14.20 CONTAINMENT RESPONSE

14.20.1 INTRODUCTION

The Containment Structure encloses the primary and secondary plant and is the final barrier against the release of significant amounts of radioactive fission products in the event of an accident. The Containment Structure must be capable of withstanding the pressure and temperature conditions resulting from a postulated LOCA or main steam line break (MSLB) accident. While other events, such as a feedwater line break also discharge mass and energy to Containment, the LOCA and MSLB have been confirmed to be the two most severe inside containment events with respect to maximizing the peak containment pressure and temperature.

The Calvert Cliffs Unit 1 and 2 Containments are each approximately 2.0 E6 ft^3 in net free volume, and have a design pressure and temperature of 50 psig and 276°F, respectively. These containment design values were selected as a result of the original analysis of the LOCA. While 50 psig reflects a maximum pressure in the vapor space, the design temperature of 276°F is a structural limit of the concrete wall inner surface and the steel liner plate. The acceptance criteria for the containment response analysis is that pressure and temperature remain below these limits. This ensures that the containment response analysis is performed in accordance with proposed General Design Criteria 10, 40, and 52 with respect to containment heat removal and design margin. In addition to demonstrating that the structural pressure and temperature limits discussed above are met, the DBEs presented in this section are used to develop an enveloping containment accident pressure and temperature profile for the purpose of demonstrating the Environmental Qualification of safety-related electrical equipment in Containment.

This section summarizes the LOCA and MSLB containment pressure and temperature as well as subcompartment analyses. The pressure and temperature analyses for LOCA and MSLB have been further divided into mass and energy release calculations and containment response calculations. These analyses have been updated to address plant changes and issues. The MSLB containment analysis was updated due to the replacement of Units 1 and 2 SGs.

Consistent with the original design analyses, the mass and energy released into Containment during a LOCA has been calculated by the NSSS vendor, Westinghouse Electric Corporation, previously Asea Brown Boveri/Combustion Engineering, Inc. (ABB/CE). This information was used to calculate the peak containment pressure and temperature and long-term containment response. The MSLB mass and energy release rates were calculated by Framatome Technologies, Inc. (FTI) as part of Unit 1 steam generator replacement. As presented in the following sections, the results of these analyses have been shown to be within the stated containment design criteria.

14.20.2 LOSS-OF-COOLANT ACCIDENT

14.20.2.1 Description of Event

The LOCA is characterized by the rapid discharge of the RCS inventory into the Containment. The initial enthalpy of this discharge is on the order of 600 Btu/lbm. The containment pressure and enthalpy determine the fraction of this discharge which flashes to steam and the fraction which falls as liquid to the containment sump. This discharge causes containment pressure and temperature to rapidly increase and the containment vapor space quickly becomes saturated. This increase in pressure will initiate a CSAS, a SIAS, and a CIS. The containment pressure increase also initiates a reactor trip, which is quickly followed by the turbine trip. The CSAS and SIAS initiate containment spray and SIAS initiates containment air coolers (CACs). High containment pressure will also initiate the

SGIS which, together with CSAS, initiates the closure of the main steam and feedwater isolation valves. Finally, SGIS and CSAS both initiate trips of the steam generator feedwater pumps (SGFPs), heater drain pumps (HDPs), and condensate booster pumps (CBPs) which rapidly terminate feedwater flow to the SGs.

The large-break LOCA causes a rapid depressurization of the RCS whose pressure quickly falls below the shut-off head of the HPSIs and LPSIs, respectively. The SI pumps, with inventory from the RWT, are the primary source of core cooling for the majority of the event and will start in response to a SIAS on containment high pressure or low pressurizer pressure. Once RCS pressure falls below the SIT cover gas pressure, the SITs will also empty their liquid inventory into the RCS to aid in cooling the core.

Three break locations have been analyzed for Calvert Cliffs: a hot leg break; a cold leg break on the RCP discharge leg; and a cold leg break on the RCP suction leg. A spectrum of break sizes has been analyzed for these locations. For the cold leg break locations, the limiting break size has been determined to be a double-ended slot break (9.8 ft^2) on pump discharge (DES/PD) with maximum SI. For the hot leg break location, the limiting break size has been determined to be a 2.0 ft^2 break. In the case of a discharge leg break, the SI flow to the ruptured cold leg will largely spill to the containment sump. Full SI flow to the core will occur for both the suction and hot leg breaks. The SIT nitrogen cover gas, which is also released to Containment, is only a small component of the overall containment pressure response.

Although the primary-to-secondary heat transfer continues for approximately five-seconds, the primary side temperature rapidly drops below the SG temperature causing reverse heat transfer to occur for the remainder of the transient. This is particularly evident in the cold leg breaks, which have a viable steam flow path through the SG tubes prior to discharging to the Containment. For the cold leg breaks, the addition of SG energy to the exiting break flow extends the duration of the initial peak pressure and temperature and for Calvert Cliffs slightly increases peak pressure and temperature.

For the limiting hot leg break, the peak pressure and temperature occurs in approximately one minute while for the limiting cold leg break, it occurs approximately three minutes after the break. During the long-term portion of the analysis, a second containment pressure and temperature peak occurs following the Recirculation Actuation Signal (RAS). This function initiates the SI pump delivery switch-over from the injection mode to the recirculation mode. The second peak following the RAS occurs after the source of the water for the spray and injection to the reactor vessel is switched from the RWT inventory to the sump. Despite the fact that the recirculation from the sump is passed through the shutdown cooling heat exchangers (SDCHX), the temperature of the spray is higher than that of spray from the RWT. This reduces the effectiveness of the spray and results in the secondary peak pressure and temperature.

Following the initial blowdown, the reactor is first refilled by the incoming SI flow, and then reflooded as the core becomes quenched. During the reflood and post-reflood phases of cold leg breaks, the exiting steam first passes through the SGs and acquires energy prior to exiting the RCS to the Containment. Therefore, a detailed analysis of the reflood and post-reflood phases is necessary for cold leg breaks. The RCS and SGs come into a quasi-equilibrium state during this process and after the end of the post-reflood phase, the reactor vessel and the primary and secondary systems cool down together. This is the long-term phase of the event, which is typically simulated until the containment atmosphere temperature returns to its initial value. For the hot leg break, the greatest quantity of two-phase mass leaves the top of the core, bypasses the SGs, and discharges to the Containment. There is no mechanism for adding significant quantities of the secondary-side energy to the break flow stream. Hot leg break reflood and post-reflood energy release is, therefore, of minimal importance, and detailed reflood and post-reflood analyses are not performed for hot leg breaks. During this time frame, SI pump flow from the RWT continues to be fed to the reactor vessel. Following RAS, the LPSI pumps are shut off and the HPSI pumps recirculate sump water into the reactor vessel while the containment spray pumps recirculate sump water through the SDCHX to the containment atmosphere. Since the DES/PD with minimum SI results in the highest peak pressure and temperature, only the results of this LOCA are presented in this chapter.

14.20.2.2 Mass and Energy Release

The analytical simulation of the LOCA event is divided into four distinct phases. These are blowdown, reflood, post-reflood and long-term cooldown. For the Calvert Cliffs Units, the NSSS vendor calculates mass and energy release data for three of these four phases. As explained below, the long-term cooldown mass and energy release calculations were performed concurrent with the containment response simulation. The mass and energy release data for the first three phases was input to the Calvert Cliffs Containment model that was prepared with GOTHIC, Electric Power Research Institute's containment response code (References 37 through 42).

The blowdown phase of the LOCA lasts approximately 20 seconds, and is basically the complete discharge of the inventory in the RCS. Break mass and energy transfer rates for this portion of the LOCA are calculated with the NSSS vendor's CEFLASH-4A Code, Reference 2. While the original CEFLASH-4 Code referenced in the Standard Review Plan (SRP) was used in the original Calvert Cliffs analysis, this version of the CEFLASH computer code is no longer available for use and has been superseded by the NRC-approved 1985 Evaluation Model version of the CEFLASH-4A Code. In Appendix K analysis, the goal is to contain core heat to maximize the fuel/cladding temperature. Conversely, for the containment analysis, the goal is to maximize the heat removed from the core to maximize the severity of the mass and energy response. Thus, the biasing of key design inputs relative to the specific criteria for each analysis make the two sets of assumptions quite different.

While the SRP specifies that LOCA containment mass and energy release calculations should be done in general accordance with the Appendix K analysis, it states that additional conservatism should be included to maximize the release to Containment. This additional conservatism is addressed via the following inputs/assumptions:

a. The Appendix K prediction of fuel clad swell and rupture is not considered. This will maximize the energy available for release from the core.

b. Calculations of heat transfer from core to coolant assume nucleate boiling. This will maximize the energy transfer to the exiting RCS coolant. While nucleate boiling is assumed for a portion of the Appendix K transient, as core conditions change, different heat transfer correlations may be selected by the code. To maximize fuel/cladding temperature, once an alternate means of heat transfer is selected, the correlation does not go back to this high heat transfer regime.

c. The initial mass of water in the RCS is based on the temperature and pressure conditions existing at 102% of full power. This differs from the Appendix K assumption of using nominal (cold) volumes without inclusion of expansion due to normal operating pressure and temperature.

d. Some typical Appendix K assumptions are to isolate the SGs at the initiation of the event and not include the addition of MFW during the blowdown. For the containment analysis, a time-dependent MFW addition and realistic isolation of the SGs is assumed.

e. The ECCS performance analysis assumes maximum loop pressure differences, while the containment analysis assumes nominal pressure differences.

Since the refill phase (the time period during which the reactor vessel fills with SI liquid from the bottom of the reactor vessel to the bottom of the active core) is conservatively omitted for containment calculations, the next phase of the transient simulation is reflood. This is only applicable to cold leg breaks. Full core quench occurs several minutes after reflood. The post-reflood phase is the next phase during which the energy in the RCS and SGs is transferred to Containment via the exiting break flow. The end of post-reflood occurs when the RCS and SGs are essentially in equilibrium.

