power CSS single-failure	**Peak pressure, psia**	**62.37**	**62.41**
		Peak temperature, °F	331.40	308.20
		Sat. temperature, °F	**273.88**	**273.95**
4	75% Power MSIV single-failure	Peak pressure, psia	61.01	61.04
		Peak temperature, °F	334.64	322.08
		Sat. temperature, °F	272.05	272.10
5	50% Power CSS single-failure	Peak pressure, psia	60.38	60.41
		Peak temperature, °F	335.06	310.84
		Sat. temperature, °F	271.15	271.23
6	50% Power MSIV single-failure	Peak pressure, psia	58.55	58.58
		Peak temperature, °F	331.24	321.30
		Sat. temperature, °F	268.59	268.65
7	20% Power CSS single-failure	Peak pressure, psia	58.03	58.05
		Peak temperature, °F	319.96	302.76
		Sat. temperature, °F	267.83	267.87
8	20% Power MSIV single-failure	Peak pressure, psia	54.74	54.77
		Peak temperature, °F	326.35	318.96
		Sat. temperature, °F	262.91	262.97
9	0% Power CSS single-failure	Peak pressure, psia	61.32	61.31
		Peak temperature, °F	328.26	303.42
		Sat. temperature, °F	272.45	272.45
10	0% Power MSIV single-failure	Peak pressure, psia	58.83	58.86
		Peak temperature, °F	330.85	313.75
		Sat. temperature, °F	268.99	269.05

Table B-3A Initial Conditions - MSLB Peak Pressure

Initial Conditions	Values	
	Design	MSLB
Containment building		
Atmosphere Pressure, psia	14.18~16.12	**16.12**
Atmosphere Temperature, ℉	50 ~ 120	120
Atmosphere Relative humidity (%)	0 ~ 100	0.0
Component Cooling Water Temperature, ℉	110	110
IRWST Water Temperature, ℉	50~120	120
Outside Air Temperature, ℉	50~120	N/A
Containment Inner Wall Temperature, ℉	50~120	120
IRWST water Volume, ft^3	83,818~89,721	89,721

Table B-3B Comparison of Re-vaporization for MSLB Peak Pressure

ID	Accidents	Description	Re-vaporization	
			GOTHIC Default	8.0 %
1	102% Power	Peak pressure, psia	62.85	62.86
	CSS single-failure	Peak temperature, °F	329.67	306.71
2	102% Power	Peak pressure, psia	62.63	62.65
	MSIV single-failure	Peak temperature, °F	334.46	314.28
3	75% Power	Peak pressure, psia	**64.83**	**64.85**
	CSS single-failure	Peak temperature, °F	327.39	304.96
4	75% Power	Peak pressure, psia	63.45	63.47
	MSIV single-failure	Peak temperature, °F	330.54	312.90
5	50% Power	Peak pressure, psia	62.41	62.44
	CSS single-failure	Peak temperature, °F	324.01	301.08
6	50% Power	Peak pressure, psia	60.97	60.99
	MSIV single-failure	Peak temperature, °F	327.35	312.10
7	20% Power	Peak pressure, psia	60.39	60.40
	CSS single-failure	Peak temperature, °F	316.10	295.98
8	20% Power	Peak pressure, psia	57.09	57.10
	MSIV single-failure	Peak temperature, °F	320.90	309.66
9	0% Power	Peak pressure, psia	63.70	63.69
	CSS single-failure	Peak temperature, °F	323.84	300.76
10	0% Power	Peak pressure, psia	61.24	61.26
	MSIV single-failure	Peak temperature, °F	326.71	306.02

Table B-4A Initial Conditions for Maximum IRWST Water Temperature

Initial Conditions	Values	
	Design	Analysis
Containment building		
Atmosphere Pressure, psia	14.18~16.12	14.18
Atmosphere Temperature, °F	50 ~ 120	120
Atmosphere Relative humidity (%)	0 ~ 100	100
Component Cooling Water Temperature, ℉	110	110
IRWST Water Temperature, ℉	50~120	120
Outside Air Temperature, ℉	50~120	N/A
Containment Inner Wall Temperature, ℉	50~120	120
Water & N_2 gas in IRWST and SITs		
IRWST water Volume, ft³	83,818~89,721	**83,818**
N_2 gas in SI Tanks, lbm	7,106	7,106

Table B-4B Summary of Maximum IRWST Water Temperature (LOCA)

Break Location	DESLSB	DESLSB	DEDLSB	DEDLSB	DEHLSB
	Maximum SI Flow	Minimum SI Flow	Maximum SI Flow	Minimum SI Flow	Maximum SI Flow
Max. IRWST Water Temp.(°F)	214.8	214.8	217.3	**217.8**	210.6
Time at Max. Temperature (°F)	27,708	27,607	25,910	**25,510**	31,810
IRWST Temp. at 10^6 sec (°F)	145.5	145.5	145.5	**145.5**	145.5

Table B-5A Maximum Surface Temperature of Each Passive Heat Sink (LOCA – DEDLSB with Max. SI Flow)

No.	Description	Time (sec)	Max. Temp. (°F)
1	Containment Cylinder Wall above EL. 100'	388	262.0
2	Containment Dome	1694	230.3
3	Containment Basement	0	120.0
4	Concrete Embeded Carbon Steel	796	263.8
5	Concrete without Embedment Plate(C,A)	360	263.4
6	Refuel Pool with SS Liner	362	275.0
7	IRWST Outside Upper Slab & HVT	0	120.0
8	Polar Crane and Bridge,M	447	270.5
9	Safety Injection Tank	1494	254.7
10	Group A(Structural Steel & PWR),C	541	268.6
11	Group B(Grating & Metal Decking),C	360	275.1
12	Group C(Pipe Support & HVAC),P,C,M	360	274.8
13	Group D(Miscellaneous Steel)A,J,M	360	275.1
14	Group E(Electrical Components),E	341	**275.3**
15	Group F(Misc. Steel from P, A, J, N(CS))	360	274.4
16	Group G(Misc. Steel from P, N, J(SS))	365	274.8
17	Group J(CS from NSSS DOOSAN)	367	274.6
18	Group K(SS from NSSS DOOSAN)	613	267.5

Table B-5B Maximum Surface Temperature of Each Passive Heat Sink
(MSLB – 75% Power, Loss of a CSS Train)

No.	Description	Time (sec)	Max. Temp. (°F)
1	Containment Cylinder Wall above EL. 100'	572	263.4
2	Containment Dome	1833	244.8
3	Containment Basement	0	120.0
4	Concrete Embeded Carbon Steel	1070	268.4
5	Concrete without Embedment Plate(C,A)	505	263.8
6	Refuel Pool with SS Liner	484	273.6
7	IRWST Outside Upper Slab & HVT	0	120.0
8	Polar Crane and Bridge,M	610	271.6
9	Safety Injection Tank	1803	265.4
10	Group A(Structural Steel & PWR),C	705	270.7
11	Group B(Grating & Metal Decking),C	477	273.7
12	Group C(Pipe Support & HVAC),P,C,M	487	273.5
13	Group D(Miscellaneous Steel)A,J,M	476	273.7
14	Group E(Electrical Components),E	468	**273.8**
15	Group F(Misc. Steel from P, A, J, N(CS))	501	273.3
16	Group G(Misc. Steel from P, N, J(SS))	493	273.5
17	Group J(CS from NSSS DOOSAN)	500	273.4
18	Group K(SS from NSSS DOOSAN)	787	270.2

Table B-6 Summary of Containment Integrity Analyses

Component	Peak condition	Accident	Unit	Calculated value	Design limit	Margin
Containment	Maximum Peak pressure	LOCA - DEDLSB with Max. SI	psig (kg_f/cm^2)	52.09 (3.662)	60.0 (1) (4.218)	13.2%
	Max. Pressure ratio @ 24 hours	LOCA - DEHLSB with Max. SI	%	29.8	50.0	20.2
	Max. Peak Temperature	MSLB - 102% power with MSIV single-failure	°F (°C)	338.6 (2) (170.3)	360.0 (3) (182.2)	21.4 (11.9)
	Max. Saturated Temperature	LOCA - DEDLSB with Max. SI	°F (°C)	275.5 (135.3)	290.0 (4) (143.3)	14.5 (8.1)
IRWST	Max. Water Temperature	LOCA - DEDLSB with Min. SI	°F (°C)	216.9 (102.7)	Subcooled	N/A

Note
(1) Containment design pressure
(2) The maximum temperature is calculated based on the use of the GOTHIC default re-evaporation option.
(3) Maximum containment atmosphere temperature that ensures the EQ for safety-related equipments in containment.
(4) Containment design temperature (Allowable maximum surface temperature of the inner structures within containment)

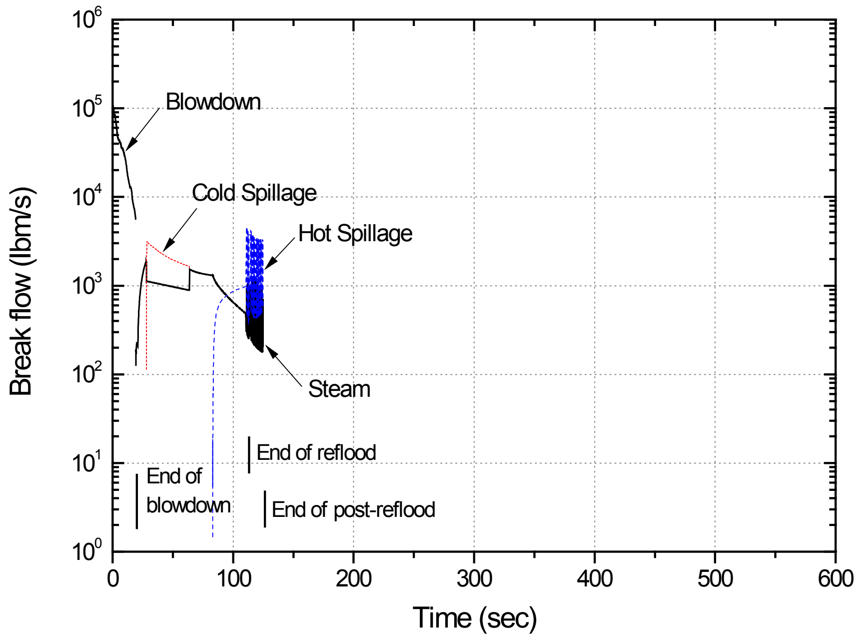

Figure B-1A LOCA Mass Release (DESLSB with Max. SI)

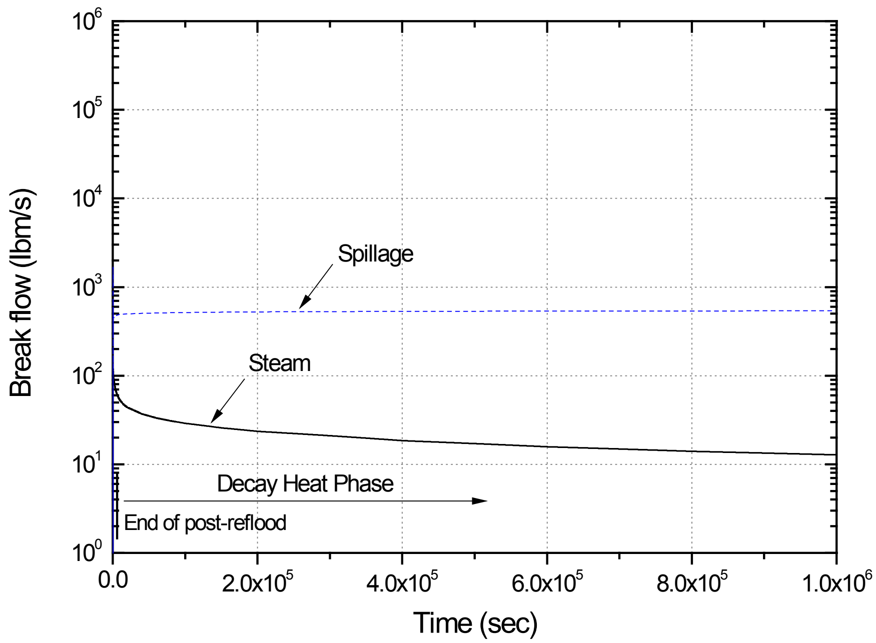

Figure B-1B LOCA Mass Release (DESLSB with Max. SI) (Long term)

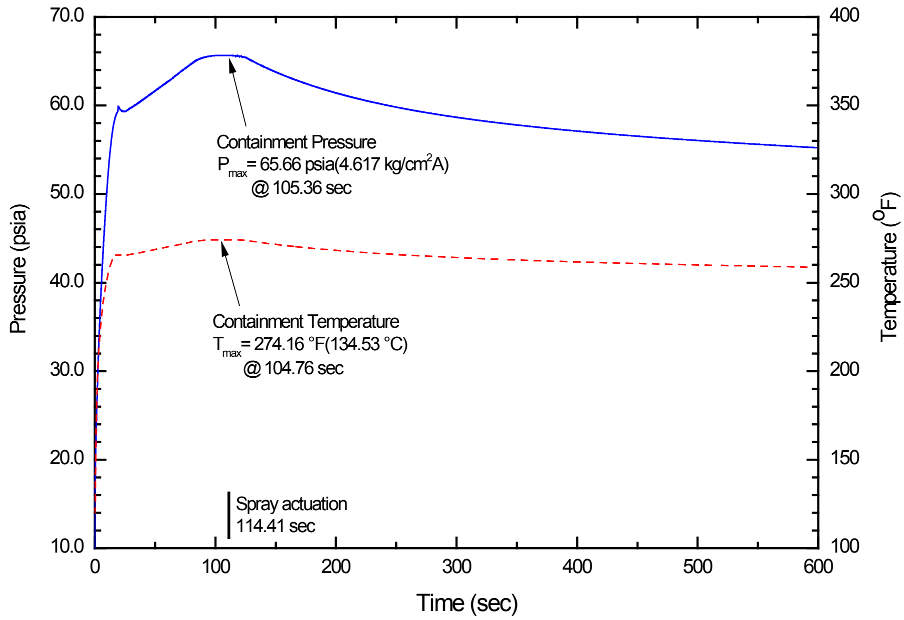

Figure B-1C LOCA Containment P/T Transients (DESLSB with Max.SI)

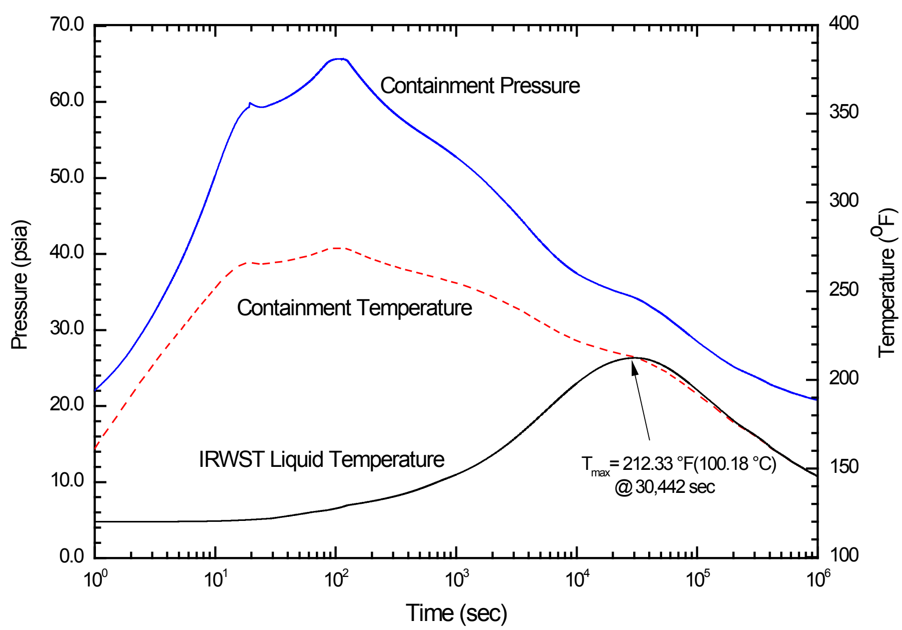

Figure B-1D LOCA Containment P/T Transients (DESLSB with Max.SI) (Long term)

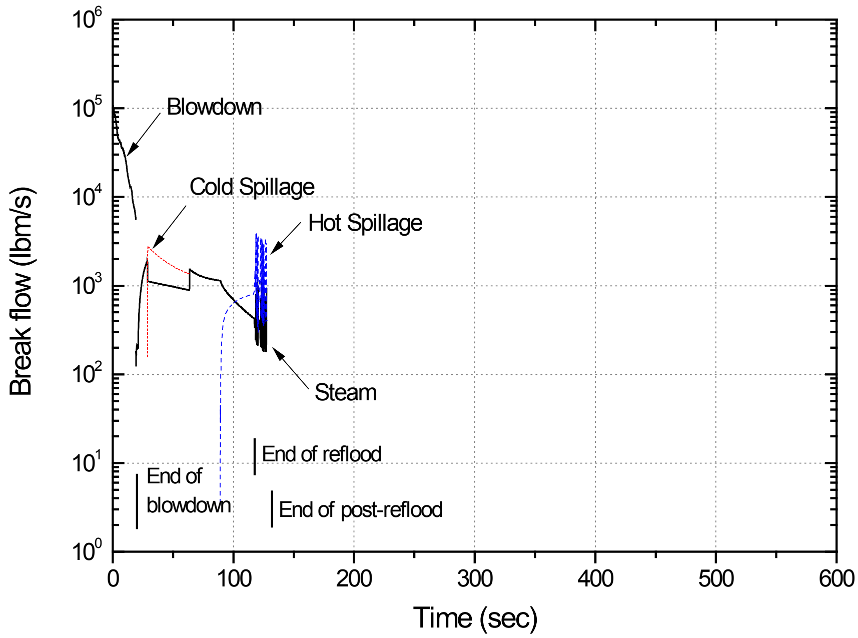

Figure B-2A LOCA Mass Release (DESLSB with Min. SI)

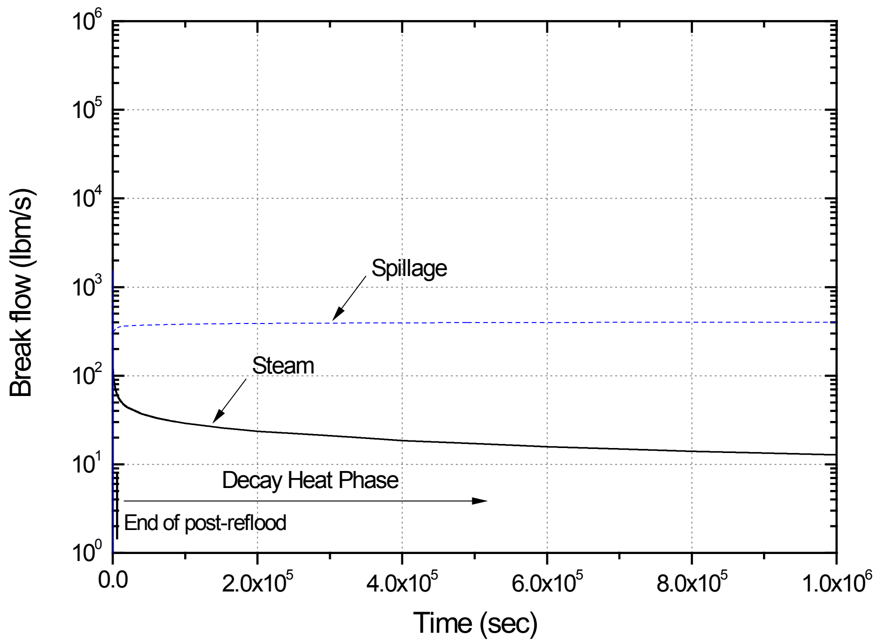

Figure B-2B LOCA Mass Release (DESLSB with Min. SI) (Long term)