The reflood and post-reflood phases of the LOCA are simulated in accordance with the NRC-approved FLOODMOD2 methodology, Reference 3. The reflood and post-reflood phases are only used for the cold leg break analysis. During the reflood and post-reflood phases, liquid entrainment in the exiting steam flow is calculated based on a carryout rate fraction specified in the SRP.

The long-term phase of the LOCA completes the transient simulation of this event. GOTHIC is used to calculate the containment pressure and temperature response (Section 14.20.2.3) throughout the transient. This is accomplished by application of the mass and energy release data as well as RCS and SG conditions provided by the NSSS vendor, from the beginning of the event up to the end of blowdown for hot leg breaks and end of post-reflood for cold leg breaks. During the long-term phase of the event, the GOTHIC Code also calculates the mass and energy release data concurrent with the transient containment pressure and temperature calculation. This follows the post-reflood mass and energy release calculation and defines the final phase of the event. Since the Calvert Cliffs Containment model for the GOTHIC Code does not have a mechanistic calculation of sensible heat addition from the primary and secondary metal (including SG inventory), the NSSS vendor's CONTRANS containment code, Reference 4, was also run for this long-term phase. The rate of energy addition due to this sensible heat was then added to the decay power and used as input to the GOTHIC mass and energy release calculation. In this manner, all sources of energy were explicitly accounted for. Table 14.20-1 provides a summary of the significant assumptions associated with the LOCA mass and energy release methodology.

14.20.2.3 Containment Response Analysis

Calvert Cliffs' containment response to a LOCA was previously analyzed by using the COPATTA computer program, Reference 5. COPATTA, a Bechtel code derived from the industry computer program CONTEMPT, Reference 6, analyzes the effects of a high energy line break on the Containment Structure. The present analysis is however performed with the GOTHIC Code (References 37 to 43).

Description of the GOTHIC Code

GOTHIC is a state-of-the-art program that solves the conservation equations for mass, momentum, and energy for multi-component, multi-phase flow. The phase balance equations are coupled by mechanistic models for interface mass, energy, and momentum transfer that cover the entire flow regime from bubbly flow to film/drop flow, as well as single-phase flows. The interface models allow for the possibility of thermal nonequilibrium between phases and unequal phase velocities. GOTHIC includes full treatment of the momentum transport terms in multi-dimensional models, with optional models for turbulent shear and turbulent mass and energy diffusion. Conservation equations are solved for up to three primary and up to two secondary fields. The primary fields include steam/gas mixture, continuous liquid, and liquid droplet. The secondary field includes ice.

For the primary fields, GOTHIC calculates the relative velocities between the separate but interacting fluid fields, including the effects of two-phase slip on pressure drop. GOTHIC also calculates heat transfer between phases, and between surfaces and the fluid. Reduced equations sets are solved for the secondary fields by the application of appropriate assumptions. The three primary fluid fields may be in thermal nonequilibrium in the same computational cell.

The steam/gas mixture is referred to as the vapor phase and is comprised of steam and, optionally, up to eight different noncondensing gases. The noncondensing gases available in the model are defined by the user. A library of properties for nearly 50 different gases is available, although the user may include any noncondensing gas for which appropriate properties are known. Mass balances are solved for each component of the steam/gas mixture, thereby providing the volume fraction of each type of gas in the mixture.

The principal element of a model is a computational volume. GOTHIC features a flexible noding scheme that allows computational volumes to be treated as lumped parameter (single node) or one-, two- or three-dimensional, or any combination of these within a single model. Volumes partitioned with a one-, two- or three-dimensional computational grid are referred to as subdivided. As a minimum, a GOTHIC model consists of at least one lumped parameter volume. Subdivision of a volume into a one-, two-, or three-dimensional mesh is based on orthogonal coordinates. Adjacent cells in a subdivided volume communicate through parameters defined by discretization of the governing equations. Turbulence and hydrogen burn models augment the volume calculations. Separate volumes communicate through junctions or flow paths. A separate set of momentum equations are solved for junctions. Mass, momentum, and energy can be added or removed at boundary conditions that are connected to volumes by flow paths. Subdivided volumes also communicate through flow connectors. A single 3D flow connector can provide multiple connections between two subdivided volumes.

GOTHIC includes a general model for heat transfer between thermal conductors and the steam/gas mixture or the liquid. There is no direct heat transfer between thermal conductors and liquid droplets. Thermal conductors are modeled as one-dimensional slabs for which heat transfer occurs between the fluid and the conductor surfaces and, within a conductor, perpendicular to the surfaces. Thermal conductors can exchange heat by thermal radiation. Any number of conductors can be assigned to a volume. Nodalization of a conductor allows variation of material properties in the direction of heat transfer. Heat generation within thermal conductors may be specified on a node-by-node basis.

GOTHIC includes an extensive set of models for operating equipment. These items include pumps and fans, valves and doors, heat exchangers and fan coolers, vacuum breakers, spray nozzles, coolers and heaters, volumetric fans (annular fans, deck fans, etc.), hydrogen recombiners (forced and natural convection), ignitors (spark device used to ignite hydrogen burns), and pressure relief valves.

<u>General Model Description</u>

The GOTHIC model is concerned both with the pressure and temperature within the containment atmosphere and the temperatures in the Containment Structure. As discussed previously, the NSSS vendor provided the rate of mass and energy transfer from the RCS to the Containment up to the post-reflood phase. These are obtained from blowdown and core thermal behavior calculations, yielding mass and/or energy input rates from a variety of sources. These sources include the release of reactor coolant, the decay heat (causing heating or boiling of residing water in the reactor vessel), superheating of the steam as it passes through the RCS loops and SG, sensible heat from the RCS metal, and metal-water reactions. The long-term mass and energy release rates, from the vessel to the Containment during a LOCA, are calculated by GOTHIC. A control volume representing the reactor pressure vessel is used to simulate heat transfer from the core to the coolant during post-RAS injection to the RCS from the sump.

The basic Containment model describes the Containment and reactor vessel regions and the effects of heat sinks following a LOCA. Included in this basic model is the capability to accommodate operation of ESFs. Several options have been incorporated in the basic model to assist in using these features.

Superposition of heat input functions is assumed so that any combination of blowdown, metal-water reaction, decay heat generation, and sensible heat energy can be used with appropriate ESFs to determine the containment pressure and temperature-time history associated with a LOCA.

To model the containment response, the lumped volume option of GOTHIC is used, which is consistent with the methodology of Bechtel's COPATTA. Each lump volume consists of a pool and a vapor region. The pool region in the lumped volume for Containment represents the containment sump. The pool region for the reactor vessel represents the inventory of the downcomer, lower plenum, core and upper plenum. Evaporation from the surface of the liquid region is accounted for as GOTHIC calculates an interface temperature, which is then used to determine the rate of heat and mass transfer at the interface. Each region is assumed homogeneous, but a temperature difference can exist between regions. In GOTHIC, drops are treated separately. Hence, by accounting for heat and mass transfer between the vapor and the drop phase, GOTHIC allows for revaporization of the droplets while falling through the hot vapor region to the pool. The non-condensable gases are included in the vapor region.

<u>Thermodynamic Assumptions</u>

Based on the input model described in the previous section, GOTHIC calculates conditions in two separate regions of the Containment, the water region (sump) and the atmosphere region (vapor/drops). Following completion of the primary system post-reflood phase, GOTHIC also calculates conditions in the water and vapor/drop regions in the reactor vessel. GOTHIC allows transfer of mass and energy across these regions as well as between various phases in a region. GOTHIC solves the conservation equations for mass in each region for four phases of drops, liquid, ice, and vapor (steam/non-condensable gas) if any of these phases are present in the control volume. GOTHIC solves the conservation of energy for drops, liquid, and vapor and for solid thermal conductors if any of these are present. GOTHIC also solves the conservation equation for momentum for drops, liquids, and vapor. The conservation equation for mass in GOTHIC expresses that the “Rate of change of mass in a control volume = mass transfer by convection + mass transfer by diffusion + boundary source + interface source + equipment source + combustion source.” The conservation equation for energy in GOTHIC expresses that the “Rate of change of energy in a control volume = convection and flow work + energy carried by thermal diffusion + energy carried by mass diffusion + boundary source + interface source + equipment source + combustion source.” Finally, the conservation equation for momentum in GOTHIC expresses that “Rate of change of momentum in a control volume + momentum transfer by convection = surface stress + body force + boundary source + interface source + equipment source.”

Integration of the governing equations, with inclusion of the equations of state, for each region, from the start of the transient to any later time, provides the thermodynamic properties with which the state point conditions or pressure and temperature can be determined. Numerical integration of the governing equations and calculation of the properties within each region are based on the following assumptions for the Containment model:

a. At the RCS break point, the discharge flow separates into a steam phase that is added to the atmosphere (vapor) region, and, as specified by boundary condition parameters in the GOTHIC model, the water is added as drops. The steam and drops enter the containment atmosphere at the conditions specified by the boundary condition parameters. In general, the steam will approach saturation at the partial pressure of steam in the atmosphere, while the drops will approach saturation at the total pressure of the atmosphere.
b. The steam and air partial pressure comprise the total containment atmosphere pressure, which is also the sump pressure. Following blowdown, the primary-system (reactor vessel region) pressure remains slightly higher than the containment pressure, which provides sufficient driving force for discharge of steam to the Containment through the break.
c. Initially, the steam-air mixture, the drops, and the water phase are each assumed homogeneously mixed with uniform properties. Specifically, thermal equilibrium between the air and steam is assumed. However, a temperature difference may exist between each phase.
d. Steam that condenses from the atmosphere onto the structure is added to the sump. During any time interval, the condensate is allowed to revaporize if sufficient heat exists in the atmosphere to cause the phase change.
e. Mass and energy will be transferred from the liquid regions (sump and reactor vessel) to the containment atmosphere by flashing, if the calculation indicates that the containment pressure is less than the saturation pressure corresponding to the liquid temperature.
f. The sump region contains no water at the beginning of the design basis accident.
g. Condensation of steam due to a vapor pressure gradient between the steam in the containment atmosphere and the water in the sump is conservatively neglected.

h. Condensation of steam on structural heat sinks occurs at the saturation temperature corresponding to the partial pressure of the steam phase in the Containment.

Atmosphere and Sump Description

The free volume of the Containment is modeled by a single control volume. In the GOTHIC model, this control volume includes the atmosphere and sump regions of the Containment, as well as the equipment models and heat structures that apply within the Containment. The atmosphere generally contains air, steam, and drops. Liquid is added to the sump and the pool as spray and liquid spills out the broken loop. Condensate on the heat structures is also added to the pool. Initially, there are no drops in the atmosphere or liquid in the pool except for a very small, but non-zero, volume fraction. The equipment models include a control volume representing the reactor vessel, coolers representing the heat removal function of the fan coolers, and heat exchangers that remove heat from the fluid when water from the sump is recirculated to the spray system. The equipment models and heat structure models are discussed in the following paragraphs.

Reactor Vessel Region Description

A separate reactor vessel region is used in the GOTHIC model to include the effects of decay power, metal-water reaction, heat transfer from the primary system metal, and SI water cooling. This region is not used during the initial mass and energy release phases (blowdown, reflood, and post-reflood) when the primary coolant system pressure is not in equilibrium with the containment atmosphere. During the initial phases, reactor coolant stored energy, decay power, and other energy sources are normally added to the vapor in the containment atmosphere as blowdown energy releases furnished by the NSSS vendor. The reactor vessel is modeled in GOTHIC as a lumped control volume in which the decay and sensible heats, as provided by the NSSS vendor, are added via a GOTHIC heater. The post-RAS portion of the break event is initiated by opening a valve on a flow path connecting the reactor vessel to the Containment, simulating a cold leg or a hot leg. The valve opens at the termination of reflood/post-reflood phase. The pre-RAS SI is modeled by a GOTHIC flow boundary condition. The post-RAS SI is modeled by a GOTHIC “coupled boundary condition” that models injection of the sump water into the reactor vessel. The vessel pressure is the same as the containment pressure at the termination of the reflood/post-reflood phase. The vessel volume is just slightly larger than that used in COPATTA model to allow steam accumulation.

Calculation of long-term mass and energy transfer from the reactor vessel region takes place at the end of the blowdown phase for hot leg breaks or at the end of the post-reflood phase for cold leg breaks.

Heat Transfer Considerations

During a LOCA, heat transfer takes place between the containment atmosphere, sump or reactor vessel water, and the exposed surfaces inside the Containment Structure. These surfaces may be building structures, primary or secondary system components, equipment, or other possible heat sinks or sources. The rate of heat transfer between the containment regions and these conducting masses, is determined by the surface area, the surface temperature, the heat transfer coefficient, the physical arrangement of the conducting masses and the thermal properties of these masses. All of the above parameters are considered by the GOTHIC Code during the transient analyses as described in this section.

Additional heat transfer from the containment system can occur via a heat exchanger system connected to the sump water recirculation piping. Heat transfer calculations made in this manner permit the removal of residual or decay heat, that has been added to the containment sump during cooling of the RCS. The method of calculating this heat transfer is described below.

a. Heat Conduction Calculations

In the GOTHIC Code, there is no limitation on the number of thermal conductors in a model. These solid conductors can be described by a one-dimensional, multi-region, heat conduction equation given by:

$$\rho c \frac{dT}{dt} = \nabla \bullet (k \nabla T) + \dot{q}'''$$

where:

T	-	temperature (°F)
t	-	time (hr)
k	-	thermal conductivity (Btu/hr-ft-°F)
c	-	specific heat (Btu/lbm-F)
ρ	-	conductor density (lbm/ft^3)
$\dot{q}'''$	-	volumetric heat generation rate (Btu/hr-ft^3)

To perform heat transfer calculations for thermal conductors in GOTHIC, the del operator, ∇, is applied in the Cartesian and the cylindrical coordinates. To be consistent with the COPATTA methodology (Reference 22), a one-dimensional slab is used to model various conductors inside the Containment in the GOTHIC model. Thermal properties of the conductors are properly allowed to change as a function of temperature.

The input for the heat conduction calculations includes provisions for specifying geometry type, surface area, number of different material regions (with coordinates), mesh spacing, and material type for each heat conductor. The magnitude of heat generation, thermal properties, and boundary conditions for each portion of the heat conductors are specified in a similar manner.

Normally, each heat conductor will include all of the solid components comprising a structure in the Containment. For example, the containment structure walls are specified by four materials, consisting of a topcoat layer of paint, a layer of primer coating, a steel liner plate, and several feet of concrete. Similar specifications are made for the other structures within the Containment Structure.

Boundary conditions ranging from perfectly insulated (adiabatic) to zero resistance are applied to the heat conductor surfaces, as appropriate. These boundary conditions may indicate exposure to a constant temperature, a time-dependent temperature (such as the containment atmosphere temperature, the sump temperature, or the reactor vessel water temperature), or some combination of the above. Solution to the thermal conduction equation requires one initial and two boundary conditions to be specified. For the initial condition, the surfaces of all thermal conductors exposed to the containment atmosphere are assumed to be at thermal equilibrium with the containment atmosphere. For boundary conditions, the surfaces of thermal conductors are either exposed to a convection boundary (i.e., a specified bulk fluid temperature and a heat transfer coefficient), or insulated. Condensing heat transfer coefficient values are based either on the steam/air ratio in the containment atmosphere (Uchida condensing heat transfer coefficient) or a turbulence parameter inside the Containment (Tagami condensing heat transfer coefficient).

b. Heat Transfer Coefficients

Heat transfer in the heat conductors within the Containment Structure is dependent upon the assumed heat transfer coefficient between the containment region and the heat conductor surface. Heat transfer to the heat sinks from the containment atmosphere region is determined by the Tagamiheat transfer coefficient correlation, References 8 and 9. This empirical correlation is applicable during the forced convection period following primary system blowdown. In the Tagami correlation, the maximum heat transfer coefficient is related to three parameters. These parameters are: the total energy released from the primary system during the beginning of blowdown to the first peak pressure in the Containment, time to the first peak pressure (t_p), and containment free volume. The shorter the time to the first peak pressure, the higher the heat transfer coefficient. Similarly, the larger the containment free volume, the higher the heat transfer coefficient. Since the time to the first peak pressure is not known initially, trial runs were made to determine the time to peak pressure. Having found the maximum value for the heat transfer coefficient, values at other points in time are found by linear interpolation. The Tagami correlation is only applicable up to time t_p. Afterward, another correlation is used as described next.

During the post-blowdown period of the transient, a quasi-steady-state condition develops due to decreasing turbulence in the Containment. Heat transfer under these conditions is dependent upon the steam-air mixture. Experimental work by Uchida, et al, Reference 13, has shown that during free convection cooling periods, the condensing heat transfer coefficient is dependent on the ratio of non-condensable gas to steam masses. Application of the Uchida data during the long-term cooling period, and adoption of a transition heat transfer coefficient between the “Modified Tagami” value and the Uchida value (based on the reduction of turbulence in the Containment), completes the specification of the condensing heat transfer coefficient during LOCA transients.

The heat transfer coefficient between the water regions of the sump and the basemat is conservatively neglected. A natural convection coefficient of 1 Btu/hr-ft^2-°F is assumed for the outer surfaces of the Containment Structure, which are exposed to the outside atmosphere. Zero heat transfer is specified at external surfaces exposed to the earth and at the liquid-vapor interface between the containment sump and atmosphere regions. These thermal boundary conditions contribute to prediction of conservative values of pressure and temperature within Containment.

c. Heat Exchanger Calculations

The GOTHIC Code provides models for both water-to-water heat exchanger and fan coolers. The heat exchanger model is used to determine the rate of heat removal from the sump during the long-term cooling period of the LOCA. Four types of heat exchangers may be specified with several optional combinations of containment spray or core SI water cooling (using either a single, two parallel, or two series units).

The available heat exchanger types are parallel flow, counter flow, cross-flow with mixed secondary flow, and parallel-counter flow (shell & tube) with mixed shell fluid. The physical and thermal characteristics of each heat exchanger are specified, as are the coolant inlet temperatures and flow rates.

The heat exchanger performance calculations are made using the method of heat transfer effectiveness as developed by Kays and London, Reference 14. This method employs the number of exchanger transfer units to evaluate an effectiveness for heat transfer. The effectiveness is defined as the ratio of the actual heat transfer to the maximum theoretical heat transfer. An effectiveness is calculated for any of the four heat exchanger types specified, and from the effectiveness, the heat exchanger duty, and system temperatures are determined.

Safety Injection System

The effect of the SI System on the containment pressure and temperature analysis is simulated in the GOTHIC model by a provision for pumped coolant injection into the reactor vessel region during the post-blowdown period. The accumulation of water in the reactor vessel region, the addition of heat to the region, and the effects of the pumped SI are all accounted for in the reactor vessel region calculations.

Safety injection water may be supplied from an external source or from recirculation from the containment sump. Variable injection flow rates and temperatures may be specified. The injection flow or a fractional part of the injection flow may be added directly to the containment sump, thereby permitting any combination of system ruptures to be simulated. Safety injection water supplied by sump recirculation may be passed through the heat exchangers.

The actions of core filling systems provided by high pressure injection or flooding are normally provided for in the NSSS blowdown data as input mass and energy entering the Containment from the primary system.

Containment Cooling Systems, Air Coolers

The GOTHIC Code is capable of simulating the effects of containment ESFs. These include the addition of either externally-supplied or internally-recirculated containment spray water and the cooling of the atmosphere region by fan cooling units.

Although CACs and the entire Service Water System can be explicitly modeled with GOTHIC, the air cooler heat removal rate as a function of steam saturation temperature is specified as boundary condition consistent with the COPATTA methodology. The number of units and the starting and terminating times for these units depend upon the assumed single-failure and operation of the containment cooling systems.

The effect of saturation temperature of the steam-air mixture on the heat removal capability of the CACs, assuming constant service water inlet temperature (105°F) and air flow rate (55,000 cfm), is shown in Figure 14.20-1, and is calculated in Reference 15.