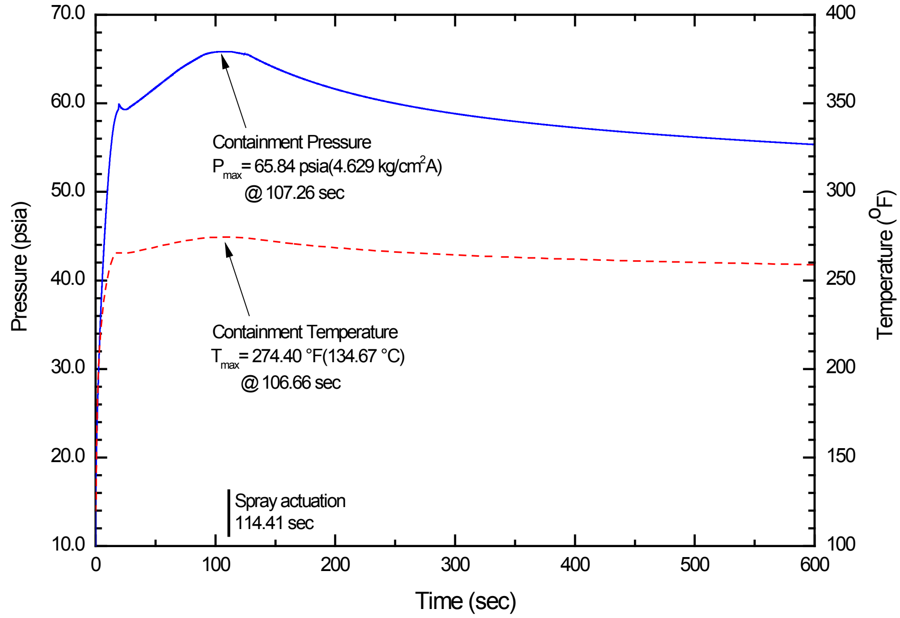

Figure B-2C LOCA Containment P/T Transients (DESLSB with Min.SI)

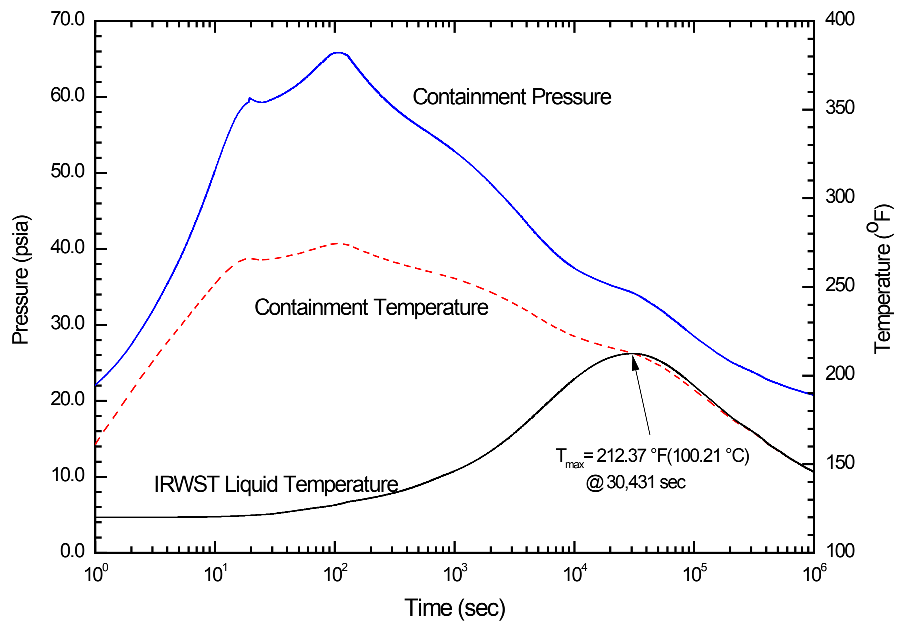

Figure B-2D LOCA Containment P/T Transients (DESLSB with Min.SI) (Long term)

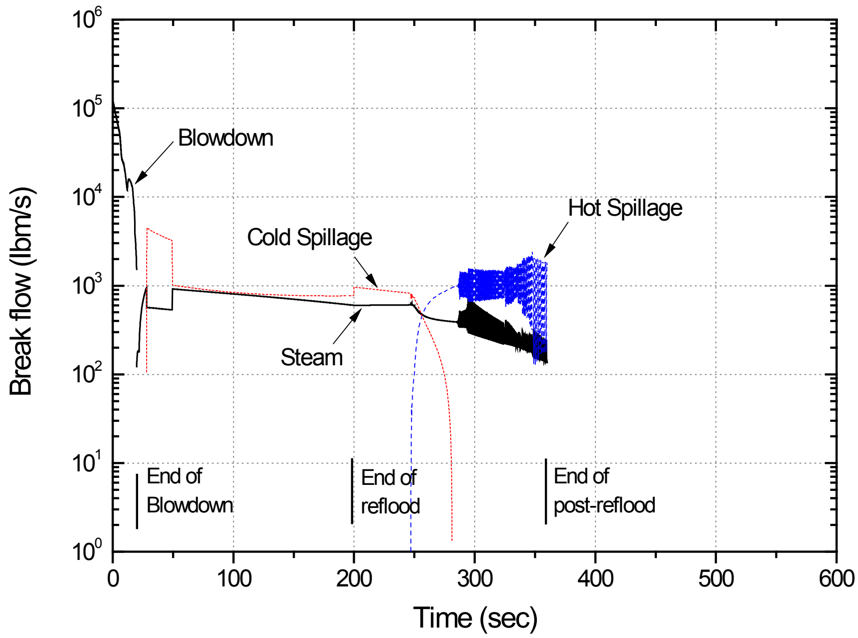

Figure B-3A LOCA Mass Release (DEDLSB with Max. SI)

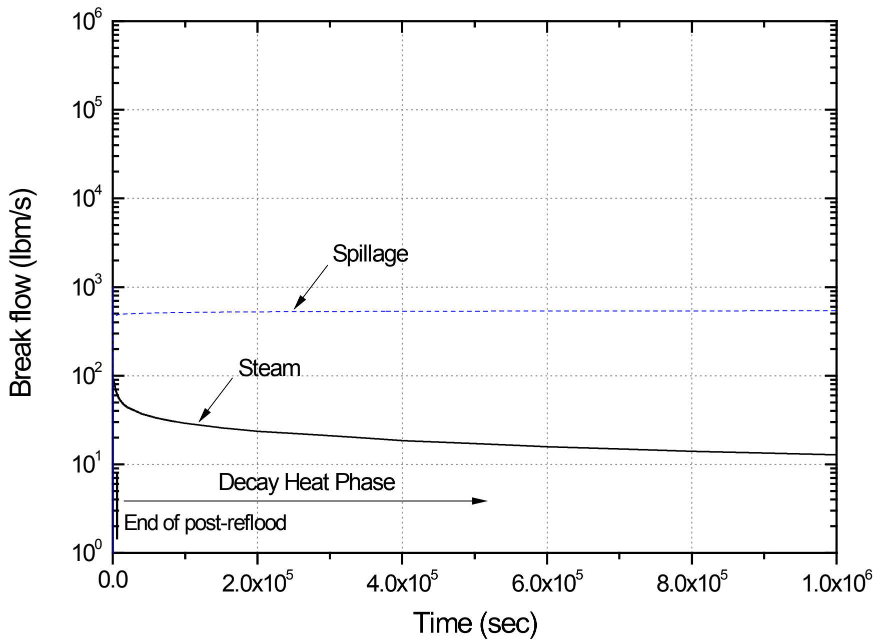

Figure B-3B LOCA Mass Release (DEDLSB with Max. SI) (Long term)

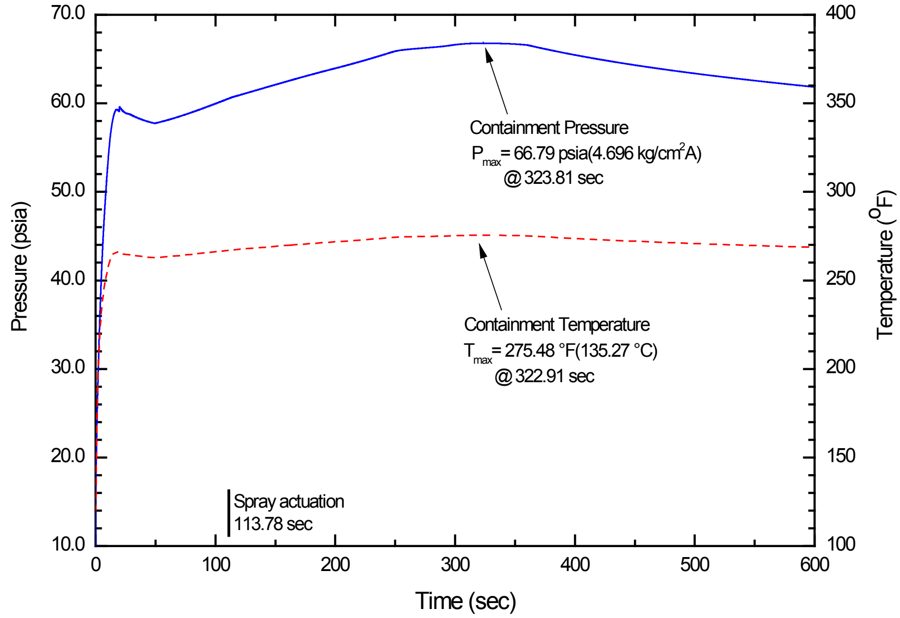

Figure B-3C LOCA Containment P/T Transients (DEDLSB with Max.SI)

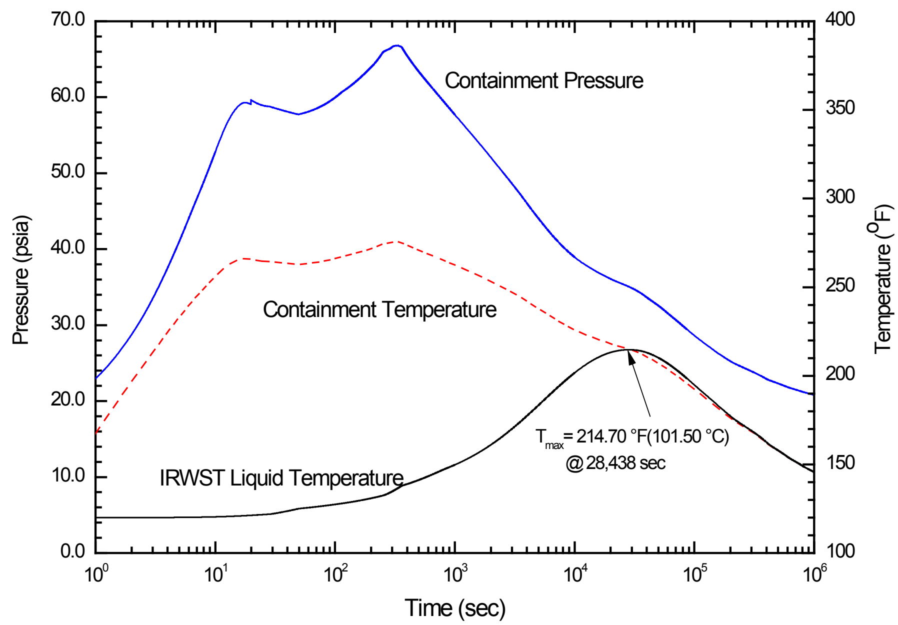

Figure B-3D LOCA Containment P/T Transients (DEDLSB with Max.SI) (Long term)

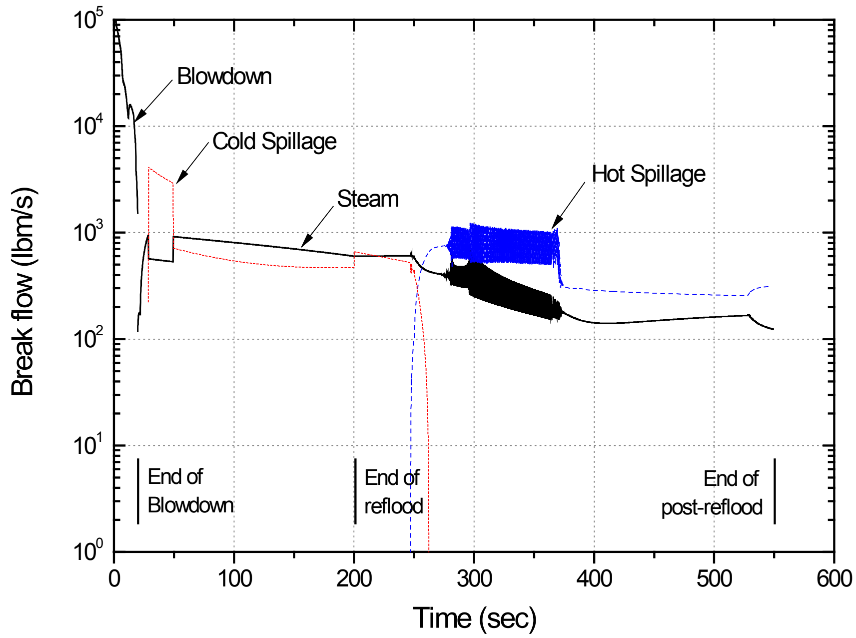

Figure B-4A LOCA Mass Release (DEDLSB with Min. SI)

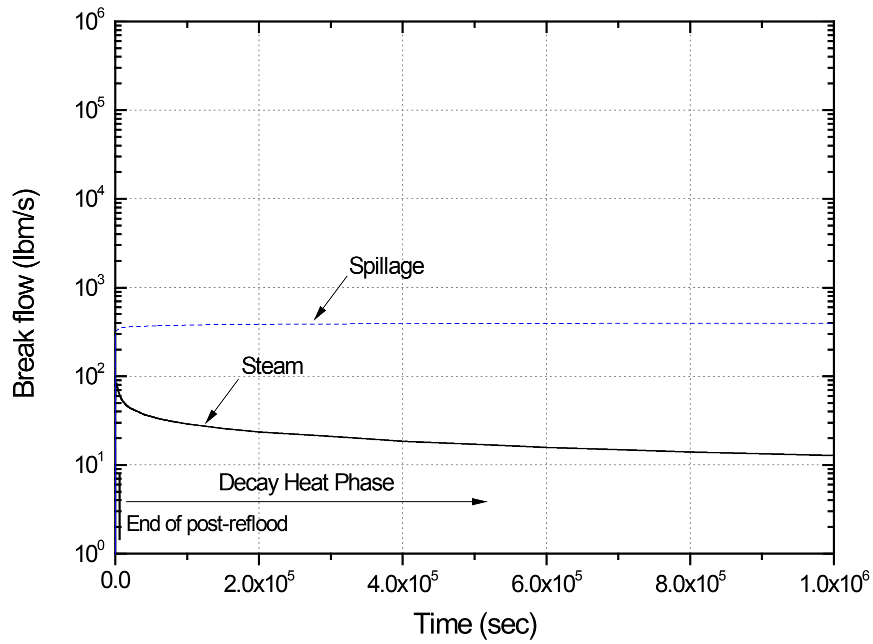

Figure B-4B LOCA Mass Release (DEDLSB with Min. SI) (Long term)

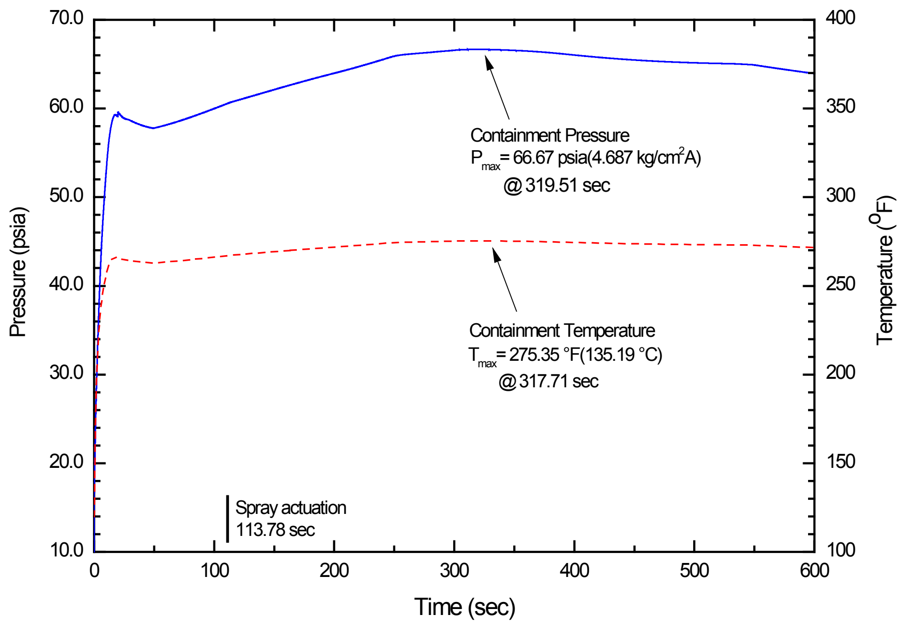

Figure B-4C LOCA Containment P/T Transients (DEDLSB with Min.SI)

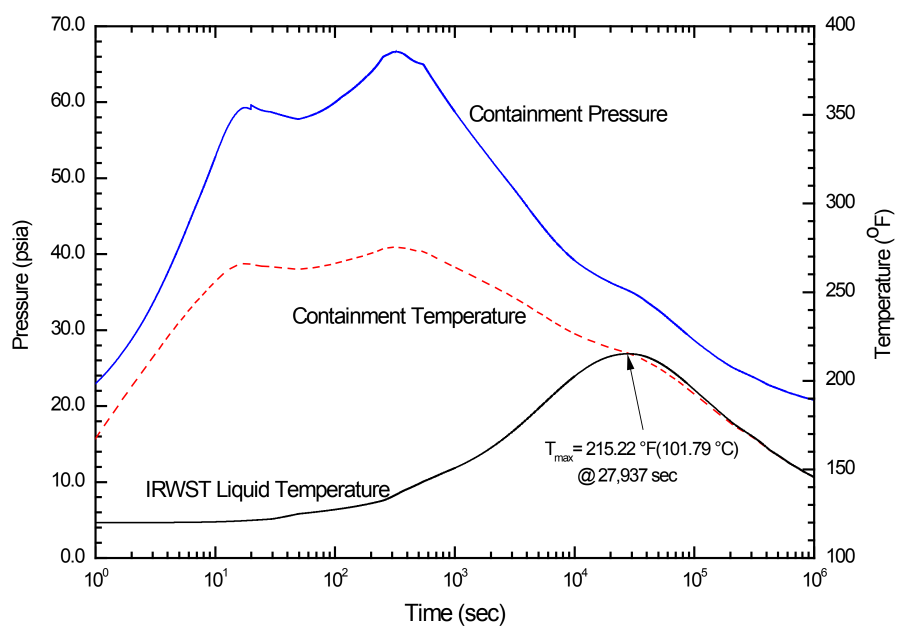

Figure B-4D LOCA Containment P/T Transients (DEDLSB with Min.SI) (Long term)