Containment Cooling Systems, Spray Trains

The GOTHIC Code is capable of simulating the effects of containment sprays. Although Containment Spray Systems can be explicitly modeled with GOTHIC, a spray flow rate and enthalpy is specified as a boundary condition to the GOTHIC model, which is consistent with the COPATTA methodology.

The Containment Spray System flow rate, inlet temperature, delay time after actuation, and termination time are specified as input data to the GOTHIC model. The water supply may be external or internal. Prior to RAS, the RWT is the source for the spray water. Following RAS, internally-recirculated water from the sump as a function of time is passed through the SDCHX before it is sprayed into the containment atmosphere as described in the portion of Section 14.20.2.3 labeled “Heat Exchanger Calculations.”

The heat removed from the atmosphere region due to spray water heating is added to the sump water. In a similar manner, any condensate due to this atmosphere cooling is also added to the sump.

To account for condensation degradation due to the presence of the non-condensable gases, containment codes such as COPATTA, CONTRANS, and CONTEMPT use a so-called spray efficiency or effectiveness. The GOTHIC Code does not require such a multiplier due to the explicit treatment of drops.

14.20.2.4 Inputs and Assumptions

Initial Conditions

Mass and Energy Analysis:

The initial plant conditions for the LOCA were selected to maximize the release of mass and energy to the Containment. The worst case 102% power level was evaluated for this effort. Presented in Table 14.20-2 is a summary of the key inputs and assumptions for the limiting DES/PD maximum SI case of this effort.

The inputs were selected to contribute to conservative predictions of the primary and secondary side mass and energy. Key inputs like initial SG water and steam mass, core flow rate, T_{cold}, SG tube heat transfer via SG tube plugging and tube removal, RCS and SG volumetric expansion, core power, and primary and secondary side metal mass were selected to achieve this condition. The trip logic associated with isolating main steam and MFW flow was also carefully biased, such that a conservative response would be obtained.

Containment Pressure and Temperature Analysis:

The containment pressure and temperature analysis input data have been developed based upon the design for the plant. A thorough compilation of geometric, thermodynamic, design, and initial operating conditions was prepared prior to the evaluation of the postulated LOCA. These physical and performance conditions were determined based upon estimates of design parameters that would contribute to conservative predictions of containment pressure and temperature. A summary of the data is given below.

The containment parameters used for the pressure and temperature transient analyses are given in Table 14.20-3. The net free internal volume was computed from a gross volume and occupied volume calculation, Reference 16. The initial thermodynamic conditions (pressure and temperature) in the Containment are the maximum expected values based on Technical Specifications.

The containment heat sink data specified for the heat transfer calculations during the LOCA are given in Tables 14.20-4 and 14.20-5, and are calculated in Reference 17. Table 14.20-5 lists the geometric configuration of the heat sinks, including the materials and thermodynamic properties, thicknesses, and surface areas. A revised analysis was performed with the GOTHIC Code to determine the effect of the degraded properties of a new coating on the containment response to design basis accidents. The conservatively determined heat transfer coefficients used in the analysis are given in Table 14.20-4. These data, plus the geometric data, completely specify the necessary heat sink conditions for the calculations of heat transfer to and within the structures of the Containment during the LOCA.

Concurrent Events

A LOOP at the initiation of the event was assumed for the limiting cases evaluated in this analysis. Although cases with offsite power available were evaluated, the LOOP case produced a slightly more severe containment peak pressure and temperature response. No other concurrent events were assumed in this analysis.

Single Failures

A range of single failures was considered in the LOCA analyses for the three break locations analyzed (References 19 through 21). Failures involving the containment heat removal systems had the greatest negative impact. Failure of a diesel generator (coupled with a LOOP), which disables one train of spray and one train of containment coolers, was shown to be the worst case for the hot leg break. However, the failure of one train of containment coolers, with SI flow maximized (i.e., with two diesel generators functioning), provided the most limiting results for a cold leg break. This is true because under this scenario, SI flow to the RCS and, ultimately the Containment, is maximized resulting in a more severe mass and energy release to the Containment. The DES/PD cold leg break with maximum SI flow provided the most severe peak containment pressure and temperature, slightly worse than the DES/PD break with minimum SI. Therefore, the limiting case presented is the DES/PD break with a LOOP and the failure of one train of containment coolers. This case is referred to as the ‘DES/PD maximum SI’ case below.

A passive failure, which disables all of component cooling water was considered. However, this failure was determined not to be limiting with respect to peak containment pressure and temperature. The passive failure need only be assumed to occur after a RAS. In addition, when a passive failure is assumed to occur, no active failure need be assumed. Therefore, all ESF equipment would be available prior to a RAS and the peak pressure and temperature for this scenario is not limiting.

Automatic RPS/ESFAS Functions

Presented below is a list of the functions credited in the limiting DES/PD maximum SI LOCA mass and energy release and containment response analysis:

RPS/ESFAS FUNCTION	EQUIPMENT FUNCTION	ANALYSIS SETPOINT	RESPONSE TIME SIGNAL + EQUIP (sec)
CSAS	MFW, Condensate Booster, HDPs Trip	4.75 psig	0.9 sec trip delay with 10 sec pump coast down
SIAS/CSAS	Containment Spray Initiated	4.75 psig	70.9 sec
SIAS	CACs Start	4.75 psig	35.9 sec
SIAS	HPSI and LPSI Inject	4.75 psig	15 sec[a]
RAS	SI Suction from RWT to Sump	47.5”[b]	N/A[c]

(a) This response time represents a minimum (during a LOOP) since SI flow makes containment response more severe.

(b) The analytical setpoint shown is the level above the bottom of the RWT. This setpoint is conservatively high since it minimizes the relatively cool RWT inventory pumped to Containment.

(c) No explicit response time is credited. However, the response time must be rapid enough to ensure continuous SI flow as the pump suction is transferred to the sump.

Note that for breaks as large as that analyzed in the limiting case, the reactor will shut down on voids, therefore no RPS trip (insertion of shutdown rods) is credited for the limiting case.

Other Equipment Safety Functions

The analysis of the containment pressure and temperature response to a LOCA credits the proper functioning of the ESFs. The performance of the ESFs for the containment design basis is given in Table 14.20-6. Except when affected by single failure assumptions, ESFs operate at 100% capacity. For the minimum SI cases, only one high-pressure pump, one low-pressure pump, one spray pump, and two fan cooling units are assumed to be in operation.

Operator Actions

Consistent with plant emergency procedures, for the maximum SI case, the operator is assumed to terminate the operation of one train of sprays when the pressure in the Containment decreases to 4.75 psig following the peak.

14.20.2.5 Results

Mass and Energy Release Results

Containment responses to design basis accident (DBA) LOCAs were reanalyzed due to the vendor using a coarse mesh to edit data. Using a finer mesh (0.05 seconds versus 0.5 seconds) increased the peak mass flow rate in the blowdown phase of the LOCA, which was obscured in the coarse mesh edit. Using a finer mesh (0.01 seconds) did not change the data. Also standard test procedures on the SI pumps demonstrated that higher total dynamic head were produced by these pumps than previously measured. Therefore, new sets of mass and energy release data were produced by Westinghouse for five LOCAs using CEFLASH-4A, CEFLOOD3, and CONTRANS2 (Reference 49). These five sets include a double-ended split (slot) break LOCA on the pump discharge with the maximum set of SI pumps, a double-ended split (slot) break LOCA on the pump discharge with a minimum set of SI pumps, a double-ended split (slot) break LOCA on the hot leg with the maximum set of SI pumps, a double-ended split (slot) break LOCA on the hot leg with a minimum set of SI pumps, and a 2 ft^2 break LOCA on the hot leg with a minimum set of SI pumps.

Using the above sets of mass and energy release data it was determined (References 46 through 48) that a double-ended split (slot) break LOCA on the pump discharge with a minimum set of SI pumps available results in highest peak pressure in the Containment. With an adjustment in the initial containment pressure in the Technical Specifications from 1.8 psig to 1 psig, the peak pressure of the most limiting LOCA is below the design limit of 50 psig (References 50 and 52). Figure 14.20-2 shows containment pressure as well as vapor and water temperatures. The sequence of events is shown in Table 14.20-7.

Containment response to a LOCA is also applicable to both RSGs. This is because the primary side of both OSG and RSG are nearly identical.

14.20.2.6 <u>Summary of LOCA Analysis and Effect of the RSGs</u>

The effect of the RSGs on the LOCA containment response was evaluated in the mid-1990s. The SG parameters that affect peak pressure and temperature during the large-break LOCA are the primary liquid mass and energy, and total system sensible heat. The peak pressure and temperature reached during the blowdown phase are solely a function of primary system mass. Because the RSG has a slightly smaller primary volume, it will have less primary mass and a slightly lower blowdown peak. Conservatively using the difference at cold conditions, the decrease in energy would be 662,000 Btu. The second, higher peak is reached during the reflood phase of the LOCA. The reflood mass release rates are not significantly affected by the RSGs because the RSG flow resistance at zero plugging is within one percent of that of the OSGs. The energy released to Containment at this time is dictated mainly by fuel-stored energy removal and secondary pressure. The RSGs will operate at a higher pressure than that assumed in the analysis. The increase in energy caused by the higher secondary pressure was compensated for by the decrease in energy due to the primary volume effect. Therefore, the peak pressure with the RSGs is bounded by the peak pressure with the OSGs.

The long-term pressure and temperature are controlled by total system sensible heat and the containment heat removal systems. The total sensible heat of the RCS with the RSGs in place was determined to be virtually identical to that of the RCS with the OSGs. Because the primary system volume is less, and the system sensible heat is virtually identical, the results of the current analysis remain applicable to the RSGs.

14.20.3 MAIN STEAM LINE BREAK

14.20.3.1 <u>Description of Event</u>

The MSLB containment event is characterized by the rapid blowdown of steam into Containment due to a rupture in the main steam line. The location of this break is at the SG outlet nozzle, upstream of the MSIVs. This location results in the largest possible break size. The initial portion of the transient is characterized by the blowdown of both SGs, including the main steam lines downstream of the

MSIVs. In this early phase of the event, steam also continues to flow to the turbine, until the reactor trips. Following the reactor trip, which occurs on containment high pressure, the turbine stop valves close. During this portion of the transient, MFW continues to feed the SGs.

Coincident with the reactor trip, CSAS and SIAS occur on containment high pressure. Containment spray actuation signal initiates the closure of the MSIVs, closure of the MFIVs, trips the SGFPs, CBPs and HDPs, and opens the containment spray valves. Safety injection actuation signal switches the CACs from the normal operation fast speed mode to the accident condition slow speed mode of operation.

Following the closure of the MSIVs, the contribution of steam to Containment from the intact SG ceases. This SG remains isolated for the reminder of the event. The remaining steam downstream of the MSIVs to the turbine stop valves is also isolated upon MSIV closure, and no longer contributes to the blowdown to Containment.

The isolation of MFW in response to the CSAS occurs via tripping of the SGFPs, CBPs, and HDPs. While some preferential flow is diverted to the ruptured SG due to the relatively high pressure difference between the SGs, the contribution of MFW flow is greatly reduced with the pump trips on high containment pressure. Following SGFP coastdown, the MFIVs shut within approximately 65 seconds to fully isolate MFW flow. The feedwater regulating valves and their associated bypass valves act to ramp feedwater flow to approximately 5% of rated feed flow within 20 seconds of the turbine trip; however, this function is not credited in this analysis. Upon closure of the MFIVs, feedline inventory upstream of the SG feedwater inlet nozzle to the MFIVs will flash into the ruptured SG.

In the event that the MFIV fails to be capable of closing completely under the analyzed conditions, action of the feedwater regulating valves and their associated bypass valves may be credited, along with a fully open MFIV, to isolate MFW flow to the affected SG.

During the initial phase of the event, the only source of heat removal is via condensation heat transfer to the heat sinks or containment walls. Following the generation of the CSAS, the containment spray line valves will open to allow spray flow to enter Containment at approximately one minute into the event. The containment spray pumps will start in response to a SIAS, also on containment high pressure.

To supplement the active containment heat removal provided by the containment sprays, the CACs also start in response to SIAS. This signal switches the fan speed from fast to slow, and also opens the appropriate service water valves to allow more cooling flow to the CAC units. There are two containment spray trains and four CACs (two trains of two) inside Containment. The operation of the containment sprays and CACs aids in terminating the increase in containment pressure and temperature.

Auxiliary feedwater is actuated on low SG level during the MSLB. Since the SG pressure differential between the ruptured and intact units quickly diverges due to the double-ended guillotine break, the high SG differential pressure setpoint for blockage of flow to the ruptured SG is quickly reached. Following approximately a 20-second delay for AFW block valve closure, the AFW flow is terminated. Thus, a relatively small integrated amount of AFW actually enters the ruptured SG for contribution to the overall mass and energy release.

With AFW isolated, the ruptured SG boils dry, thus terminating the mass and energy release to Containment. At this point, the active and passive containment heat removal devices continue to decrease containment pressure and temperature to their initial values.

14.20.3.2 Mass and Energy Release Methodology

The sensitivity study performed on the mass and energy release for the MSLB event, References 36 and 44, focused on a matrix of cases. This matrix included four different initial power levels and numerous different single failures. The goal of the analysis was to maximize the severity of the mass and energy release, which in turn maximizes the containment pressure and temperature response.

The methods followed for this analysis are consistent with FTI's NRC-approved RELAP5/MOD2-B&W MSLB methodology (Reference 45). A detailed feedwater system is included in the reference such that the modeling of feedwater flow is similar to that approved by the NRC as part of the NRC Bulletin 80-04 analyses for Calvert Cliffs.

A summary of the significant assumptions or methods which have been included in this analysis are provided in Table 14.20-8.

RELAP5/MOD2-B&W is the primary computer code used to model the mass and energy release during a MSLB. This model includes both primary and secondary systems, coupled through the SG tubes. As such, the model accounts for the reactor core, vessel, RCS piping, RCPs, and the pressurizer. The model for the secondary side of the SG includes the main feedwater and the main steam systems. Nuclear heat production in the core is modeled by one group point kinetics with six delayed neutron groups. The neutronics model also accounts for the effect of such thermal feedback as Doppler and moderator temperature on reactivity. Shutdown CEAs and decay heat generation are also modeled. As discussed in Section 14.20.3.5, the input data were conservatively biased to maximize the mass and energy release.

Framatome Technologies, Inc. used the NRC-approved containment code CONTEMPT to predict the timing of the containment high pressure set point.

The RELAP5/MOD2-B&W Code was used to calculate the contribution of main feedwater, including flashing, to the ruptured and intact SGs. This code was used to simulate the Calvert Cliffs MFW trains, which included SGFP, CBPs, and HDPs. These trains were represented by a total of 51 nodes, pumps, valves, and feedwater heaters. The resistance in the feedwater piping was conservatively minimized and no credit was taken for the closure of the MFW regulating valves. Although the feedwater heaters were conservatively represented as hot slabs, this analysis used a realistic representation of the cooldown of the feedwater heaters following the isolation of shell side steam flow following turbine trip.

A realistic coastdown of all feed train pumps was modeled after the time to reach the CSAS setpoint on containment high pressure.

14.20.3.3 Containment Response Analysis Methodology

The containment pressure and temperature response to a MSLB is calculated using the GOTHIC computer program, References 36 to 44. The program model description and thermodynamic assumptions are provided in Section 14.20.2.3. The primary differences between the LOCA analysis and the MSLB analysis are:

the reactor vessel region model is not employed in the MSLB analysis; and the Uchida correlation is used for the heat transfer coefficient to the structural heat sinks in the MSLB, rather than the Tagami, as described in the portion of Section 14.20.2.3 labeled "Heat Transfer Coefficients."

14.20.3.4 Inputs and Assumptions

Initial Conditions

Mass and Energy Analysis:

The initial plant conditions for the MSLB analysis were selected to maximize the mass and energy release. The initial power levels assumed for this analysis were 102%, 75%, 50%, and 0% of 2700 MWt. An additional 17.1 MWt was included to account for the rate of heat addition from the RCPs to the reactor coolant. Since four power levels were evaluated in this analysis, a number of power dependent inputs were adjusted to conservatively reflect plant conditions for each power level. Presented in Table 14.20-9 is a summary of the key inputs and assumptions for the limiting case of this analysis. The design basis assumption of a full double-ended guillotine break with 0% moisture carryover is used in this analysis.

The RELAP5/MOD2-B&W inputs for each power level were selected to maximize the primary and secondary side inventories and energies. Key inputs, like initial SG water and steam mass, feedwater flow, T_{cold}, SG pressure, primary-to-secondary heat transfer via SG tube plugging and tube removal, RCS flow rate, RCS and SG volumetric expansion, core power, and primary and secondary side metal mass, were selected to achieve this condition. The trip logic associated with isolating the intact SG as well the MFW flow was also carefully biased, such that a conservative response would occur. Since the diversion of AFW to the intact SG reduces the energy of the RCS (albeit a small amount), AFW flow to the intact SG was conservatively omitted in this analysis.

Since a number of trade-offs are present in the MSLB event, the determination of the most limiting case is only possible by the computer code simulation. One key trade-off exists in the power level versus inventory and feedwater flow inputs. As initial power level increases, RCS temperature and core decay heat increases and more primary-to-secondary energy is present to boil off the SG inventory. Main feedwater flow rate and enthalpy increase accordingly. However, initial SG inventory decreases with increasing initial core power. Therefore, the MSLB analysis includes an evaluation of multiple power levels.

Containment Pressure and Temperature Analysis:

The containment pressure and temperature analysis input data have been developed based upon the design of the plant. A thorough compilation of geometric, thermodynamic, design, and initial operating conditions prior to the hypothetical occurrence of an MSLB has been prepared. These physical and performance conditions were determined based upon conservative estimates of the most adverse design parameters with respect to maximizing containment pressure and temperature. The initial plant conditions assumed in the analysis of the containment response to an MSLB are provided in Table 14.20-10. In addition to the Containment initial conditions, this table also lists several of the key assumptions concerning the actuation and performance of the CACs and the containment sprays.

Concurrent Events

A LOOP at the initiation of the event with the coincident failure of one diesel generator was evaluated as part of this analysis. It was determined that the LOOP scenario produces a less severe containment response than with offsite power available. This is due to the continued operation of the RCPs with offsite power available, which maximizes the primary-to-secondary heat transfer. This offsets the loss of one train of CACs and one train of containment sprays for the LOOP scenario. Although the limiting case did include the worst single failure, no concurrent event (such as LOOP) was assumed.

Single Failures

The updated MSLB containment analysis included a detailed single failure analysis. Each of these failures was evaluated at four different power levels: 102%, 75%, 50%, and 0%. Note that for each case, no credit was taken for the closure of the main feedwater regulating valves, both the feedwater regulating valves and the associated bypass valves were assumed to fail as is for the duration of the analysis. This assumption is consistent with the NRC Bulletin 80-04 evaluation conducted to address the effects of extended feedwater addition. Presented below is a list of the single failures addressed in this analysis.

a. Loss-of-offsite power and one emergency diesel fails to start, resulting in the loss of one spray train and two CACs. This will leave one spray pump and two CAC units available. Reactor coolant pumps coast down on loss of power. This represents the LOOP case.
b. A service water pump fails which disables a train of CACs. This will leave two containment sprays and two CAC units (one train) available.
c. One containment spray pump fails to actuate. This will leave one containment spray and four CAC units available.
d. The CSAS fails to trip a SGFP.
e. The CSAS fails to trip a CBP.
f. The CSAS fails to trip a HDP.
g. The failure of a MSIV to close. This is the MSIV on the ruptured side since the steam in the steam lines downstream of the other MSIV will blowdown to Containment.
h. The failure of an MFIV to close.