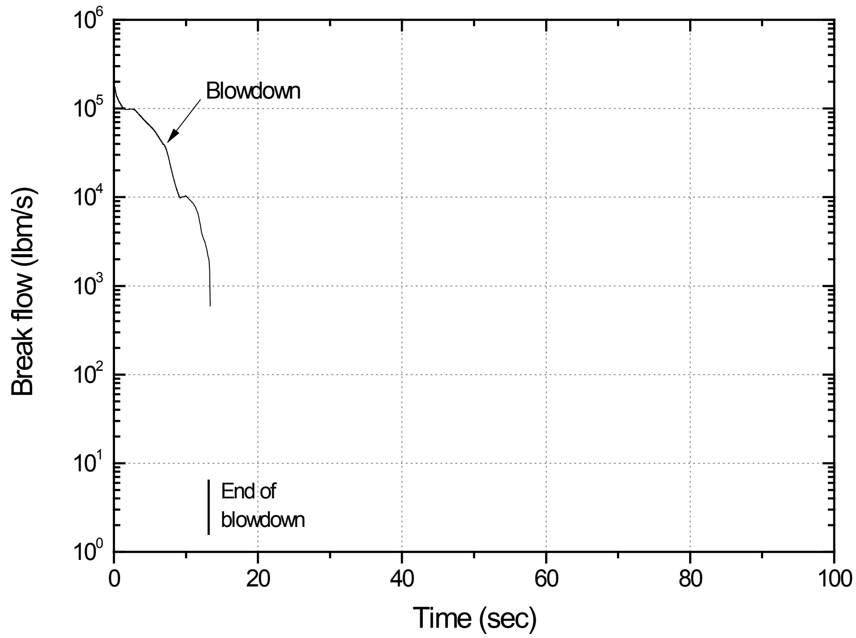

Figure B-5A LOCA Mass Release (DEHLSB with Max. SI)

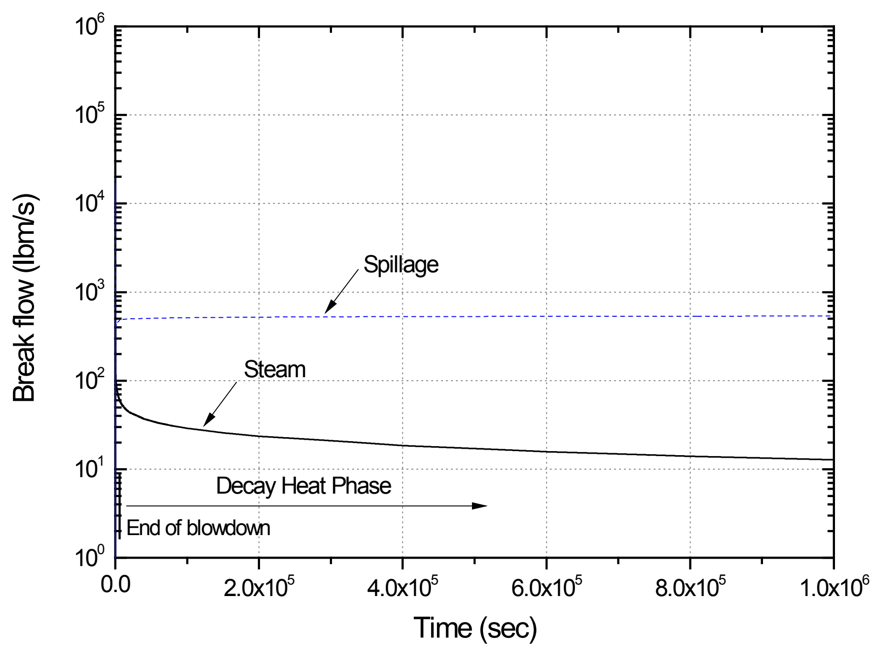

Figure B-5B LOCA Mass Release (DEHLSB with Max. SI) (Long term)

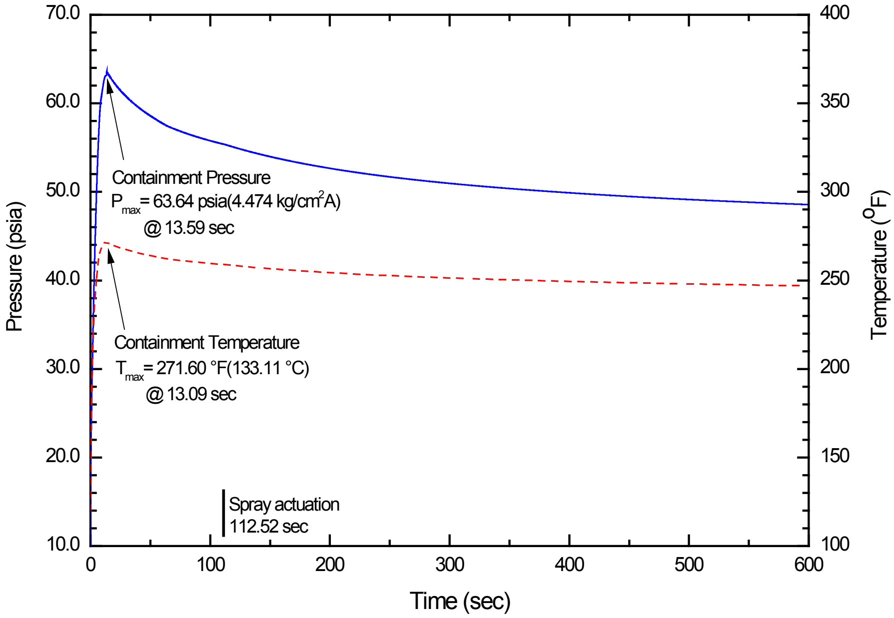

Figure B-5C LOCA Containment P/T Transients (DEHLSB with Max.SI)

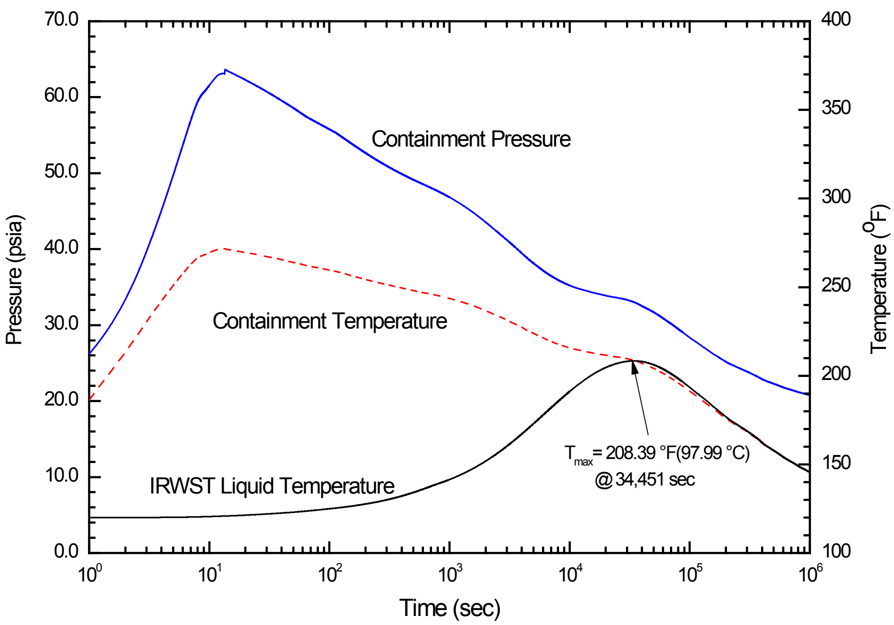

Figure B-5D LOCA Containment P/T Transients (DEHLSB with Max.SI) (Long term)

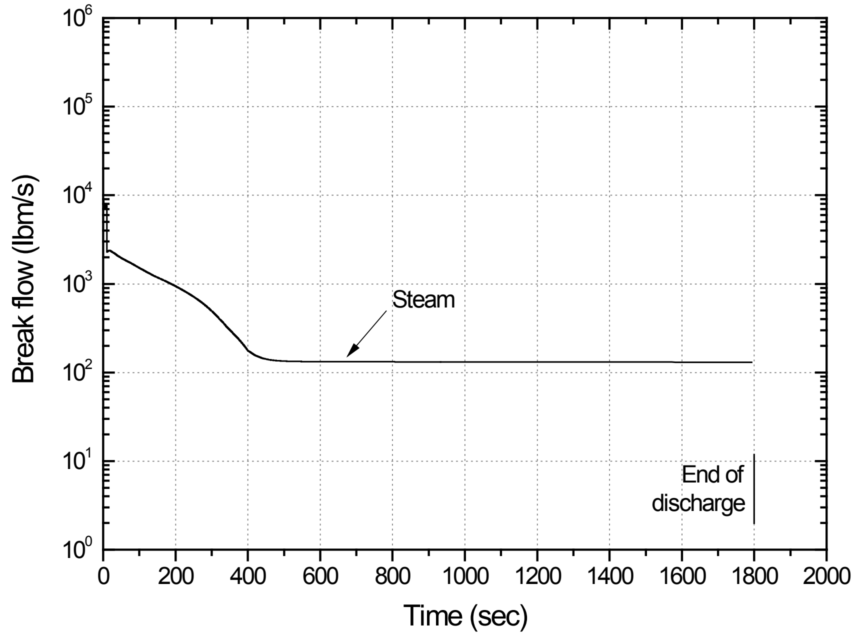

Figure B-6A MSLB Mass Release (102% Power, Loss of a CSS train)

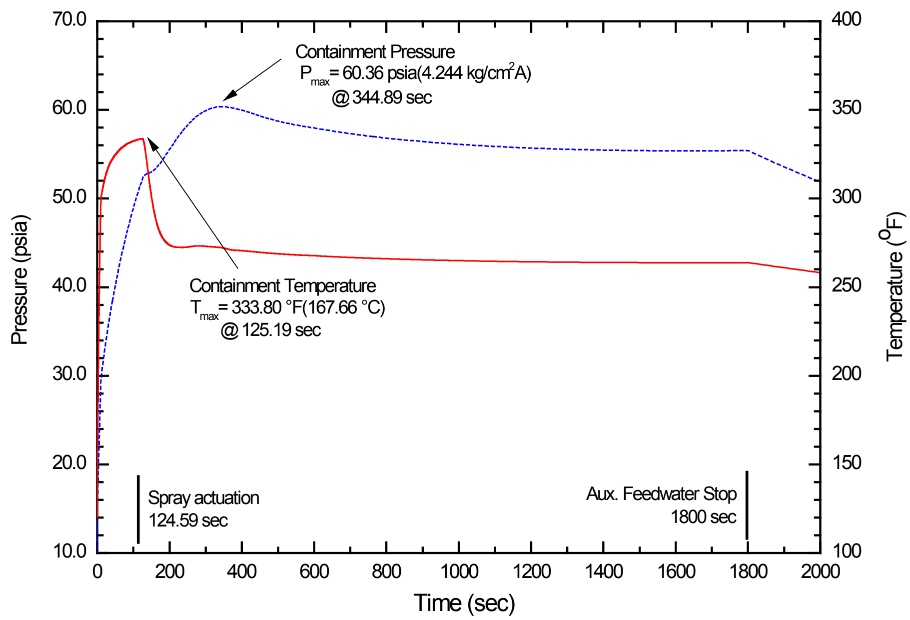

Figure B-6B MSLB Containment P/T Response (102% Power, Loss of a CSS train)

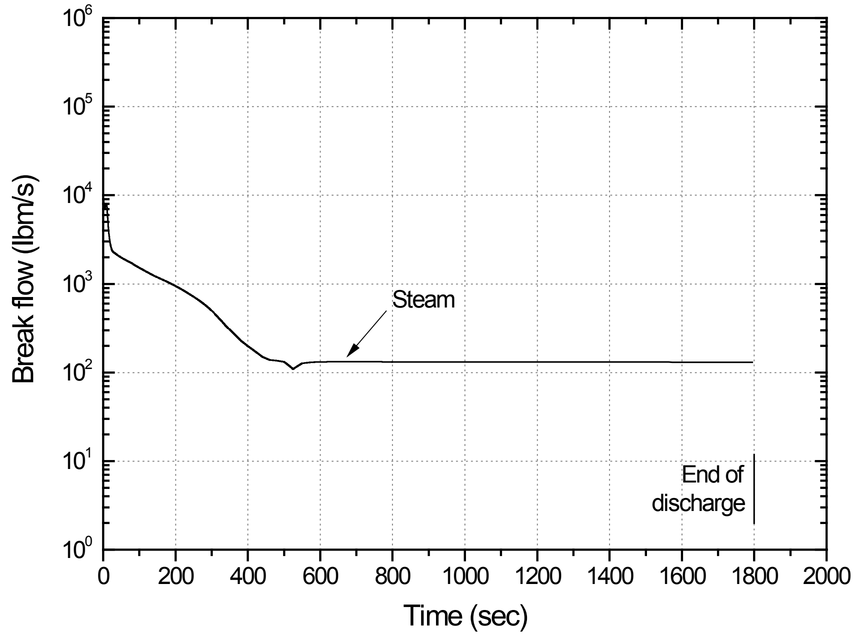

Figure B-7A MSLB Mass Release (102% Power, MSIV failure)

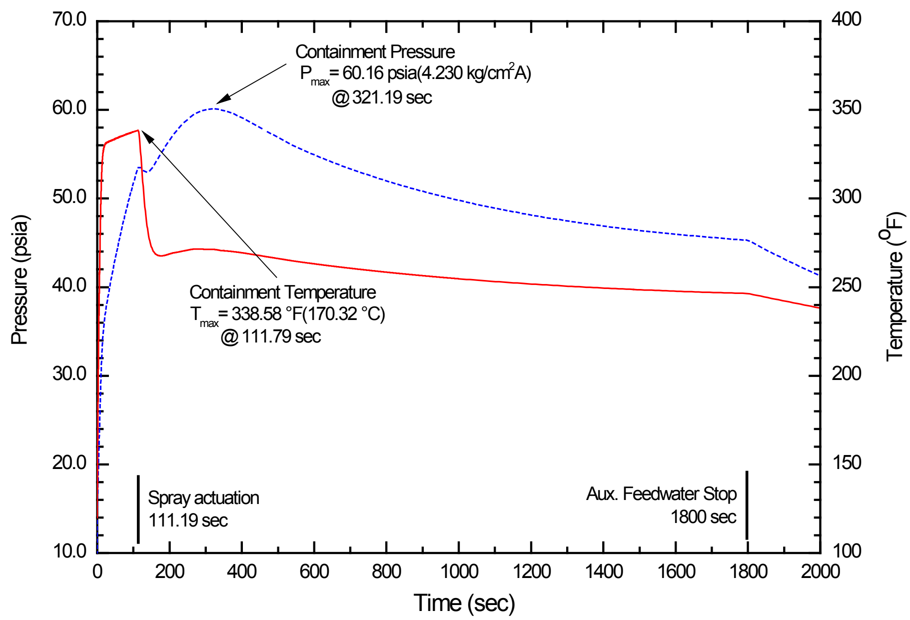

Figure B-7B MSLB Containment P/T Response (102% Power, MSIV failure)

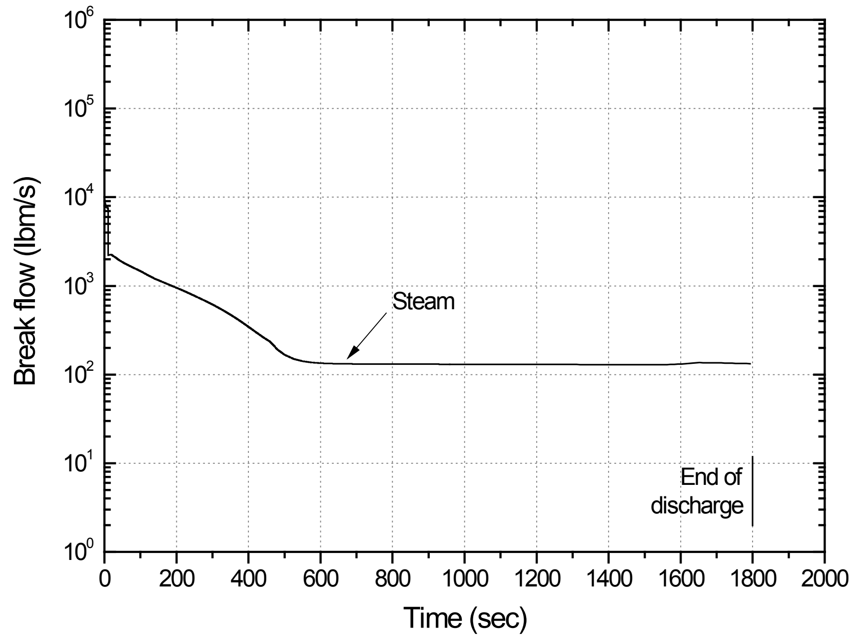

Figure B-8A MSLB Mass Release (75% Power, Loss of a CSS train)

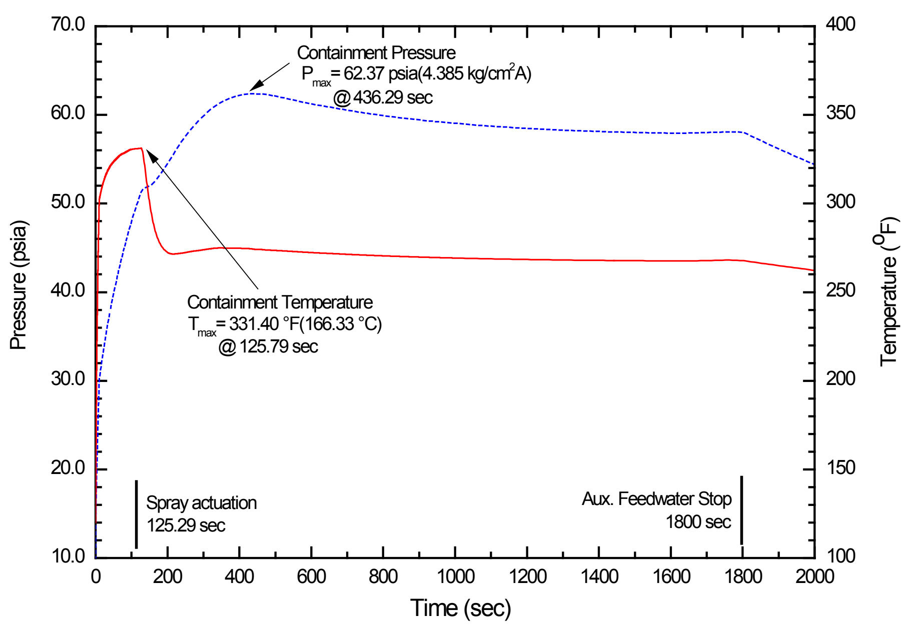

Figure B-8B MSLB Containment P/T Response (75% Power, Loss of a CSS train)