The single failure of a service water pump (which disables one train of CACs) was shown to be more limiting than the loss of a containment spray pump. As expected, the LOOP with the coincident failure of a diesel generator was not a limiting case due to the tripping of the RCPs. This degraded the primary-to-secondary heat transfer, which drives the boil-off process.

The failure of an MSIV or MFIV was not shown to be a limiting single failure. In the case of the MSIV failure, the additional steam downstream of the MSIV on the intact SG was not significant relative to other more severe feedwater-related single failures. For the MFIV failure, the flow rate from the condensate pump was not significant and the water injected was relatively cool.

The most limiting case was determined to be the 75% power case with the failure of a SGFP to trip in response to an SGIS (CSAS) on containment high pressure. This event assumed the availability of offsite power and continued operation of RCPs since this condition results in a more severe containment response. Containment pressure and temperature for the RSG MSLB are shown in Figure 14.20-3.

Automatic RPS/ESFAS Functions

The following trips were relied upon for the mass and energy release analysis.

RPS/ESFAS FUNCTION	EQUIPMENT FUNCTION	ANALYSIS SETPOINT	RESPONSE TIME SIGNAL + EQUIP (sec)
RPS Trip on High Containment Pressure	Reactor Trip Breakers Open	4.75 psig	0.9
CSAS	MSIV Closure	4.75 psig	0.9 + 7.0 = 7.9
CSAS	MFIV Closure	4.75 psig	0.9 + 65 = 65.9 (No LOOP)
CSAS	SGFPs, CBPs, and HDPs trip on CSAS	4.75 psig	0.9 signal delay with 1 sec pump trip delay
AFAS	AFW Initiated to SG	66.5“ below normal water level	0.9 + 20.0 (timer delay) = 20.9 (minimum)
AFAS Block	AFW to Ruptured SG Isolated	250 psid	0.9 + 20.0 = 20.9
SIAS/CSAS	Containment Spray Initiated	4.75 psig	0.9 + 62.0 = 62.9 (No LOOP)
SIAS	CACs Start	4.75 psig	0.9 + 10.0 = 10.9 (No LOOP)

Other Equipment Safety Functions

For the MSLB containment analysis, the ESFs credited are the CACs and the containment sprays. Since the worst single failure has been identified to be failure of a SGFP to trip, all four CACs and both trains of containment sprays are assumed to be in operation. A summary of the performance parameters for these two ESFs is provided in Table 14.20-11.

The MSSVs were relied upon to remove energy from the intact SG. The opening setpoint of the first bank was 1010 psia, while the full open pressure of the last bank, including accumulation, was 1112.4 psia.

Operator Actions

No operator actions are credited in the MSLB analysis.

Status of Non-Safety-Related Control Systems

A normal initial SG water level is assumed. In addition, while the majority of the components relied on to trip the MFW-related pumps on CSAS are safety grade, a few of the components are non-safety-related. The operability of these non-safety-related components, however, was accepted by the NRC in Reference 18 during the extended MFW addition analysis conducted to respond to NRC Bulletin 80-04.

Closure of the turbine stop valves is assumed following reactor trip. These valves are closed instantaneously following reactor trip. Since delaying the closure of the turbine stop valves would reduce the severity of energy content of the SGs, this response is conservative. Closure of the turbine stop valves is not a safety function in this instance since their rapid closure makes containment response slightly worse.

14.20.3.5 Analysis Results

Mass and Energy Release Results

Mass and energy release data were calculated for a matrix of cases. As discussed in the portion of Section 14.20.3.5 labeled "Single Failures," this matrix included eight different single failures, each evaluated at four different power levels. Framatome Technologies, Inc. used the NRC-approved CONTEMPT containment code to determine the most limiting single failure at each power level, which resulted in the determination of the single most limiting event. The most limiting case was determined to be an MSLB initiated from 75% power with the failure of a SGFP to trip in response to a CSAS.

In general, when considering the range of single failures, the CONTEMPT analysis showed an increase in peak containment pressure with increasing power level. This is due to the increase in feedwater flow rate as power increases. For the limiting single failure (being the failure of SGFP to trip), the initial SG pressure and the rate of depressurization contributed to increased flashing and reduced rate of feedwater flow at full power. This resulted in the prediction of a lower peak pressure in the Containment. For the zero power case, the large initial SG inventory was the dominant effect. However, the peak pressures were less than those for the full power case.

Table 14.20-12 provides a sequence of events for the limiting case. For completeness, this table includes both mass- and energy-related, as well as containment response-related, information.

Containment Response Results

The pressure and temperature profiles for the containment response to the MSLB are calculated in Reference 43 and provided in Figure 14.20-3. Results are shown in Table 14.20-12.

The effect of increasing the full power SG mass inventory on the MSLB containment response was evaluated. The SG mass inventory may increase as a result of partially bypassing the pressure feedwater heaters, which lowers the feedwater inlet temperature to the SGs. The evaluation concluded that the effect of this increase in SG inventory would be to increase the peak containment pressure by less than 0.5 psi with no increase in peak containment temperature. Therefore, peak pressure in the Containment during a MSLB will remain below 50 psig.

14.20.3.6 Summary of MSLB Analysis

Framatome Technologies, Inc. produced the MSLB break mass and energy transfer rates from the RSGs into the Containment using RELAP5/MOD2-B&W Code. The single failure resulting in the most limiting containment response is due to the failure of SGFP to trip. To ensure a set of conservative mass and energy transfer rates, FTI performed a spectrum of analysis based on the reactor power level and single failure criterion. Various reactor power levels of 0%, 50%, 75%, and 102% were examined. The largest break size is limited to the venturi flow area of 1.9 ft^2 installed in the RSG steam outlet. In the calculation of the break mass and energy transfer rates, a 0% moisture carryover was assumed. The GOTHIC Code was used to predict the containment response to a MSLB using the FTI produced mass and energy transfer rates. Steam superheat was predicted in the Containment for a short duration of about 90 seconds.

14.20.4 SUBCOMPARTMENT ANALYSIS

14.20.4.1 Methodology

For the original compartment designs, the occurrence of a LOCA was postulated to result from the rupture of the RCS piping, including the main loop piping, either within the reactor cavity or the SG compartments of the Containment. For the current compartment designs, breaks are not postulated to occur in the main loop piping based on the Leak-Before-Break Evaluation documented in References 1 and 35. Since only main loop piping is present in the reactor cavity, no LOCA is currently postulated to occur in this compartment and no analysis is presented herein for the reactor cavity. However, smaller bore piping connected to the RCS is present in both SG compartments and the pressurizer compartment. Since Reference 1 only applies to main loop piping, a LOCA is postulated to occur in these compartments, and the original design analyses are presented herein for these compartments as they remain bounding.

Subcompartment analyses are made with the Bechtel computer program COPDA, Reference 30, and its predecessor COPRA, Reference 31, which calculate the transient pressure and temperature responses of interconnected volumes subject to high energy pipe break accidents. The differential pressures across structural components are calculated based on the time-dependent compartment pressures. COPDA (as well as COPRA) calculates a mass and energy balance of the two-phase, two-component steam-water-air mixture as reactor coolant enters the compartment during the LOCA and exits through vents and openings into adjacent compartments or into the main Containment Structure. There is no provision in the code for heat transfer to structures or for operation of ESFs, since these options generally have a negligible effect on compartment pressures for the short time following the rupture within which peak differential pressures occur. Nor is credit taken for operator action since peak differential pressures occur so quickly (well before the time typically assumed for operator action) after the start of the transient.

A pipe rupture of this type, within a compartment, results in the expulsion of high enthalpy water out of the ruptured pipe, flashing partly to steam. As the pressure builds up within the compartment, the steam-water-air mixture flows through the openings into the adjacent compartments or the main containment. The maximum differential pressure achieved between the compartments can determine the design strength of walls and supports between the compartments. The maximum pressure differential will depend on the number and shape of the openings leading between compartments, the volume of each compartment, and the blowdown rate from the broken pipe. The ensuing flow from the cavity or compartment follows orifice flow relations with the entrance and friction losses included in the flow coefficient for each case. The vent area from the cavity or compartment controls the differential pressure transient.

14.20.4.2 Inputs and Assumptions

Steam Generator Compartments

For the SG compartment, only the double-ended guillotine break in the hot leg is considered since it provides the largest rate of mass and energy release. The relief areas are divided into three classes: long sharp-edged nozzles; sharp-edged orifices; and well-rounded orifices. A coefficient of 0.61 is applied to the areas of the long nozzles, and a coefficient of 0.97 is applied to the areas of the well-rounded orifices. Coefficients for the sharp-edged orifices are supplied by the computer code. The initial conditions, main containment volume, SG compartment volumes, and total relief flow areas are listed in Table 14.20-13.

Pressurizer Compartment

The upper portion of the pressurizer is enclosed in a box-like structure that has been analyzed as a separate compartment. Because the nozzle for the pressurizer relief valve line is located within the boundaries of this compartment, a subcompartment analysis was performed using the mass and energy release rates from a postulated break at the nozzle. The initial conditions for the compartment volume and relief flow area are listed in Table 14.20-13. The relief openings consist of ventilation openings at the top of the compartment and the opening around the lower portion of the pressurizer. The latter is available only after a baffle plate, made to withstand normal ventilation pressure, blows open at a design pressure differential of 5 psi.

Jet Forces

Jet force pressures associated with postulated primary coolant pipe breaks are considered in the design of walls and slabs adjacent to those pipes. Both the slot and guillotine types of break are investigated. The opening area of a break is assumed to be, at most, the inside cross-sectional area of the pipe. After a break has been fully developed, the escaping reactor coolant produces a thrust, or a reaction on the piping system. The maximum magnitude of this thrust is found to be equal to system operating pressure times the rupture area, or the pipe inside cross-sectional area based on investigations of the Calvert Cliffs system blowdown data. The expanding reactor coolant which forms the jet plume is assumed to diverge at a half-angle of 10° from the break opening. The total jet force is assumed to be equal to the thrust reaction.