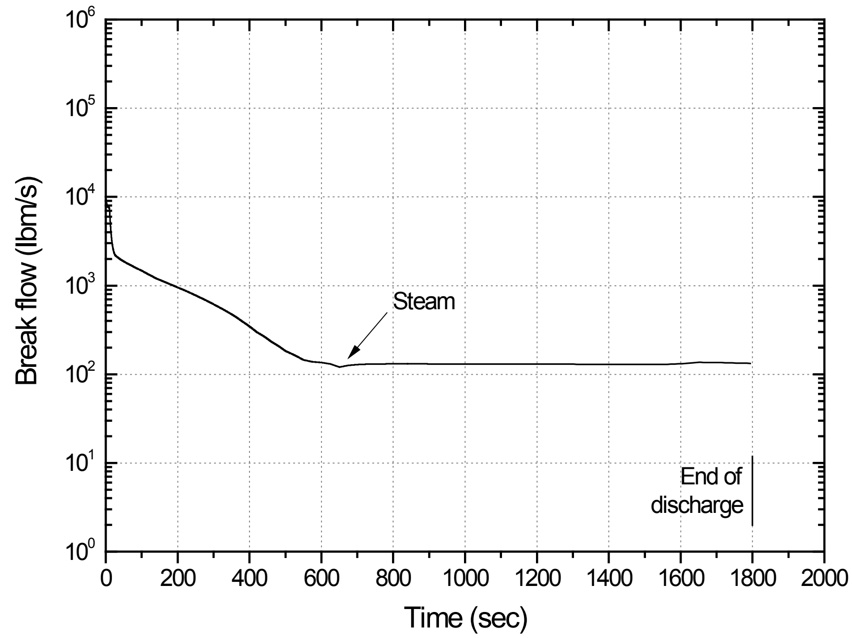

Figure B-9A MSLB Mass Release (75% Power, MSIV failure)

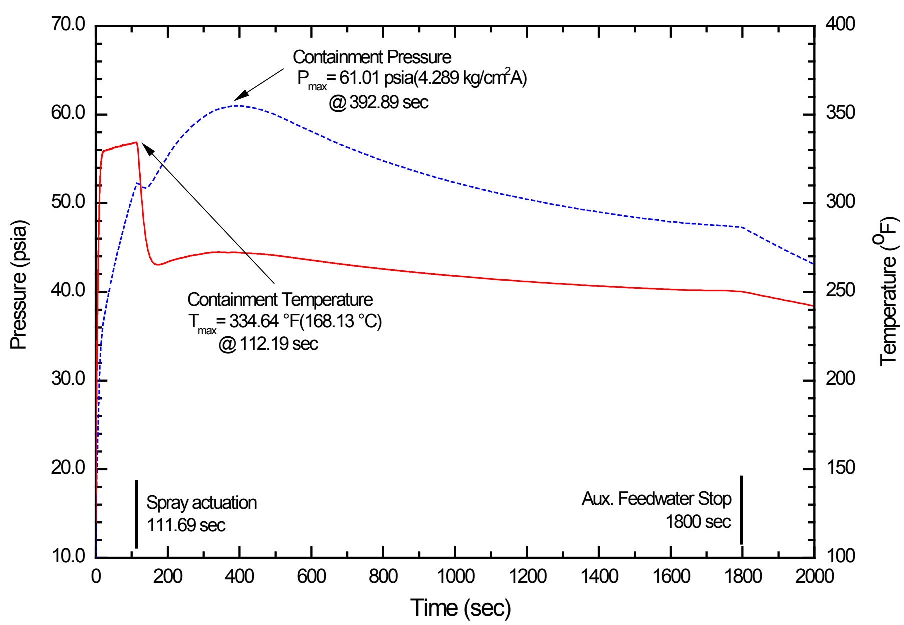

Figure B-9B MSLB Containment P/T Response (75% Power, MSIV failure)

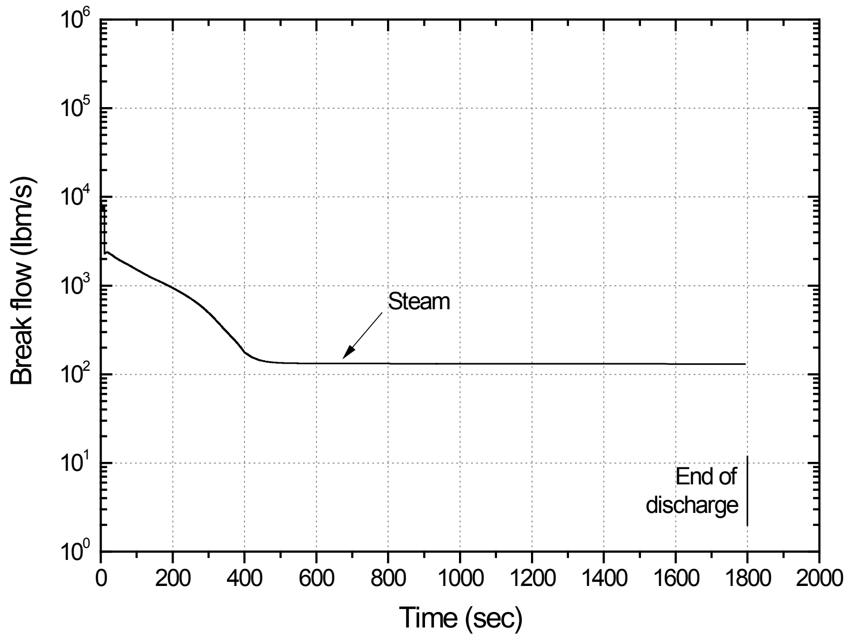

Figure B-10A MSLB Mass Release (50% Power, Loss of a CSS train)

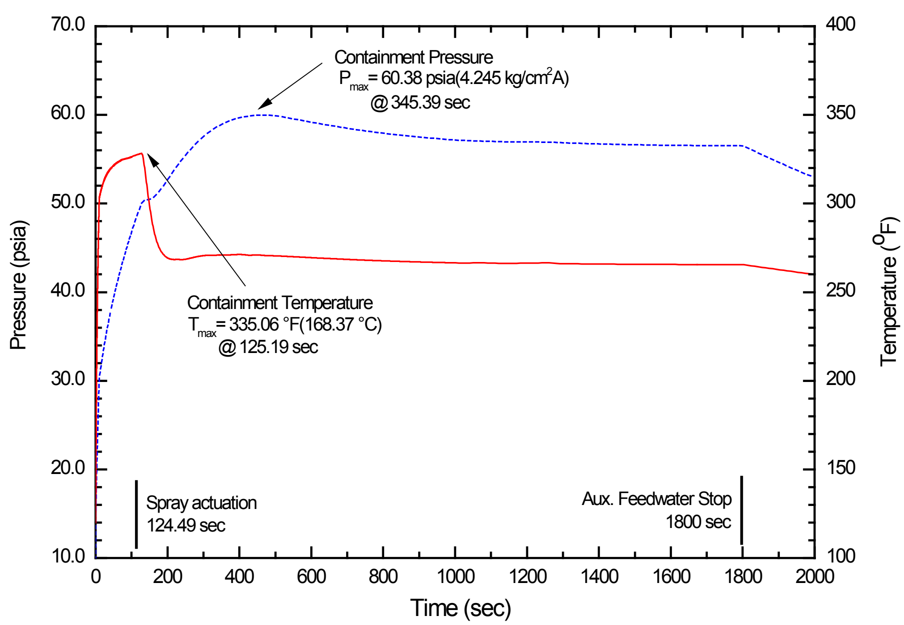

Figure B-10B MSLB Containment P/T Response (50% Power, Loss of a CSS train)

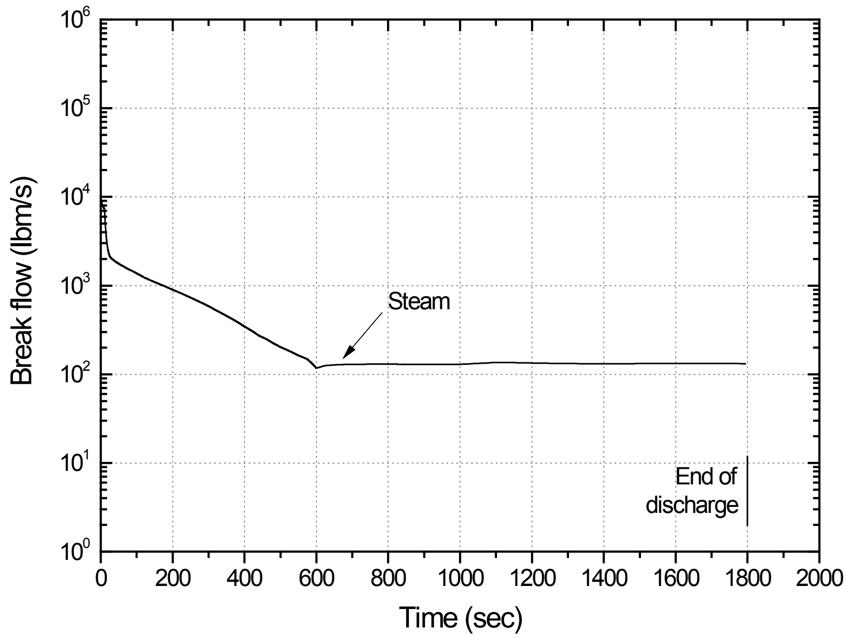

Figure B-11A MSLB Mass Release (50% Power, MSIV failure)

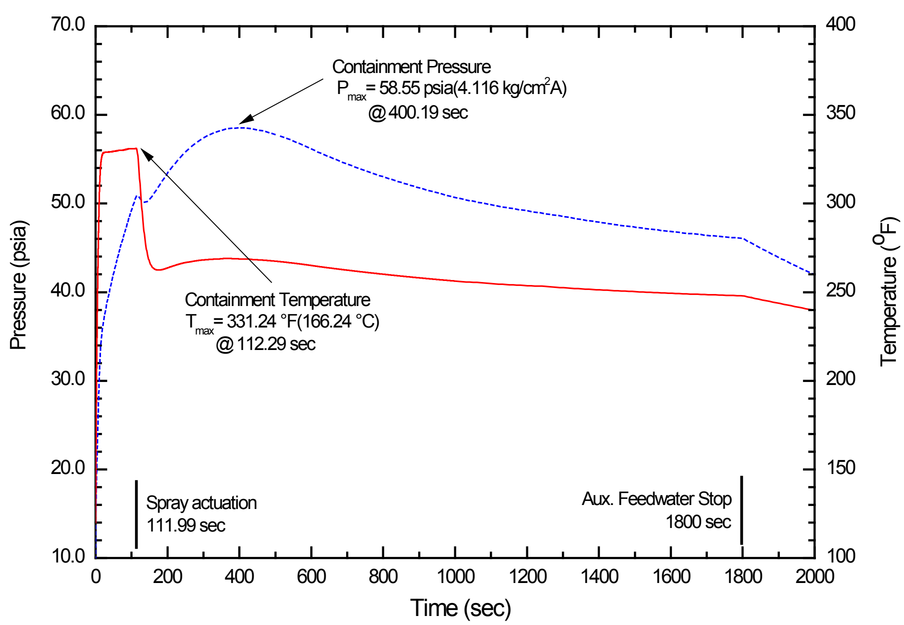

Figure B-11B MSLB Containment P/T Response (50% Power, MSIV failure)

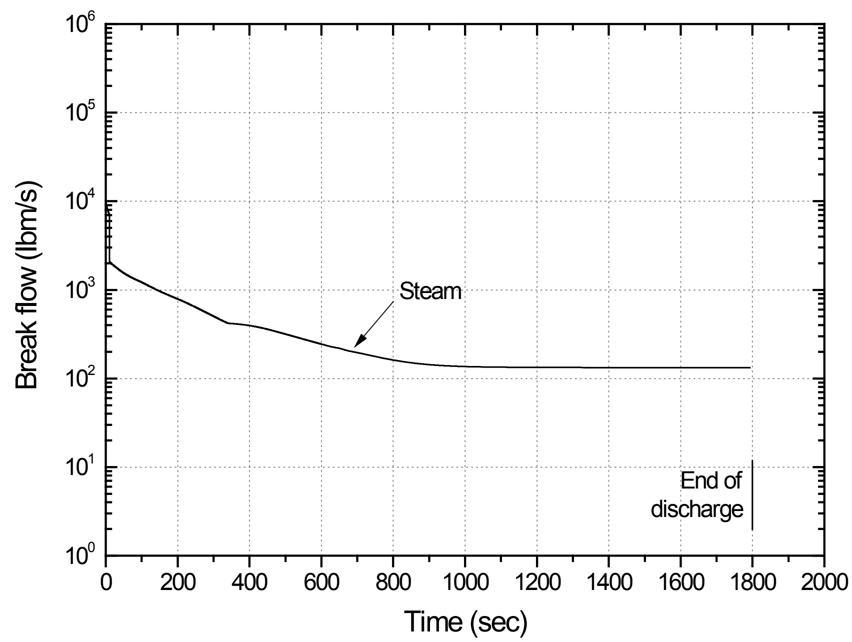

Figure B-12A MSLB Mass Release (20% Power, Loss of a CSS train)

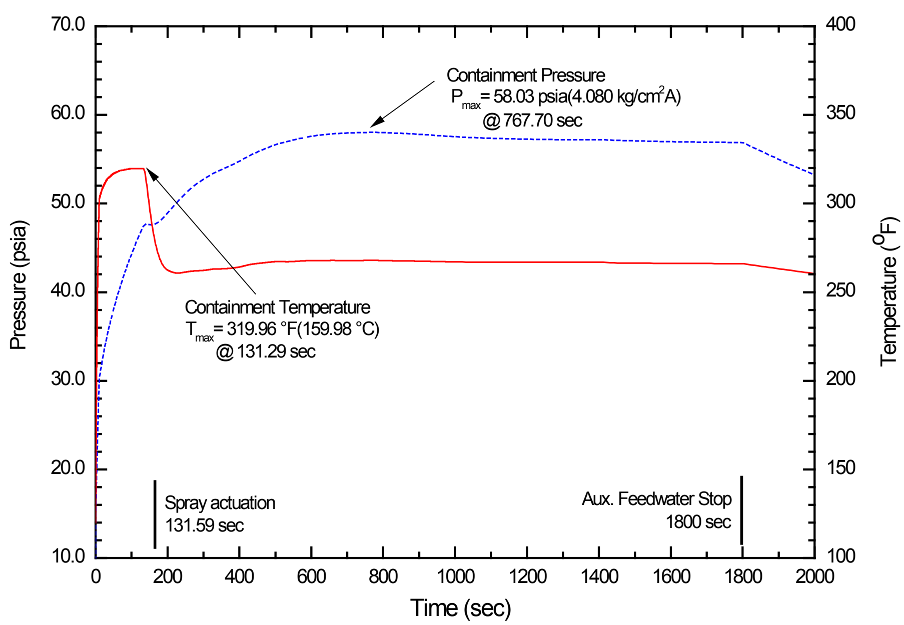

Figure B-12B MSLB Containment P/T Response (20% Power, Loss of a CSS train)

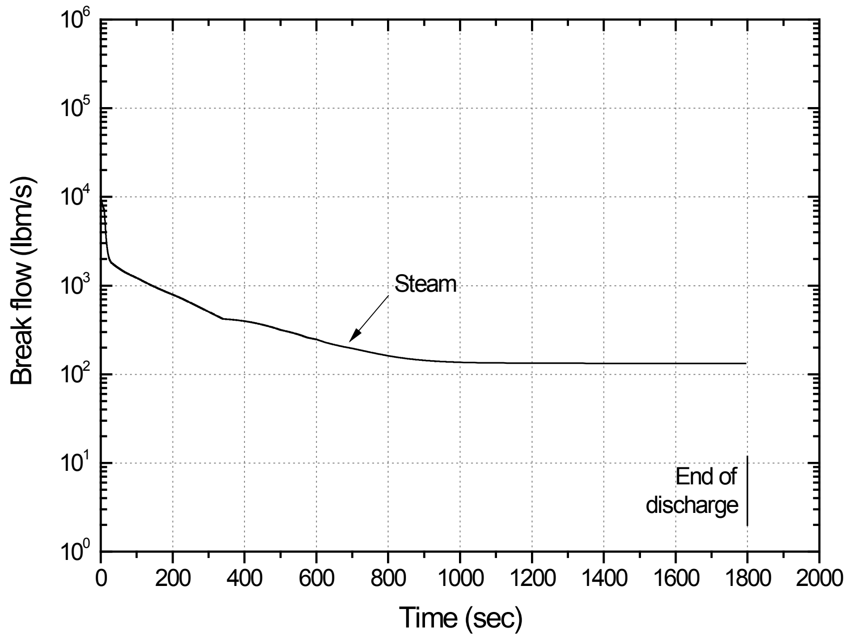

Figure B-13A MSLB Mass Release (20% Power, MSIV failure)

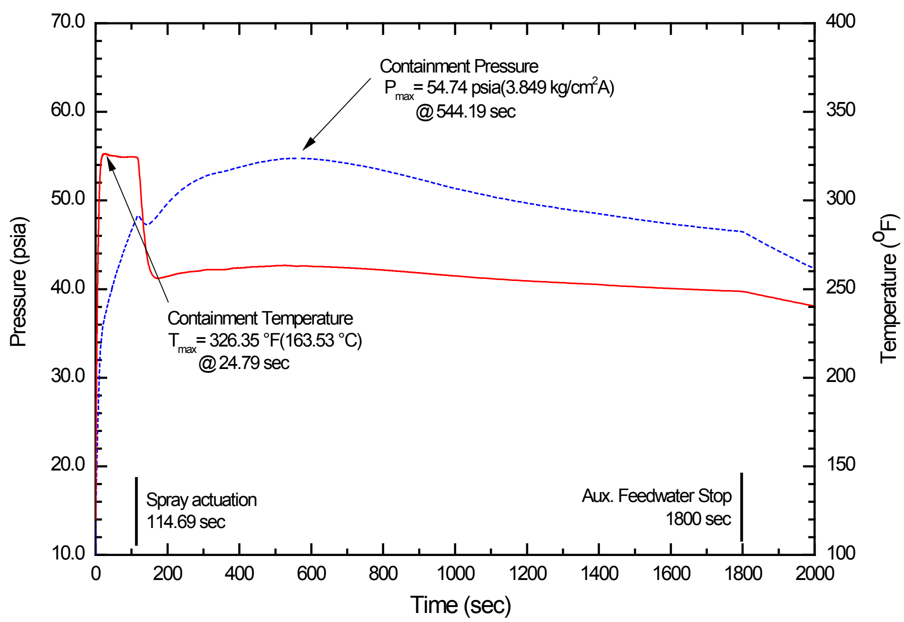

Figure B-13B MSLB Containment P/T Response (20% Power, MSIV failure)

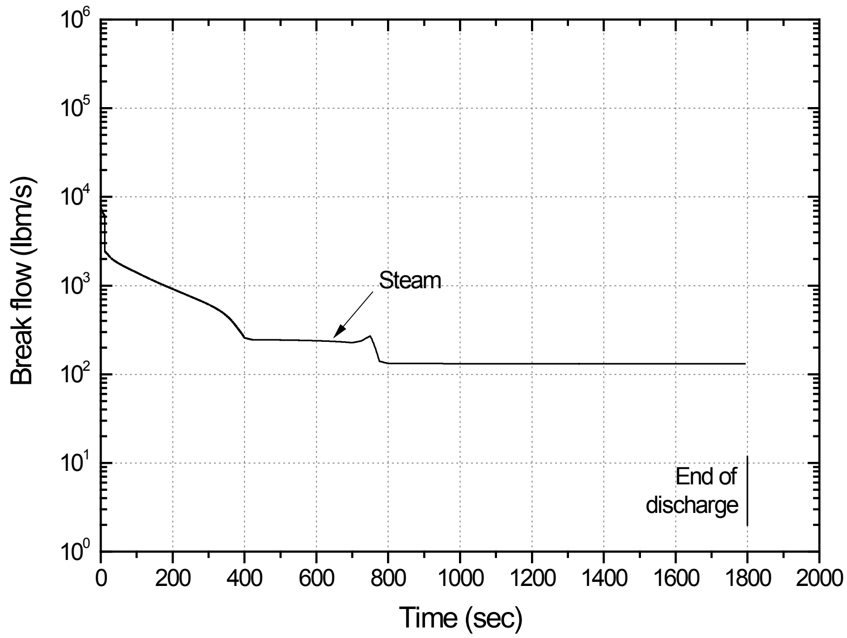

Figure B-14A MSLB Mass Release (0% Power, Loss of a CSS train)

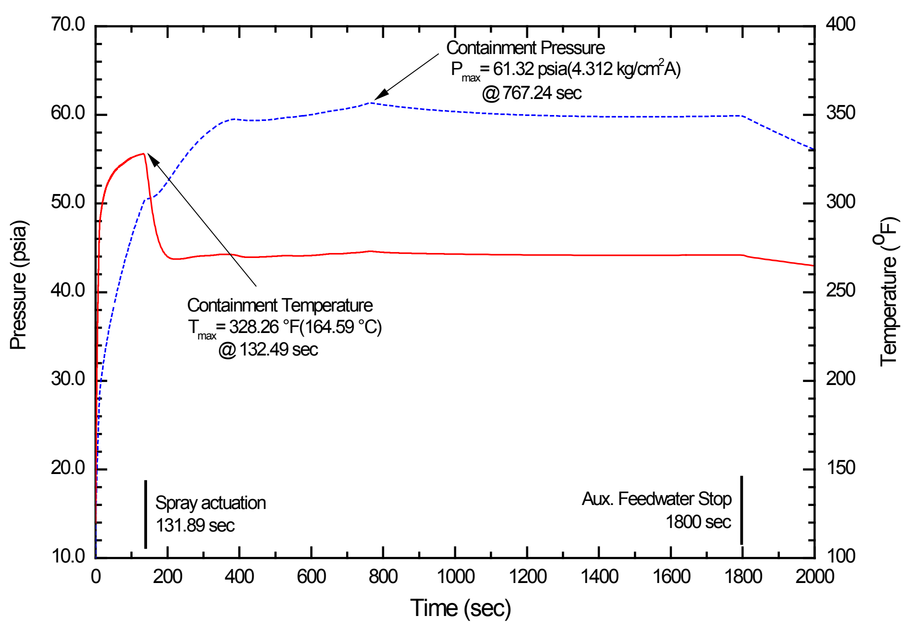

Figure B-14B MSLB Containment P/T Response (0% Power, Loss of a CSS train)

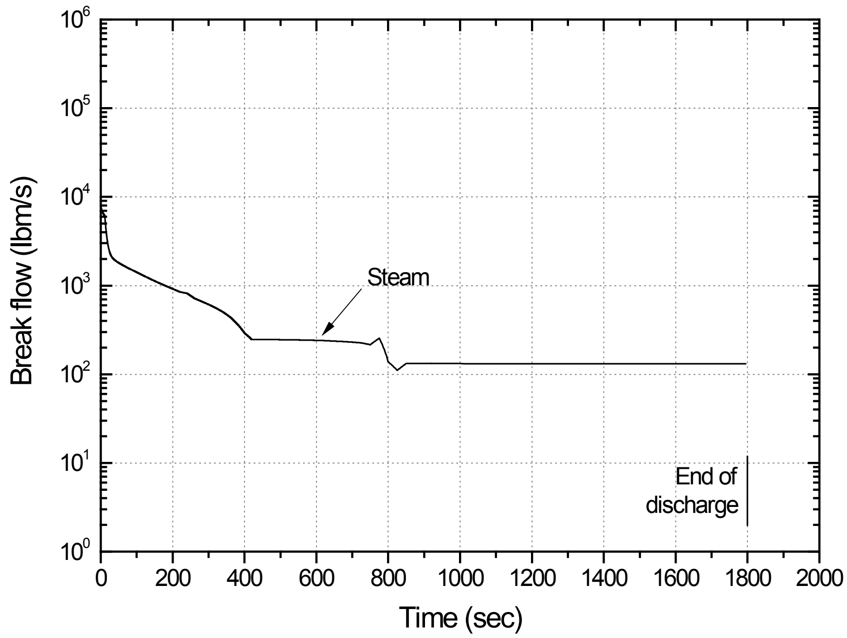

Figure B-15A MSLB Mass Release (0% Power, MSIV failure)

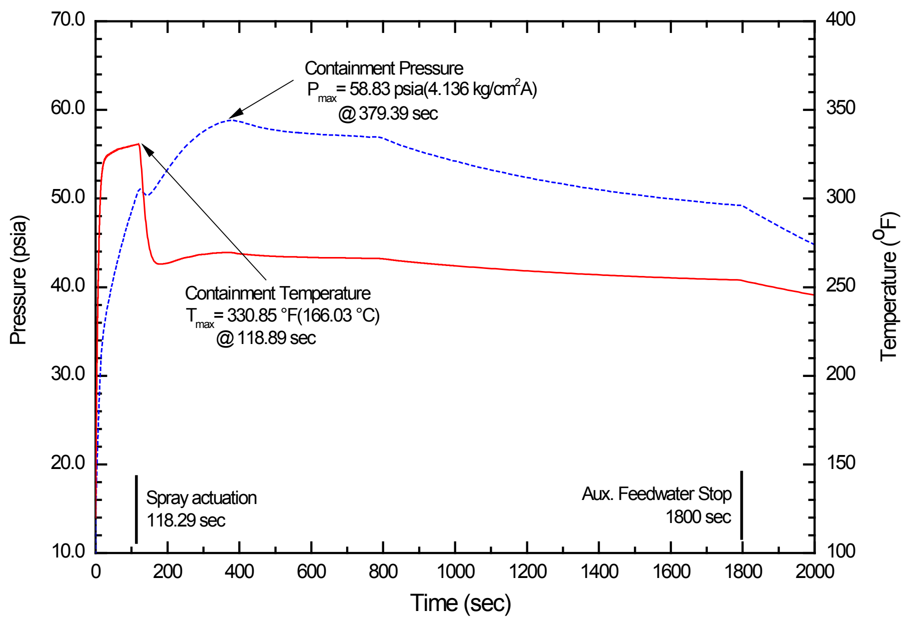

Figure B-15B MSLB Containment P/T Response (0% Power, MSIV failure)

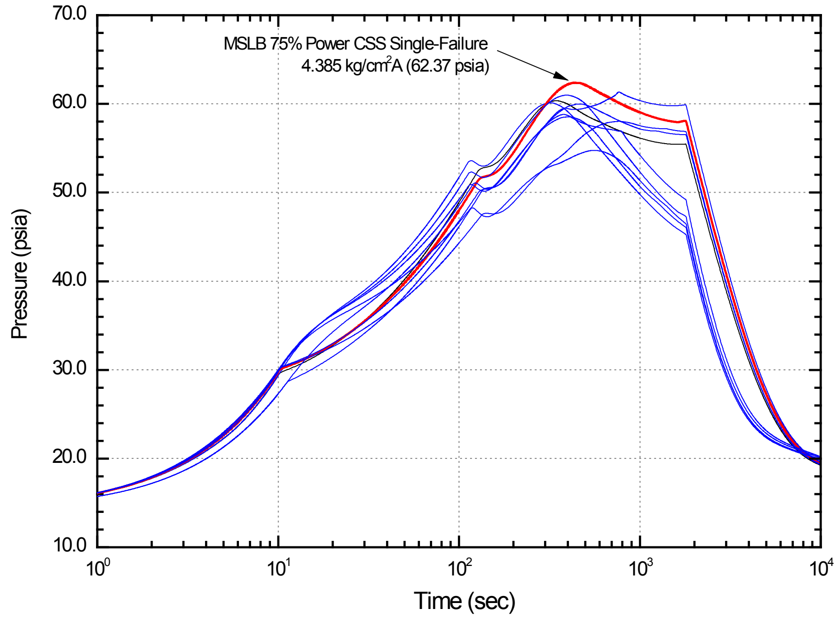

Figure B-16A MSLB Pressure Transients (Re-evaporation – GOTHIC Default)

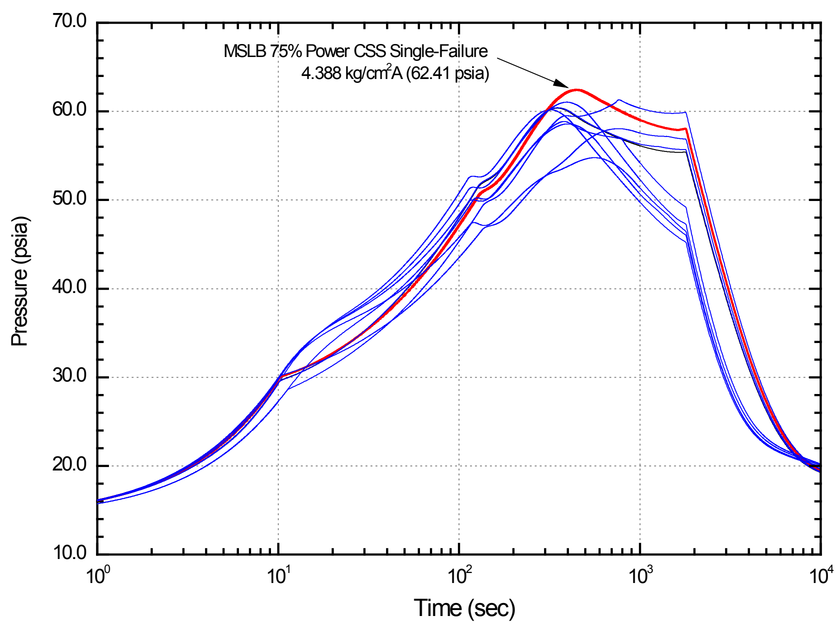

Figure B-16B MSLB Pressure Transients (8% Re-evaporation)

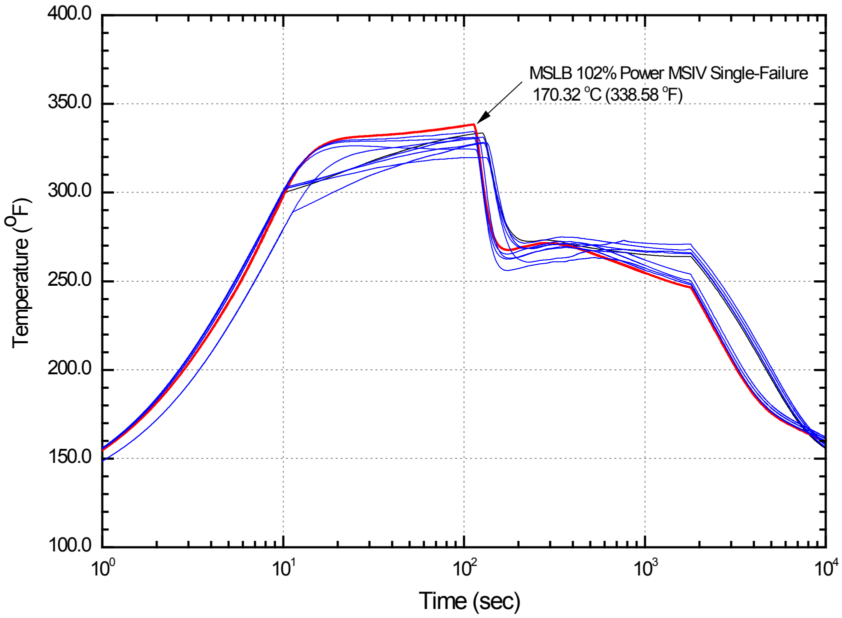

Figure B-17A MSLB Temperature Transients (Re-evaporation – GOTHIC Default)

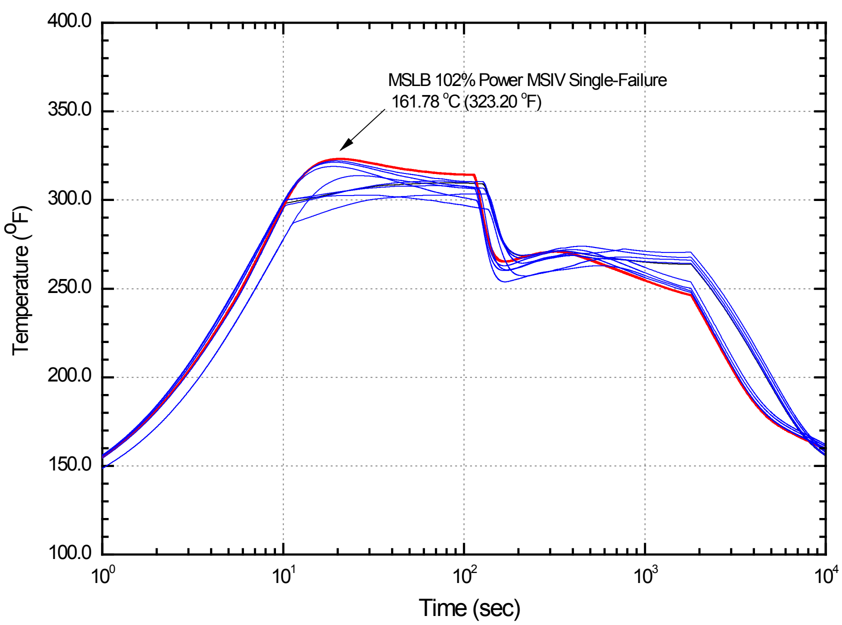

Figure B-17B MSLB Temperature Transients (8% Re-evaporation)

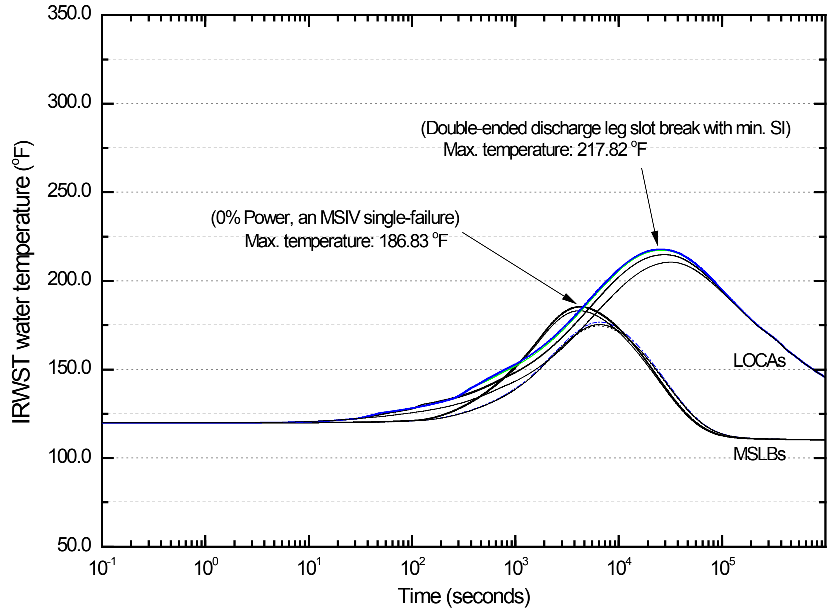

Figure B-18A IRWST Water Temperature Transients (LOCAs, MSLBs)

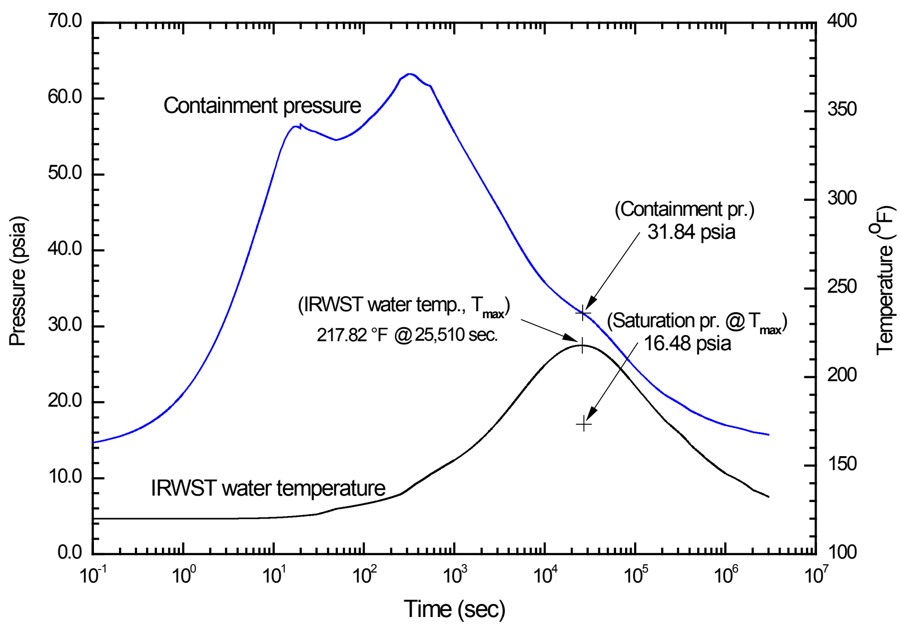

Figure B-18B Maximum IRWST Water Temperature

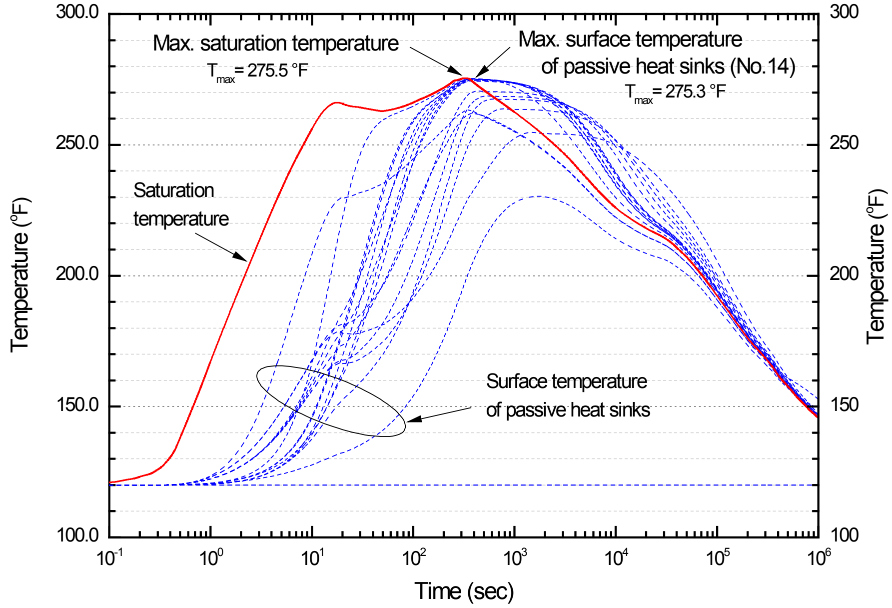

Figure B-19A Surface Temperature Transients of Passive Heat Sinks
(LOCA – DEDLSB with Max. SI Flow)