The jet impingement area is computed by using the distance from the postulated break to the target structure and the 10° half-angle divergence. The total jet force is assumed to act on this area and thus the jet pressures are found. Those breaks that result in highest pressures and/or stresses are chosen as the governing ones for each wall, slab, or their portions thereof.

14.20.4.3 Containment Internal Structure Evaluation Results

The results of the cavity pressurization analyses are listed below. The calculated compartment volumes and relief areas, combined with the computed mass and energy discharge rates, were used with the COPDA/COPRA model to ensure an accurate analysis of the differential pressures. The safety margins used in the design of the compartment walls are indicated in UFSAR Chapter 5.

For the SG compartments, the maximum pressure differentials across the compartment walls are 16.4 psi and 18.4 psi for the east and west compartments, respectively. These occur at about 0.1 seconds.

For the pressurizer compartment, the maximum differential pressure of 5.02 psi occurs 0.10 seconds after the break of the relief valve nozzle. This is the worst pressure gradient that can result from a break within this compartment; however, this compartment will be exposed to a greater pressure differential due to a LOCA hot leg break in the adjacent SG compartment. Hence, the pressurizer compartment walls are designed to the same differential pressure loads as the SG compartment.

COMPARTMENT	MAXIMUM ∇P, psid	CONCURRENT COMPARTMENT PRESSURE, psig
East SG Cavity	16.4	18.7
West SG Cavity	18.4	20.8
Pressurizer Cavity	16.4	18.7

The resulting jet pressures on the containment internal compartments vary from 30 ksf to 76 ksf. However, these loads act on, at most, one-third of the span for one-way walls or slabs.

14.20.5 CONCLUSIONS

The peak containment pressure for both the LOCA and MSLB DBEs remains below the containment design pressure of 50 psig. Although the peak vapor temperature exceeds the containment design temperature of 276°F, this occurs only for a brief period during a time when the containment atmosphere is superheated. Due to steam condensation on the colder surfaces, the surface temperature of revised structures and mechanical components in contact with the containment atmosphere remains at or below the saturation temperature for the steam in Containment. This temperature is below the design temperature of 276°F. The pressure differentials and jet impingement forces that could occur across the walls of enclosed compartments have been analyzed and incorporated in the current compartment design. Therefore, since the methods used to predict the peak pressure, temperature, and jet forces are conservative, the containment design is adequate and contains sufficient margin. This conclusion is consistent with the NRC Safety Evaluations documented in References 32, 33, and 34, that established the acceptability of the original containment design.

This event is not affected by the transition to Advanced CE-14 HTP™ fuel because the key parameters for this event are plant related system responses which are unchanged from, or bounded by, the current analysis.

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TABLE 14.20-1

SUMMARY OF SIGNIFICANT ASSUMPTIONS FOR LOSS-OF-COOLANT ACCIDENT MASS and ENERGY RELEASE METHODOLOGY

Sources of Energy

- Reactor power and decay heat, including metal water reaction
- Stored metal energy in the core and primary system, including the core and reactor vessel internals
- Steam generator steam and liquid inventory
- Steam generator metal energy, including tubes
- Main Feedwater prior to feedwater trip

Sources of Mass Release

- Primary system inventory
- Water and nitrogen from SITs
- Refueling water tank

Mass and Energy Release Calculations

CEFLASH-4A

- A double-ended slot break was assumed for the RCP suction and discharge cold leg breaks.
- A spectrum of break sizes was investigated for the hot leg break.
- A LOOP was assumed at the initiation of the LOCA. The maximum SI cases assumed the operation of two diesel generators, while the minimum SI cases assumed the failure of a diesel generator.
- The reactor is shut down because of voiding in the RCS for cold leg breaks and by shutdown control rod insertion for the hot leg break.
- The core is allowed to stay in pre-DNB condition except when in heat transfer to steam. In addition, it is allowed to return to nucleate boiling as conditions permit throughout the transient.
- A two-phase heat transfer coefficient, via the Jens-Lottes correlation, is used to calculate core to coolant heat transfer in the nucleate boiling regime.
- The critical flow of mass discharge was modeled via the Henry-Fauske/Moody choked flow model.
- Main Feedwater was conservatively modeled and then isolated in response to the MFW pump trip via SGIS on high containment pressure.
- Steam flow was conservatively isolated by rapid closure of the turbine stop valves following reactor trip on high containment pressure.
- Volumetric expansion due to pressure and temperature considerations was included in both the primary and secondary systems.
- A minimum Technical Specification RCS flow rate was assumed to maximize the energy release to Containment.
- Nominal RCS loop flow resistances were assumed.
- The initial cold leg temperature was maximized to increase the energy release to Containment.
- Consistent with the LOOP assumptions, the RCPs were tripped at the initiation of the LOCA.
- Decay heat was based on the original Combustion Engineering standard decay heat curve, with a multiplier of 20%. The curve is a conservative predecessor to the 1971 ANS Standard Curve.
- A nominal SIT liquid volume, initiated at the maximum Technical Specification pressure was conservatively assumed.

TABLE 14.20-1

SUMMARY OF SIGNIFICANT ASSUMPTIONS FOR LOSS-OF-COOLANT ACCIDENT MASS and ENERGY RELEASE METHODOLOGY

SIT Nitrogen Discharge

- The discharge of nitrogen from the SITs was conservatively modeled via a quality assured utility code, the main equations of which were extracted from the NRC approved model in the ABB/CE COMPERC Code topical report (CENPD-134P), Reference 29.

FLOODMOD2 Simulation

- In accordance with Section 6.2.1.3 of the SRP, the refill period was conservatively omitted. By this approach, the water level is assumed to be at the bottom of the active core at the end of blowdown. This results in a continuous high mass and energy release rate to Containment. Crediting the refill period would result in a time interval of decreased mass and energy release, which would allow the passive heat sinks time to reduce the severity of the transient containment response.
- Single failures resulting in both minimum and maximum SI pump flow cases were evaluated.
- Decay heat was based on the conservative 1971 ANS Standard Curve, with a multiplier of 20%.
- Nominal RCS loop flow resistances were assumed.
- Consistent with the design basis assumptions, credit was taken for 50% condensation of break flow in the limited interval from the annulus being full to the SITs completing the discharge of water. No credit for condensation due to SI pump flow was assumed. The condensation-related assumptions were consistent with the original FSAR design analyses.

CONTRANS Sensible Energy Addition Calculation

- Decay heat was based on the NRC Branch Technical Position ASB 9-2 Guidelines.
- Consistent with the reflood methodology for cold leg breaks, all primary and secondary system metal, and SG secondary inventory, was included in the calculation.
- Consistent with the blowdown assumptions, only the reactor vessel and internals energy below the elevation of the hot leg and the core stored energy contributed to the sensible heat addition.
- The pre- and post-RAS SI flow rates were consistent with Bechtel's long-term model assumptions.

TABLE 14.20-2

INITIAL CONDITIONS AND KEY ASSUMPTIONS FOR MASS AND ENERGY RELEASE ANALYSIS OF LOSS-OF-COOLANT ACCIDENT

	ITEM	VALUE/ASSUMPTION
1.	Methodology	
	Vintage	Current Day, Consistent with SRP
	Break Type	9.8 ft² Double-Ended Slot in RCP Discharge Leg (Suction leg and hot leg breaks also considered)
2.	Initial Nuclear Steam Supply System Parameters	
	Mode	1
	Power Level	102%
	Initial Primary Pressure	2250 psia
	Initial RCS Inlet Temperature	550°F
	Initial Secondary Pressure	815 psia
	Steam Generator Level	35.06' above tube sheet (Normal Water Level)
3.	Reactor Shutdown	On voids
4.	Reactor Coolant Pumps	Tripped at Initiation of Event
	Total RCS flow rate	370,000 gpm
5.	Safety Injection Pump Flow	Maximum SI (Two HPSIs/Two LPSIs) (Minimum SI 1 HPSI/1 LPSI also considered)
6.	Main Steam Isolation Valves	Not credited. SG isolation due to turbine trip
7.	Main Feedwater	
	Initial Flow Rate	102% of full flow
	MFW Enthalpy	425 Btu/lbm
8.	Main Feedwater Isolation Valves	Not credited, MFW contribution terminated following coastdown of SGFPs after SGIS pumps trip
9.	AFW Contribution	None

TABLE 14.20-3

CONTAINMENT PARAMETERS

Containment Design Pressure, psig	50
Containment Design Temperature, °F	276
Net Free Internal Volume, ft^3	1.989E6
Initial Pressure, psia	15.7
Initial Relative Humidity, %	20
Initial Inside Temperature, °F	125
Outside Temperature, °F	125
Service Water Temperature, °F	105
RWT Water Temperature, °F	100

TABLE 14.20-4

CONTAINMENT HEAT SINK THERMODYNAMIC DATA

HEAT SINK BOUNDARY	HEAT TRANSFER COEFFICIENT
Containment atmosphere to heat sink surfaces	"Modified Tagami" (Section 14.20.2.3)
Containment atmosphere to sump	0.00
Containment sump to heat sink surfaces	0.00
Containment walls and dome to outside atmosphere	1.0 Btu/hr-ft^2-°F

TABLE 14.20-5

CONTAINMENT HEAT SINKS

Heat Sink #1 - Containment Cylinder and Dome

Containment cylinder -	52080 ft^2
Containment dome -	21150 ft^2
	73230 ft^2

Material		Node Spacing (in.)	Thickness (in.)
Paint*		1.0×10^{-3}	18×10^{-3}
Primer		7.5×10^{-4}	3×10^{-3}
Carbon steel		6.25×10^{-2}	2.606×10^{-1}
Concrete region			
	2	5.4×10^{-2}	1.5
	3	2.1×10^{-1}	4.0
	4	1.3	6.5
	5	1.07	30.0

Heat Sink #2 - Miscellaneous Unlined Concrete

Steam generator compartment walls -	25508 ft^2
Equipment hatch loading platform -	800 ft^2
Reactor shield platform -	880 ft^2
Pressurizer wall and roof -	2040 ft^2
Refueling canal (outside) -	6750 ft^2
Fuel canal buttresses -	2432 ft^2
Steam generator buttresses -	3580 ft^2
	41900 ft^2

Material		Node Spacing (in.)	Thickness (in.)
Concrete region	1	6×10^{-2}	3.0
	2	1.2×10^{-1}	3.0
	3	1.2	12.0

(Exposed on one side to the containment atmosphere and insulated on the other.)