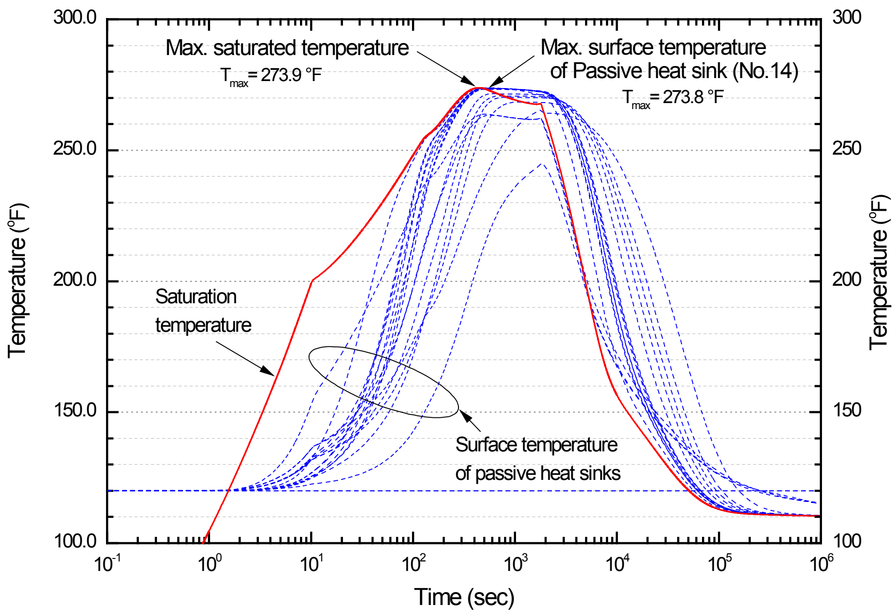

Figure B-19B Surface Temperature Transients of Passive Heat Sinks
(MSLB – 75% Power, Loss of a CSS Train)

APPENDIX C

CASE STUDIES FOR

MODELING CHARACTERISTICS

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C. CASE STUDIES FOR THE MODELING CHARACTERISTICS

This appendix provides the bounding analyses to estimate the conservative initial conditions, nodding sensitivity of the containment model, determination of the droplet discharge duration for the break flow, and sensitivity analyses with respect to containment spray.

C.1 Bounding Analysis for Initial Conditions

In the analyses for providing reasonable assurance of containment integrity to LOCA and secondary system pipe rupture, each of the containment initial values such as containment pressure and temperature, is considered as an upper or lower bounding value to maximize containment pressure and temperature or IRWST water temperature.

The key parameters considered as initial values, which affect peak conditions in the transient, include pressure, temperature, containment atmosphere relative humidity, and IRWST water volume. The appropriate combinations of upper or lower bounding values of these parameters could maximize containment peak pressure or peak temperature, or increase the highest IRWST water temperature during the long-term cooling phase.

This section presents the sensitivity analyses to determine the most conservative initial conditions that produce the worst containment responses to LOCA and MSLB. The bounding limits of each initial value are determined as those that encompass the limiting condition for operation (LCO) specified in the DCD Technical Specifications. The upper or lower limits of each initial value are tabulated in Table C-1A.

Initial Conditions for Peak Pressure

The containment response to LOCA gives higher peak pressure than in MSLB accidents. The highest peak pressures in LOCA and MSLB accidents are summarized in Table B-1G and B-3B, respectively. The impact of each initial value on containment peak pressure is individually estimated for the limiting LOCA case (double-ended discharge leg slot break with maximum SI flow).

Five cases that change the parameters individually in the list of initial values are chosen to estimate the pressurization effect by each initial value. From the results of sensitivity studies presented in Table C-1B, it is identified that the combination of higher initial pressure and temperature with lower relative humidity and air volume gives the highest peak containment

pressure. Figure C-1A shows the pressure transients from the calculations using each initial condition described in Table C-1B.

The upper-bound estimate of containment initial pressure maximizes non-condensable gases and steam mass in containment at the accident initiation. [

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The initial IRWST water volume is considered as a parameter that may affect peak pressure. Larger IRWST water volume reduces the containment initial atmosphere space, which includes IRWST vapor region, resulting in higher peak containment pressure. For the LOCA containment response analysis to determine peak pressure, the maximum IRWST water level is chosen as one of the bounding initial values, though it produces a small impact on peak pressure.

Initial Conditions for Peak Temperature

From the summarized results of containment response to LOCA and MSLB listed in Table B-1G and B-2L, the highest peak temperature occurs from an MSLB accident. Hence the effect of each bounding initial value on peak temperature is estimated for the worst MSLB accident from peak temperature standpoint (102 percent power level with an MSIV single failure).

From the results of sensitivity studies for the peak temperature presented in Table C-1C, it is identified that the combination of lower initial pressure and relative humidity and higher temperature with maximum IRWST water volume produces the maximum peak temperature. Figure C-1B shows the temperature transients for each initial condition described in Table C-1C.

In order to maximize the peak temperature following MSLB, the lower-bound pressure estimate and upper-bound temperature value are chosen to minimize the initial mass of cold air and

steam, and to reduce heat absorption to containment heat structures from the atmosphere. Furthermore, the lower initial pressure delays the containment high-high setpoint initiation, resulting in higher peak temperature at spray actuation.

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<u>Initial Conditions for IRWST Maximum Water Temperature</u>

The maximum IRWST water temperature is used to estimate the net positive suction head (NPSH) of emergency core cooling system (ECCS) pumps and to verify that IRWST water is maintained in subcooled condition at containment atmosphere pressure. In comparison of IRWST water temperature between LOCA and MSLB, as shown in Figure B-18A, the maximum water temperature occurs during a LOCA event. Hence, the influence of each bounding initial value on IRWST water temperature is estimated for the limiting LOCA case (DEDLSB with maximum SI flow).

As presented in Table C-1D, it is estimated that the initial conditions consisting of lower pressure, higher temperature, and higher relative humidity with minimum IRWST water volume produce the highest IRWST water temperature. Among the bounding values, the minimum IRWST water volume has the greatest impact on increasing IRWST water temperature. The IRWST temperature water under various combinations of initial values listed in Table C-10 are shown in Figure C-1C.

C.2 Comparison of Nodalization for Containment and IRWST

The IRWST is part of the containment building occupying a large volume in the lowermost region, yet it is physically separated from the containment atmosphere region by a concrete slab, except for four vent paths connecting two regions. Hence, the APR1400 containment building is [

]TS For that reason, an analysis is needed to demonstrate that the two-node approach gives more conservative results with respect to peak pressure and temperature than the single-node model.

Figure C-2A shows the difference in nodding structure between single-node and two-node containment models. In the single-node model, the IRWST vapor and water volumes are merged into the containment volume. The flow resistance caused by friction and form loss on the junction (J2) in the two-node model is assumed to be minimized to maintain the pressure balance between two nodes. The size of each node volume and initial water volume for a single-node and two-node models are presented in Table C-2A.

[

]TS Thus, the break node would always have higher pressure, although larger flow path area as well as lower flow restriction between the break node and other adjacent nodes can make the pressure differentials insignificantly small.

For the temperature differential between two models, [

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Consequently, the break volume in two-node model would always have a higher temperature than the single-node model.

Table C-2B shows a comparison of peak containment pressures and temperatures for the single-node and two-node models. The two-node model shows a higher peak pressure than that of the single-node model by (0.032 kg/cm^2 [0.45 psi]). The peak temperature of the two-node model is also higher (0.44 ^{o}C [0.8 ^{o}F]) than the single-node model. The pressure and temperature transients for the two models are shown in Figure C-2B.

In conclusion, it is demonstrated that the APR1400 containment model which divides the IRWST from the containment volume, is conservative, and gives more accurate analysis results than the traditional single-node model.

C.3 Sensitivity Analysis for Duration of Droplet Discharge

Phase separation of LOCA break fluid depending on the transient containment condition may produce various containment pressure and temperature results. In general, the assumption of droplets for break flow is limited to the period when the liquid after phase separation, produces continuous containment heating. In this section, sensitivity analysis for the duration of droplet consideration is performed to estimate the various combinations of droplet discharges for break fluid. The drop diameter is assumed to be 100 microns, which is small enough to reach thermal equilibrium with the containment atmosphere before reaching the containment floor. Table C-3A presents four cases of analyses covering application of droplets to the blowdown and post-blowdown phases. The peak pressure results from the sensitivity analysis are tabulated in Table C-3B.

Cases 1 and 2 give the identical peak pressure value for each accident case, and the peak pressure is greater than the results from other cases (Cases 3 and 4). This means the vapor release is maintained as superheated steam during the entire post-blowdown phase. Cases 3 and 4, which assumed droplets for hot and cold spillage, give lower peak pressure results than Case 1.

From the results, it can be seen that droplet discharge during blowdown provides atmospheric heating due to liquid superheat relative to the transient atmospheric conditions, while continuous discharge of the spillage as droplets following blowdown produces an atmospheric cooling effect. Therefore, the assumed combination of droplet discharge during blowdown and liquid stream discharge following blowdown leads to the worst containment response. Figure A-5 shows the fluid phases applied to the break flow of a LOCA cold leg break.

C.4 Sensitivity Analysis for Containment Spray

A parametric study was performed to analyze effects caused by changes in containment spray (CS) actuation behavior in containment responses to LOCA and MSLB. This study is based on the limiting LOCA (double-ended discharge leg slot break with maximum SI) with respect to peak pressure, and the limiting MSLB (102 percent power with an MSIV single failure under offsite power available) with respect to peak temperature. The CS inputs for base cases of LOCA and MSLB, for which the analysis results are compared to those resulting from the changed parameters, are as follows:

Base Case

The key design parameters used for the base case in this parametric study are:

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The sensitivity study was performed for each key design parameter through its change of value within an appropriate range. A total of ten cases were selected for each LOCA and MSLB accident to estimate effects of parameter changes on peak pressure and peak temperature. Table C-4A presents the list of the key parameters and the values changed for each parameter.

Change of Spray Flow Rate (L-1A, L-1B and M-1A, M-1B)

As shown in Table C-4B, peak pressure decreases as the spray flow rate is increased; however, the pressure reduction effects (less than 0.021 kg/cm^2 [0.3 psi] per 1,893 L/min [500 gpm]) are negligible for the LOCA that produces peak pressure. The change of spray flow rate does not affect peak temperature because the key parameter determining the highest temperature value in an MSLB is the onset time of containment spray, not the amount of

droplet flow through the nozzles. Figures C-3A and C-3B show the pressure and temperature transients following the change in CS flow rate during LOCA and an MSLB, respectively.

Change of Spray Setpoint Pressure (L-2A, L-2B and M-2A, M-2B)

As presented in Table C-4B, the effect of spray setpoint pressure change on peak pressure in a LOCA is negligible, as shown in Figure C-4A, because the containment atmosphere remains in a saturated condition during the entire transient. However, this parameter change results in a small variation in peak temperature (less than 0.056 ^{o}C [0.1 ^{o}F] per 0.07 kg/cm^2 [1.0 psi]) for an MSLB, as shown in Figure C-4B. The setpoint pressure change in an MSLB has little effect on peak pressure.

Change of Spray Delay Time (L-3A, L-3B and M-3A, M-3B)

Regarding the effect of a change in spray actuation delay time, peak pressure variation in a LOCA is negligible (less than 0.007 kg/cm^2 [0.1 psi] per 10 seconds) since, as described for the change of spray setpoint pressure, the containment atmosphere does not reach the superheated condition. For an MSLB case, peak temperature is affected slightly by the variance of spray actuation delay time (less than 0.83 ^{o}C [1.5 ^{o}F] per 20 seconds) because the peak temperature condition is established at the point of spray actuation in containment. Figures C-5A and C-5B show the pressure and temperature transients following spray delay time variation.

Change of Spray Droplet Size (L-4A through L-4D and M-4A through M-4D)

This study phase produces an estimate of the effect of spray nozzle droplet size on containment peak pressure and temperature. Four cases that are based on smaller droplets than the base case (1,000 microns) are chosen since the diameter of liquid droplets from the CS nozzles is between 90 microns and 500 microns, according to the APR1400 CS nozzle design specification sheet.

For a LOCA, as shown in Figure C-6A, variance in droplet size does not influence peak conditions due to the saturated atmosphere condition. On the other hand, for an MSLB, as shown in Figure C-6B, temperature and pressure transients vary depending on droplet size; however, peak temperature and pressure values are affected little by variations in droplet diameter. The only influence from droplet size, which occurs only in an MSLB temperature transient, relates to how fast the superheated atmosphere approaches the saturation condition. From this result, reasonable assurance is provided that assuming a single-droplet diameter of 1,000 microns for the CS system provides enough conservatism for the containment peak pressure and temperature analyses.

Table C-1A Upper & Lower Bounding Initial Values

Input Parameter	Unit	Min. value	Max. value
Pressure	psia	14.18	16.12
Temperature	℉	50.0	120.0
Relative Humidity	%	0.0	100.0
IRWST Liquid Volume	ft^3	83,818	89,721

Table C-1B LOCA Bounding Initial Values for Peak Pressure

Event	Case	Min. or Max. (Bounding values)				Peak Pr. (psia)	Temp. (˚F)	Time (sec)
		Pressure	Temp.	Humidity	Liq. lev.			
LOCA	1	max	max	min	max	**66.79**	275.5	323.5
	2	min	max	min	max	64.24	275.4	323.9
	3	max	min	min	max	60.65	264.1	17.4
	4	max	max	max	max	66.00	277.2	323.5
	5	max	max	min	min	66.72	275.4	323.8

Table C-1C MSLB Bounding initial Values for Peak Temperature

Event	Case	Min. or Max. (Bounding values)				Pressure (psia)	Peak T. (˚F)	Time (sec)
		Pressure	Temp.	Humidity	Liq. lev.			
MSLB	1	min	max	min	max	53.36	**338.58**	111.8
	2	max	max	min	max	55.28	334.46	106.5
	3	min	min	min	max	50.30	298.88	112.1
	4	min	max	max	max	52.71	338.48	114.0
	5	min	max	min	min	53.32	338.50	111.9

Table C-1D LOCA Bounding Initial Values for Maximum IRWST Temperature

Event	Case	Min. or Max. (Bounding values)				Max. Liq. Temp.(˚F)	Time (sec)
		Pressure	Temp.	Humidity	Liq. lev.		
LOCA	1	min	max	max	min	**217.29**	25,910
	2	max	max	max	min	217.06	26,112
	3	min	min	max	min	190.57	44,022
	4	min	max	min	min	216.45	26,511
	5	min	max	max	max	215.71	27,737

Table C-2A Comparison of Volume Size for Two Models

Description	Unit	1-node	2-nodes
Containment Air Volume	ft^3		
IRWST Volume	ft^3		
Liquid Volume (Max.)	ft^3		
Liquid Volume Fraction	%		

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Note

(1) The ratio of the maximum liquid volume to the containment volume (89,721 ft^3 / 3,128,000 ft^3)

(2) The ratio of the maximum liquid volume to the IRWST volume (89,721 ft^3 / 118,151 ft^3)

Table C-2B Results of Nodding Structure Sensitivity Analysis

Description	Unit	1-node	2-nodes
Containment Peak Pressure	psia	66.34	66.79
Containment Peak Temperature	^oF	274.7	275.5

Table C-3A Duration of Droplet Discharge

Phase	Break fluid	Case 1	Case 2	Case 3	Case 4
Blowdown	Liquid	O	O	O	O
Reflood/ Post-Reflood	Vapor	X	O	O	O
	Hot Spillage	X	X	O	O
	Cold Spillage	X	X	X	O

Note
(O) Use of droplets(diameter of 100 micron) for the break fluid
(X) No use of droplets for the break fluid

Table C-3B Peak Pressure Results depending on duration of Droplet Discharge

Accident		Peak Pressure (psia)			
		Case 1	Case 2	Case 3	Case 4
DESLSB	Max. SI	65.665	65.665	65.664	65.618
	Min. SI	65.843	65.843	65.843	65.807
DEDLSB	Max. SI	**66.791**	66.791	66.786	63.428
	Min. SI	66.666	66.666	66.662	64.519
DEHLSB	Max. SI	63.639	63.639	63.639	63.639

Table C-4A List of Parameters for CS Sensitivity Analyses

Parameter	Case ID		Values
	LOCA	MSLB	
Spray Flow Rate (4,000 ~ 5,000) [gpm]	L-base[1]	M-base[2]	4,500
	L-1A	M-1A	4,000
	L-1B	M-1B	5,000
CS Setpoint Pressure (10.0 ~ 22.0) [psig]	L-Base	M-Base	22.0
	L-2A	M-2A	16.0
	L-2B	M-2B	10.0
Spray Delay Time (70 ~ 110) [sec]	L-Base	M-Base	110
	L-3A	M-3A	90
	L-3B	M-3B	70
Spray Droplet Size (200 ~ 1,000) [micrometer]	L-Base	M-Base	0.0394 (1000)
	L-4A	M-4A	0.0315 (800)
	L-4B	M-4B	0.0236 (600)
	L-4C	M-4C	0.0157 (400)
	L-4D	M-4D	0.0079 (200)

Note

(1) L-base is the limiting case of LOCA (DEDLSB with Max. SI) with respect to peak pressure

(2) M-base is the limiting case of MSLB (102% power, MSIV single-failure) with respect to peak temperature

Table C-4B Analysis Results of CS Parametric Study

Case	Maximum Pressure			Maximum Temperature			*Δp* (1)	△*T* (1)
ID	*psia*	*kg/cm²*	*sec*	*°F*	*°C*	*sec*	*Psid*	*°F*
L-Base	66.79	4.70	323.81	275.48	135.27	322.91		
L-1A	67.08	4.72	324.11	275.86	135.48	323.81	0.29	0.37
L-1B	66.51	4.68	322.01	275.12	135.06	320.51	-0.28	-0.37
L-2A	66.78	4.69	323.81	275.46	135.26	323.21	-0.02	-0.02
L-2B	66.76	4.69	323.81	275.45	135.25	322.91	-0.03	-0.04
L-3A	66.57	4.68	323.81	275.19	135.11	323.51	-0.22	-0.29
L-3B	66.35	4.66	323.81	274.90	134.95	323.51	-0.44	-0.58
L-4A	66.79	4.70	323.81	275.48	135.27	322.91	0.00	0.00
L-4B	66.79	4.70	323.81	275.48	135.27	323.21	0.00	0.00
L-4C	66.79	4.70	323.81	275.48	135.27	322.91	0.00	0.00
L-4D	66.79	4.70	323.81	275.48	135.27	323.21	0.00	0.00
M-Base	60.16	4.23	321.19	338.58	170.32	111.79		
M-1A	60.71	4.27	324.49	338.58	170.32	111.79	0.55	0.00
M-1B	59.62	4.19	317.19	338.58	170.32	111.69	-0.54	0.00
M-2A	59.98	4.22	321.29	337.95	169.97	101.69	-0.18	-0.63
M-2B	59.91	4.21	321.29	337.65	169.81	97.39	-0.25	-0.93
M-3A	59.81	4.21	321.19	337.23	169.57	91.79	-0.35	-1.35
M-3B	59.49	4.18	321.19	335.66	168.70	71.79	-0.67	-2.92
M-4A	60.13	4.23	321.09	338.58	170.32	111.69	-0.02	0.00
M-4B	60.11	4.23	320.99	338.58	170.32	111.69	-0.05	0.00
M-4C	60.08	4.22	320.99	338.57	170.32	111.59	-0.07	0.00
M-4D	60.03	4.22	320.86	338.57	170.32	111.59	-0.13	-0.01

Note

(1) Δp and ΔT indicate the differential pressure and temperature between reference case(L-base / M-base) and the target case, respectively.

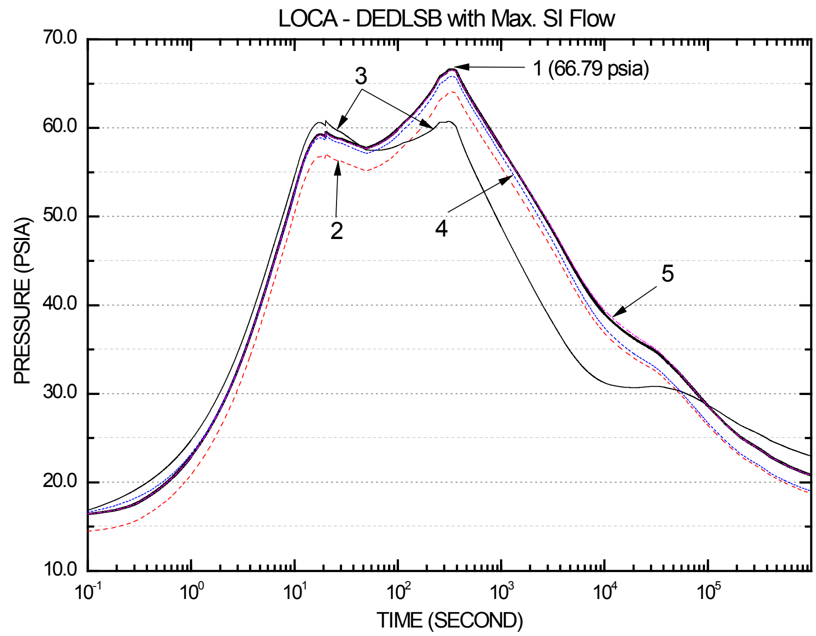

Figure C-1A Pressure Transients to various LOCA Initial Conditions

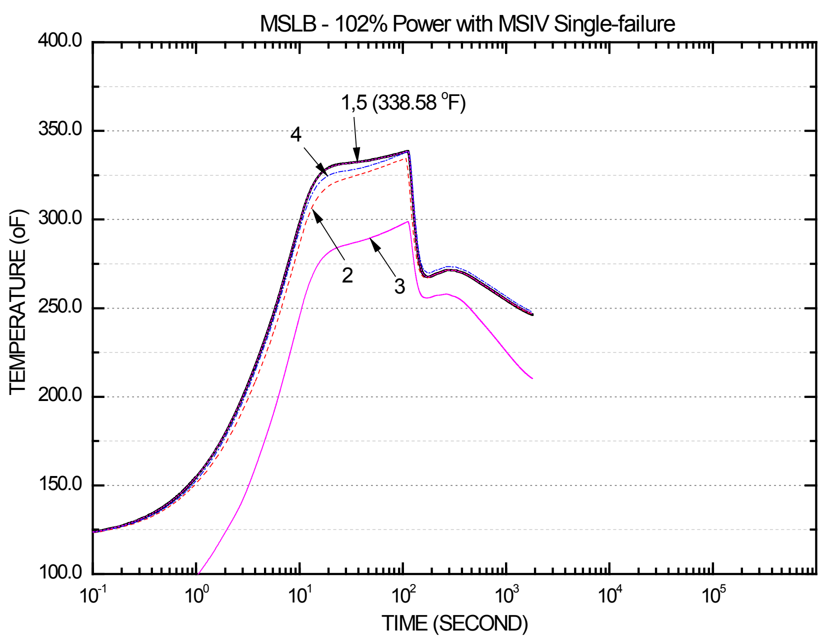

Figure C-1B Temperature Transients to various MSLB Initial Conditions

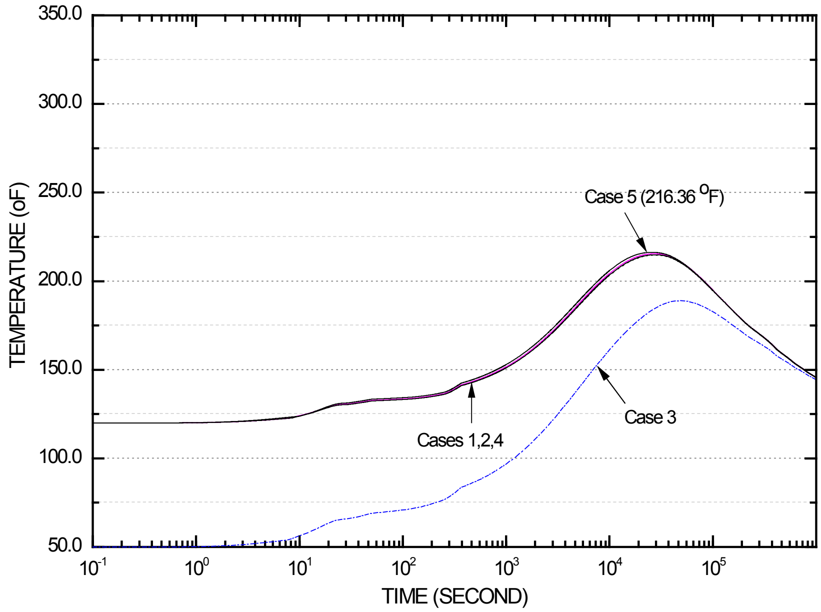

Figure C-1C IRWST Water Temperature Transient to Various Initial Conditions

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Figure C-2A Comparison of Nodding Structure (Single node / Two nodes)

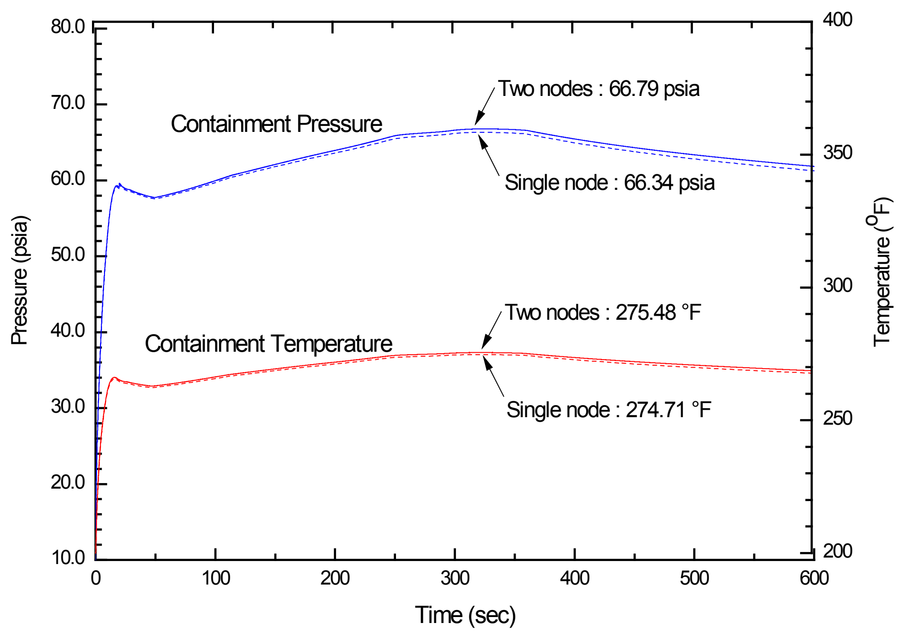

Figure C-2B Comparison Analysis for Nodding Structure (Single node / Two nodes)

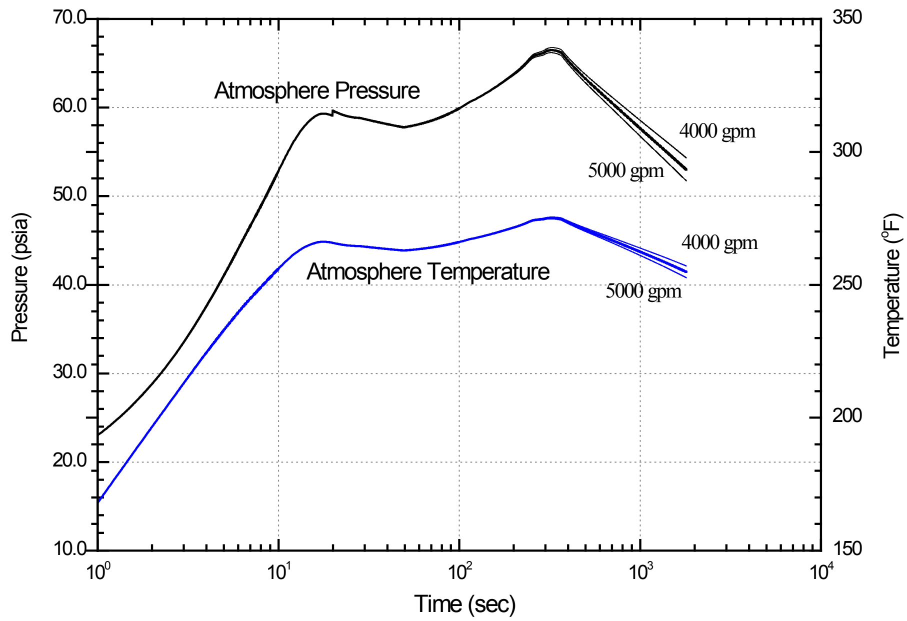

Figure C-3A LOCA P/T Transients to Spray flow Variation

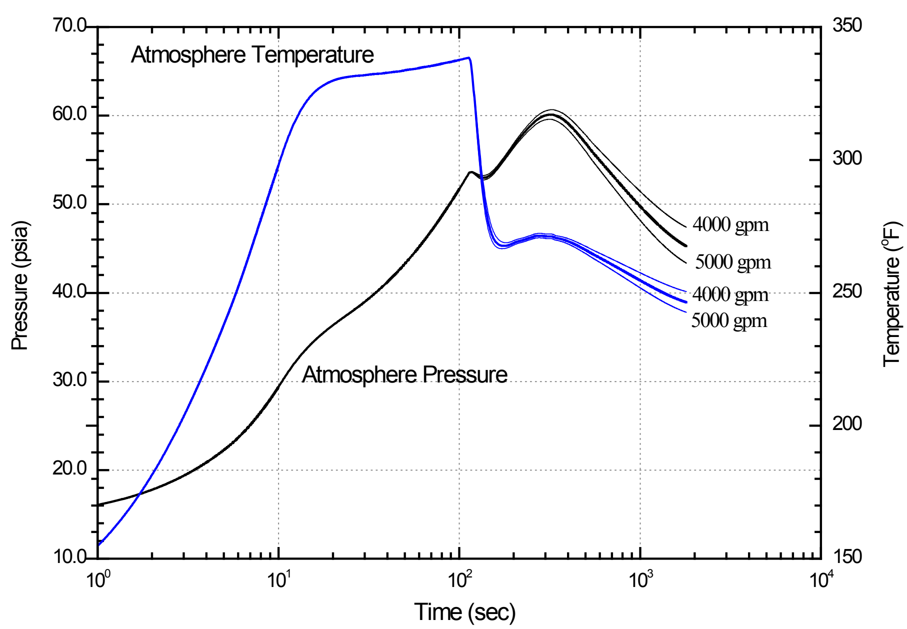

Figure C-3B MSLB P/T Transients to Spray flow Variation

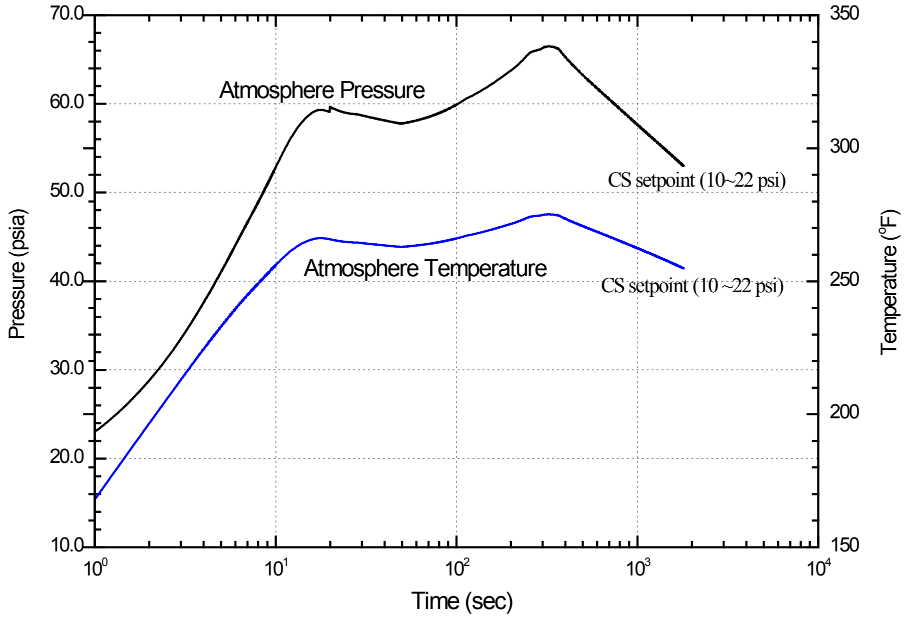

Figure C-4A LOCA P/T Transients to Spray setpoint Variation

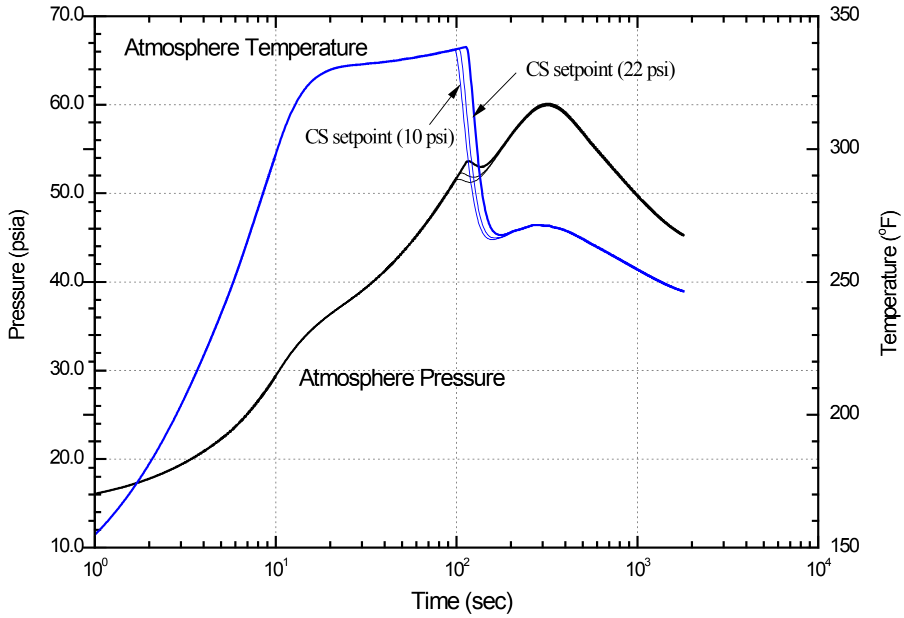

Figure C-4B MSLB P/T Transients to Spray setpoint Variation

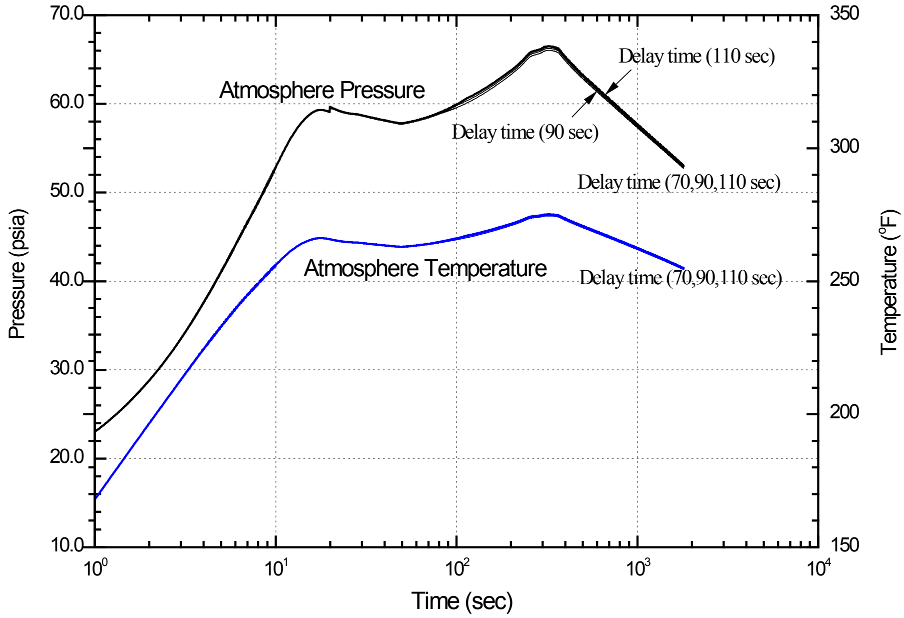

Figure C-5A LOCA P/T Transients to Spray delay time Variation

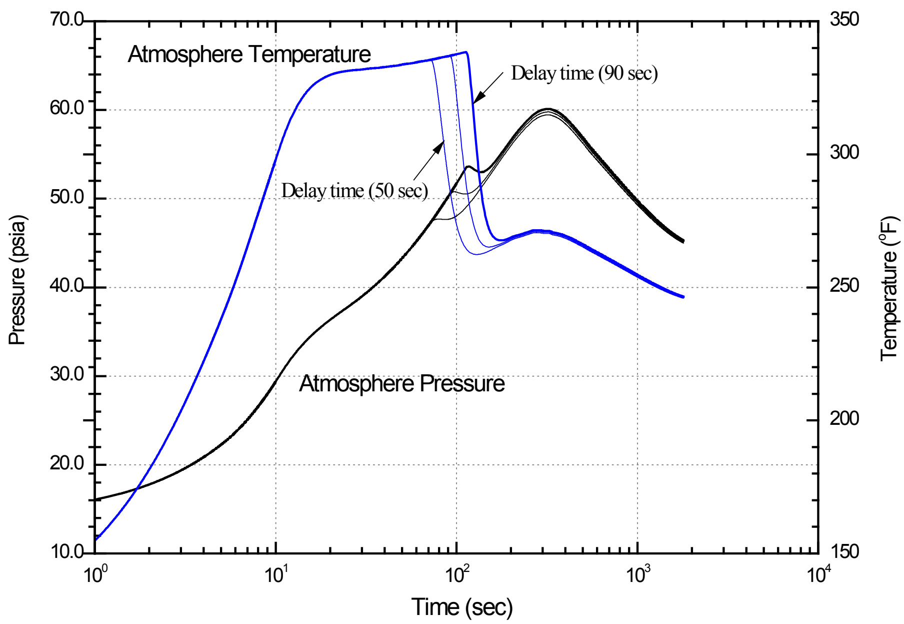

Figure C-5B MSLB P/T Transients to Spray delay time Variation

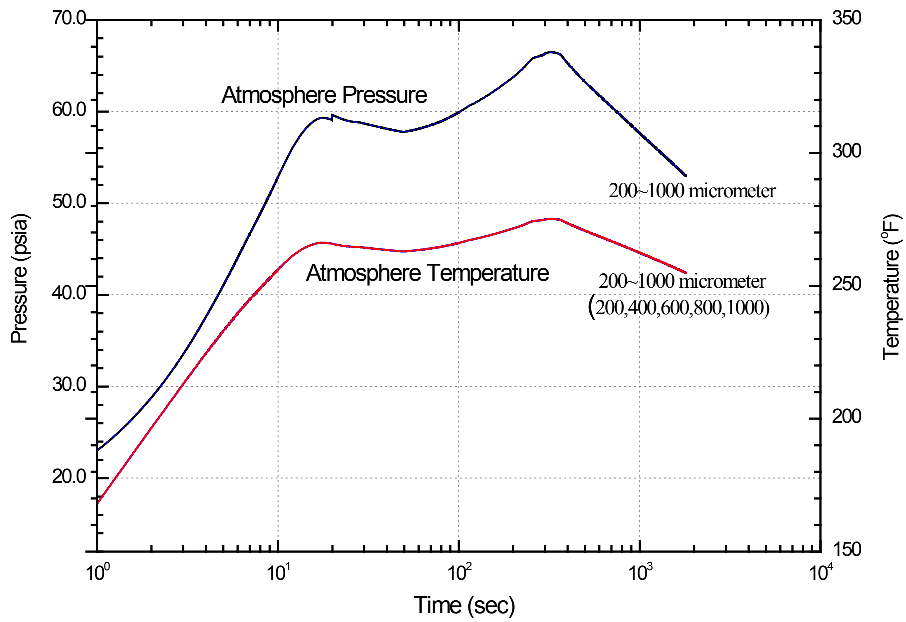

Figure C-6A LOCA P/T Transients to Spray droplet size Variation

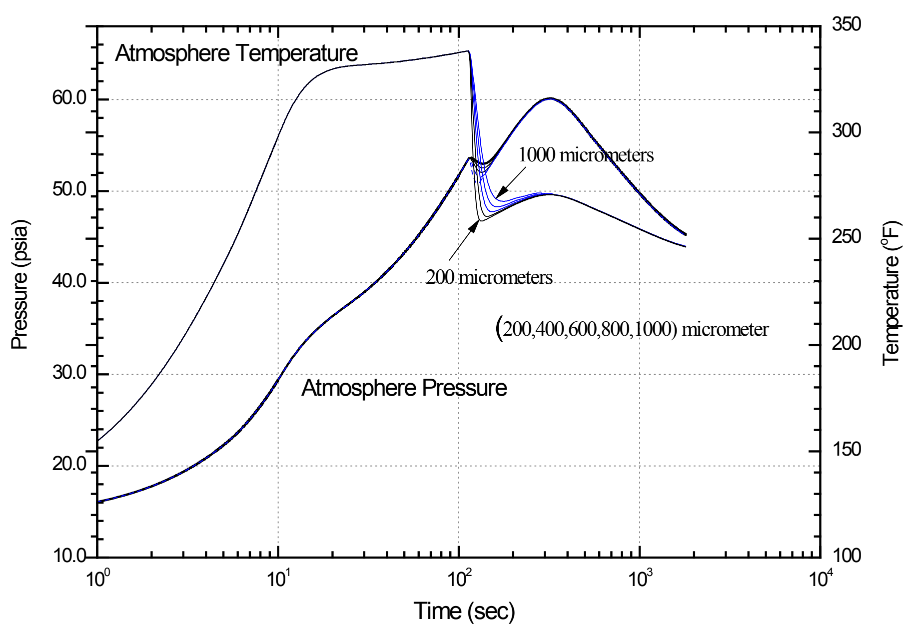

Figure C-6B MSLB P/T Transients to Spray droplet size Variation

APPENDIX D

CONTAINMENT EXTERNAL PRESSURE ANALYSIS BY THE INADVERTANT OPERATION OF CONTAINMENT SPRAY

TABLE OF CONTENTS

LIST OF TABLES

D. CONTAINMENT EXTERNAL PRESSURE ANALYSIS BY THE INADVERTANT OPERATION OF CONTAINMENT SPRAY

This section appendix provides the containment external pressure loading analysis. The purpose is to determine the containment external pressure load and demonstrate that the containment building and related structures are designed to accommodate the maximum external pressure resulting from an inadvertent operation of containment heat removal systems such as the spray system, purge system, and fan cooler system.

The pressure reduction effect caused by inadvertent actuation of the reactor containment fan cooler (RCFC) units is regarded to be negligible because the cooling water temperature is higher than the minimum IRWST water temperature. Considering the result due to inadvertent operation of the purge system (i.e., operation of the exhaust train with the supply train isolated), the maximum feasible internal vacuum for this case is limited to only a few inches of water (gauge) based on the design characteristic curve of the exhaust fan.

The decrease in containment internal pressure from an inadvertent operation of the CS system with opening of the containment purge valves is negligible. A significant pressure reduction can occur when the containment is sealed and all the purge valves are closed when the spray actuates. Consequently, the worst accident case for determination of the containment external pressure is the inadvertent operation of the CS system; therefore, the analysis described here is based on the CS system mal-function.

This section consists of three subsections: assumptions, initial condition, and analysis method including calculation results. The calculation results presented in this section are consistent with DCD Subsection 6.2.1.1.3.5.

D.1 Assumptions

In calculating the maximum external pressure load on containment, an analytical model based on the ideal gas equation and Dalton's partial pressure law is used without computer code runs because only the minimum containment pressure is of interest, and the transient response is not considered. For simplicity of the analytical model and conservatism in the calculation, the following assumptions are made.

- Air and steam in the containment reach thermal equilibrium at the temperature of the containment spray liquid droplets.
- The containment is completely isolated at the time of spray actuation, that is, all of purge valves are closed and a leakage into the containment is not considered.
- There is neither heat transfer from containment structures nor containment volume reduction due to the addition of spray water.
- All heat sources in containment are disregarded.

D.2 Initial Condition

The key initial parameters for the analysis include pressure, temperature, relative humidity and spray water temperature. The lower-bound estimate of initial pressure and upper-bound initial temperature minimizes the containment steam and air mass at accident initiation, and upper-bound relative humidity decreases the initial ratio of non-condensable gases to steam. The lower temperature of spray water, which determines the containment atmosphere temperature after spray actuation, produces higher negative pressure. The initial values for containment external pressure analysis are presented in Table D-1.

D.3 Analysis Method

The general approach used to determine the pressure reduction caused by inadvertent spray actuation is as follows:

- Determining the initial containment total pressure as a sum of air and steam partial pressure.
- Calculating the final containment air partial pressure (after spray actuation) using the ideal gas law and the corresponding equation of state.
- Adding the containment steam pressure (corresponding to the spray water temperature) to the final air partial pressure to obtain the final containment total pressure.
- Comparing the initial and final containment total pressures to determine the pressure difference across the containment wall, which acts as the containment external pressure load.

The pressure reduction in containment by the subcooled spray water can be represented as the following reduced equation.

[ ] TS

Where

ΔP	pressure differential, psid
P_{T_f}	total pressure after spray actuation (final state), psia
P_{T_i}	total pressure before spray actuation (initial state), psia
P_{S_f}	steam partial pressure after spray actuation (final state), psia
P_{S_i}	steam partial pressure before spray actuation (initial state), psia
P_{A_i}	air partial pressure before spray actuation (initial state), psia
T_i	temperature before spray actuation (initial state), ^oR
T_f	temperature after spray actuation (final state), ^oR

Thus, the pressure reduction is determined as follows:

[ ] TS

Subsequently, the containment pressure after spray actuation is:

$$P_{T_f} = \left(P_{T_i} + \Delta P\right) = (14.18 - 3.02) = 11.16 \text{ psia } (0.785 \text{ kg}/cm^2\text{A})$$

Thus, the external pressure load on the containment outside wall is determined from the difference between atmospheric pressure and the containment pressure after spray actuation.

$P =$ [ ] TS $= 3.54$ psi (0.25kg/cm^2)

The APR1400 containment is designed to withstand an external pressure loading of 0.281 kg/cm^2 (4.0 psi) relative to ambient pressure. Therefore, it is demonstrated that the design external pressure load on the containment provides more than a 10 percent margin $(11.43\% \ [1.0 - 3.54/4.0])$ in accordance with the requirements of GDC 15 and 50. Table D-2 presents the calculation results of the containment external pressure analysis.

Table D-1 Initial Conditions for Containment External Pressure Analysis

Parameter	Initial value
Initial pressure	14.18 psia (0.997 kg/cm²A) (1)
Initial temperature	120 °F (48.9 °C)
Relative humidity	100 %
Spray droplet temperature	50 °F (10 °C)

Note

The minimum pressure is determined from the value, (14.7-0.1[LCO min. value] - 0.42[indicator uncertainty]) psia.

Table D-2 Calculation results of Containment External Pressure Analysis

Description	Value	Unit	Note
Initial total pressure	14.18	Psia	Given values
Initial temperature	120 (579.7)	°F (°R)	
Final temperature	50 (509.7)	°F (°R)	
Initial relative humidity	100.0	%	
Final relative humidity	100.0	%	
Initial steam pressure	1.69	psia	
Final steam pressure	0.18	psia	
Initial air pressure	12.49	psia	
Final air pressure	10.98	psia	Calculated values
Final total pressure	11.16	psia	
Pressure difference	-3.02	psid	
External maximum pressure	3.54	psia	
External design pressure	4.0	psig	
Pressure margin	**11.43**	%	

APPENDIX E

E. CONCLUSIONS

These appendices describe the GOTHIC containment methodology to estimate the containment maximum pressure and temperature responses to a spectrum of high-energy pipe breaks in the containment building. The analysis method to calculate M&E releases during the long-term boil-off phase is also described. The long-term M&E releases are calculated within GOTHIC using an integrated RCS/SGs model.

Application of the GOTHIC containment model to the APR1400 containment integrity analyses was performed and it was shown that the analysis results from the APR1400 GOTHIC containment model are bounded by the containment design limits with sufficient margins.

The APR1400 GOTHIC containment analysis methodology is thus established and will be used when determining maximum containment pressure and temperature and maximum IRWST water temperature following LOCA and MSLB accidents in containment.

APPENDIX F

REGULATORY REQUIREMENTS

FOR CONTAINMENT RESPONSE ANALYSIS

F. REGULATORY REQUIREMENTS FOR CONTAINMENT RESPONSE ANALYSIS

This section compares the proposed analysis methodology to NUREG-0800 and ANSI/ANS-56.4 guidelines. The APR1400 containment methodology is summarized with respect to each requirement outlined in the following table.

SRP 6.2.1.1.A PWR Dry Containments, Acceptance Criteria		
No.	Requirements	APR1400 Methodology
1	GDC 16 and GDC 50 The peak calculated containment pressure following a loss of coolant accident, or a steam or feedwater line break, should be less than the containment design pressure.	
2	GDC 38 The containment pressure should be reduced to less than 50% of peak calculated pressure for the design basis loss of coolant accident with 24 hours after the postulated accident.	
3	GDC 38 and GDC 50 For containment response to the loss-of-coolant accident, the analysis should be based on the assumption of loss of off-site power and the most severe single failure in the emergency power system (e.g., a diesel generator failure) the containment heat removal systems (e.g., a fan, pump, or valve failure), or the core cooling systems (e.g., a pump or valve failure). The selection made should result in the highest calculated containment pressure.	

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4	GDC 38 and GDC 50 For containment response to secondary system pipe ruptures, the analysis should be based on the most severe single failure in the containment heat removal systems (e.g., a fan, pump, or valve failure.) The analysis should also be based on a spectrum of pipe break sizes and reactor power levels. The accident conditions selected should result in the highest calculated containment pressure or temperature depending on the purpose of the analysis.	

ANS 56.4-1983 Requirements for Containment Integrity Analysis		
Subsection	Requirements	APR1400 Methodology
4.2.1	Postulated Accidents The analysis shall include a spectrum of break sizes, location and power level as required to ensure that the breaks yielding the maximum pressure and temperature transients are identified.	
4.2.2	Duration of Analysis Each analysis shall be carried out for a sufficient duration to ensure that the maximum pressure and temperature have been ascertained.	
	For the case yielding highest maximum pressure, the analysis shall be extended to demonstrate that the vapor region pressure is reduced below 50% of the peak calculated pressure within 24 hours and maintained below this pressure for the duration of the accident.	
4.2.3	Dry Primary Containment Analysis Model The model shall be based on a solution of the conservation equations for mass and energy for the dry primary containment system. In developing the containment model, two distinct regions, the atmosphere and sump regions, are typically identified to exist in the dry primary containment volume and are, therefore, identified as such in the analytical model.	
4.2.3.1.1	Dry Containment Atmosphere Region The steam and non-condensable components making up this region shall be considered to be homogeneously mixed and in thermal equilibrium with each other.	

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	The existence of water droplets in the dry containment atmosphere may be included if the treatment of their thermodynamic and mechanical behavior is justified	
4.2.3.1.2	Dry Containment Sump Region The sump region is defined as that volume of accumulated water on the dry primary containment floor. This region has no vapor space. The sump region may be assumed to be in pressure equilibrium with the containment atmosphere region.	
4.2.3.2.1	Pipe Break Blowdown As a minimum, the mass and energy release from the break shall be assumed to go directly to the containment atmosphere region for subsequent distribution, except that portion defined as spillage mass immediately to the sump region. For that portion of M&E released to the vapor region, a phase-separation model shall be used. This model shall produce a steam addition rate at least as large as that which is computed using the assumption of flashing to the saturation temperature at transient dry primary containment atmosphere steam partial pressure.	
4.2.3.2.2	Energy Source Terms Consideration shall be given to all credible energy sources not previously accounted for in the generation of M&E release data for their influence on atmosphere region pressure and temperature.	
4.2.3.2.3	Structural Heat Transfer	

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	The structural heat sinks are to be modeled conservatively with a lower bound estimate of the number, volume and heat transfer area.	
	The heat sinks are assigned to the vapor region or the liquid region by the arrangement of the containment. The assignment may be transient or split based on the geometric configuration of the sump water pool.	
	The rate of heat transfer within a heat sink is determined by the physical arrangement of the conducting layers, their thermal properties, surface properties and boundary conditions. The temperature profile through the heat sink is determined by an appropriate solution of the transient conduction equation. An appropriate value of contact resistance will be modeled where distinct material layers interface within the heat sink.	
	The thermal properties of the materials will be chosen to provide a conservatively low estimate of thermal capacitance and transmission capabilities.	
	Free convection, condensation and (where appropriate) radiation heat transfer will be addressed at the heat sink surfaces. Forced convection is difficult to defend in a 1-D model.	
4.2.3.2.4	<u>Containment Spray System</u> Transient heat removal from the containment vapor region due to sprays will be modeled. If the atmosphere is saturated, the spray will not evaporate. If the atmosphere is superheated, the evaporation rate of the sprays may be assumed to be unlimited. Un-evaporated spray water is assumed to go to	

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	the sump region at a temperature in equilibrium with the containment atmosphere. The residence time of the sprays in the containment atmosphere may be assumed to be zero.	
4.2.3.2.5	CHRS Energy Removal Terms Containment heat removal components, such as fan-coolers and recirculation system heat exchangers must model the mechanism and efficiency of energy removal for each component.	
	Sources of coolant for the containment heat removal components are assumed to be their highest credible temperature throughout the accident. A transient temperature may be used if it can be justified.	
	Modeling of heat removal components shall include effects of fouling, condensate build up or any conditions that may be expected to degrade the performance of the component.	
4.2.3.2.6	Atmosphere - Sump Interface M&E transfer across the atmosphere-sump interface by evaporation need not be treated unless the sump region bulk temperature exceeds the saturation temperature at the total pressure of the atmosphere region. Mass and energy transfer across the atmosphere-sump interface shall be considered for this "pool boiling" case.	
4.2.3.3	Modeling Considerations Selection of time step size and heat sink geometric nodalization shall be sufficient to ensure a physically representative solution that describes the dry primary containment	

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	system.	
4.2.4	Initial Conditions Initial conditions shall be chosen to yield a conservatively high peak containment atmosphere region pressure and temperature. In selecting the initial dry primary containment atmospheric conditions and structural temperatures, consideration shall be given to the competing effects of the initial air mass and the active and passive heat sink thermal capacities.	
4.2.5	Single Failure Criteria Dry containment response analyses shall incorporate the effects of the most severe single failure. The single failure chosen will be consistent with the single failure chosen for the generation of the M&E release data. The loss of offsite power to the plant shall be postulated concurrent with the LOCA. Continued availability of offsite power is typically limiting for MSLB	
4.4	Minimum Containment Pressure Analysis The minimum containment pressure analysis shall be performed to determine the worst-case negative pressure differential across the containment structure.	
4.4.1	Duration of Analysis The analysis shall be of sufficient duration to ensure that the absolute min. dry containment atmosphere pressure has been found.	
4.4.2	Initial Conditions For inadvertent spray actuation transients, the upper bound initial containment atmosphere temperature and lower bound initial containment pressure shall be used. For dry containment which does not employ vacuum breaking devices, the initial relative humidity	

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	shall be chosen to produce the lowest dry containment atmosphere pressure	
4.4.3	Structural Heat sinks In taking credit for the availability of structural heat sinks as an energy source, a lower bound estimate of their number and surface area shall be chosen. In addition, a lower bound surface heat transfer coefficient shall be used for these heat sinks.	

APPENDIX G

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G. REFERENCES

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