Heat Sink #3 - Outside Reactor Cavity (unlined concrete): Concrete – 6160 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Concrete	2×10^{-1}	12.0

(Exposed on one side to the containment atmosphere and insulated on the other.)

Heat Sink #4 - Galvanized Steel

Ventilation ductwork -	27788 ft^2
Grating -	51359 ft^2
Cable trays -	16436 ft^2
	95583 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Zinc	1.70×10^{-3}	3.4×10^{-3}
Carbon Steel	2.42×10^{-2}	9.7×10^{-2}

TABLE 14.20-5

CONTAINMENT HEAT SINKS

Heat Sink #5⁺ - Miscellaneous Steel 0.12 to 0.15 in. Thick

Polar crane -	20350 ft^2
Stairway framing -	1286 ft^2
Cable supports -	1872 ft^2
SG Platforms	1500 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	375 ft^2
	25383 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$9.79x10^{-3}$	$1.37x10^{-1}$

Heat Sink #6⁺ - Miscellaneous Steel 0.18 to 0.24 in. Thick

Polar crane -	3759 ft^2
Stairway platforms -	1528 ft^2
Cable supports -	397 ft^2
Ventilation duct plenum supports -	623 ft^2
SG Platforms	3850 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	7383 ft^2
	17540 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$1.01x10^{-2}$	$2.03x10^{-1}$

Heat Sink #7⁺ - Miscellaneous Steel 0.24 to 0.3 in. Thick

Polar crane -	2598 ft^2
SITs	138 ft^2
Stairway framing -	193 ft^2
Reactor head shroud -	1439 ft^2
Ventilation duct plenum supports -	3553 ft^2
Equipment hatch lifting rig -	563 ft^2
Cable supports -	323 ft^2
Shield barrier and SG Platforms	147 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	4207 ft^2
	13161 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$1.24x10^{-2}$	$2.48x10^{-1}$

TABLE 14.20-5

CONTAINMENT HEAT SINKS

Heat Sink #8+ - Miscellaneous Steel 0.3 to 0.4 in. Thick

SITs	448 ft^2
Polar crane -	2643 ft^2
Shield barrier and lifting beam -	119 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	4231 ft^2
	7441 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$1.78x10^{-2}$	$3.56x10^{-1}$

Heat Sink #9 - Miscellaneous Steel 0.4 to 0.5 in. Thick

Polar crane -	1692 ft^2
Main steam pipe supports -	371 ft^2
Shield barrier -	73 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	1578 ft^2
	3714 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$1.21x10^{-2}$	$4.25x10^{-1}$

Heat Sink #10+ - Miscellaneous Steel 0.5 to 0.625 in. Thick

Polar crane -	5364 ft^2
Reactor head shroud -	1120 ft^2
Miscellaneous (I-beams, channel beams, angle iron, and plates)	2546 ft^2
	9030 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$2.57x10^{-2}$	$5.15x10^{-1}$

Heat Sink #11+ - Miscellaneous Steel 0.625 to 0.75 in. Thick

SITs -	70 ft^2
Polar crane -	2160 ft^2
	2230 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$3.38x10^{-2}$	$6.77x10^{-1}$

Heat Sink #12 - Miscellaneous Steel 0.75 to 1.0 in. Thick

SITs -	3682 ft^2
Polar crane -	1449 ft^2
	5131 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$4.21x10^{-2}$	$8.42x10^{-1}$

TABLE 14.20-5

CONTAINMENT HEAT SINKS

Heat Sink #13[+] - Miscellaneous Steel 1.0 to 1.5 in. Thick

Polar crane -	2649 ft^2
RCP supports -	962 ft^2
Reactor head shroud -	732 ft^2
	4358 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$5x10^{-2}$	1

Heat Sink #14[+] - Miscellaneous Steel 1.5 in. Thick or Greater

Polar crane -	1236 ft^2
Equipment hatch -	343 ft^2
Personnel hatch -	269 ft^2
Emergency airlock -	67 ft^2
	1915 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint*	$1.0x10^{-3}$	$8x10^{-3}$
Primer	$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel	$4.82x10^{-2}$	2.412

Heat Sink #15 - Containment Wall in Penetration Areas

Reinforcing plates for containment liner at penetration area -	2470 ft^2

Material		Node Spacing (in.)	Thickness (in.)
Paint*		$1.0x10^{-3}$	$8x10^{-3}$
Primer		$7.5x10^{-4}$	$3x10^{-3}$
Carbon Steel		$7.5x10^{-2}$	$7.5x10^{-1}$
Concrete region	1	$5x10^{-2}$	1.5
	2	$2x10^{-1}$	4
	3	1.3	6.5
	4	1.32	33

Heat Sink #16 - Stainless Steel Liner Plate

Refueling pool -	7750 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Stainless Steel	$1.875x10^{-2}$	$1.875x10^{-1}$

Heat Sink #17 - Containment Shield Barrier

Lead Shield -	203.3 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Lead	$4.0x10^{-2}$	1.0

Heat Sink #18 - Reactor Cavity Below El. 29'-4"

Reactor Cavity Wall -	1280 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint	$1.0x10^{-3}$	$4.0x10^{-3}$
Primer*	$7.5x10^{-4}$	$6.0x10^{-3}$
Carbon Steel	$6.25x10^{-2}$	$2.5x10^{-1}$
Air	$1.429x10^{-1}$	1.0
Carbon Steel	$6.25x10^{-2}$	$2.5x10^{-1}$
Concrete	$1.6x10^{-1}$	12.0

TABLE 14.20-5

CONTAINMENT HEAT SINKS

Heat Sink #19 - Reactor Cavity Between El. 29'-4" and 44"
Reactor Cavity Wall - 968.8 ft^2

Material	Node Spacing (in.)	Thickness (in.)
Paint	$1.0x10^{-3}$	$4.0x10^{-3}$
Primer*	$7.5x10^{-4}$	$6.0x10^{-3}$
Carbon Steel	$6.25x10^{-2}$	$2.5x10^{-1}$
Concrete	$1.6x10^{-1}$	12.0

Material Properties

	Thermal Conductivity Btu/hr-ft-°F	Volumetric Heat Capacity Btu/ft^3-°F
Concrete	2.2	32.835
Carbon Steel	29.6	53.6
Stainless Steel	8.6	60.1
Paint	0.3	47.1
Primer	1.01	21.70
Zinc	62.2	42.0
Lead	19.6	22.3
Air	0.017	0.0156

Heat Sink #20 - Containment Sump Strainer Between El. 10'-0" and 14'-0"

Thickness	Surface Area	El.
0.157 in.	307.9 ft^2	3'
0.157 in.	0.874 (H-3) ft^2	H in inches from 3" to 35"
0.236 in.	116.5 ft^2	3'
0.236 in.	14.961 (H-3) ft^2	H in inches from 3" to 30"
0.236 in.	29.877 (H-30) ft^2	H in inches from 30" to 34"
0.118 in.	3.00 H ft^2	H in inches from 3" to 35"
0.049 in.	381.5 ft^2	6.59 in.
0.049 in.	381.5 ft^2	10.18 in.
0.049 in.	381.5 ft^2	13.77 in.
0.049 in.	381.5 ft^2	17.36 in.
0.049 in.	381.5 ft^2	20.95 in.
0.049 in.	381.5 ft^2	24.54 in.
0.049 in.	381.5 ft^2	28.13 in.
0.049 in.	381.5 ft^2	31.72 in.
0.049 in.	381.5 ft^2	35.31 in.

Material
Uncoated stainless steel

* The analysis conservatively assumes that the entire surface of Heat Sink 1 has a paint thickness of 18 mils and Heat Sinks 5 – 15 have a paint thickness of 8 mils. The analysis conservatively assumes that Heat Sinks 18 and 19 have a primer thickness of 6 mils. The above coating assumptions conservatively envelop the existing coating in the Containment.

\+ The current paint and primer utilized within the Containments on carbon steel is Carboline 890 at a maximum thickness of 6 mils primer and 6 mils paint. The paint and primer thicknesses and material properties listed in the above table are more conservative.

TABLE 14.20-6

ENGINEERED SAFETY FEATURES PERFORMANCE FOR LOSS-OF-COOLANT ACCIDENT CONTAINMENT ANALYSES

SAFETY FEATURE			CONTAINMENT DESIGN BASIS MINIMUM SI	CONTAINMENT DESIGN BASIS MAXIMUM SI
1.	PASSIVE SI			
	Water Source: SITs			
	No. tanks and lines		4	4
	Quantity available (water at 120°F)		4,000 ft^3	4,000 ft^3
	Operating point (reactor pressure)		250 psig	250 psig
2.	ACTIVE SI			
	Water Sources:			
	RWT (360,000 gal)[h] and recirculation from sump			
	No. of pumps (HPSI/LPSI)			
	Pre-RAS		1/1	2/2
	Post-RAS		1/0	2/0
	Flow rate			
	Pre-RAS		~5400 gpm[a]	~8000 gpm[c]
	Post-RAS		575 gpm[b]	1000 gpm[b]
3.	CONTAINMENT SPRAY			
	Water Sources:			
	RWT (360,000 gal)[h] and recirculation from sump			
	No. of lines and headers		1	2(d)
	No. of pumps		1	2
	Flow rate		1250 gpm	2500 gpm
4.	CONTAINMENT ATMOSPHERE COOLING FAN			
	No. of units		2	2
	Flow rate:	(air side)	55,000 cfm/CAC	55,000 cfm/CAC
		(SRW side)	1400gpm/1900gpm[i]	1400gpm/1900gpm[i]
	Heat removal (Btu/hr)		Figure 14.20-1	Figure 14.20-1
5.	SHUTDOWN COOLING HEAT EXCHANGER			
	Cooling Water Supply: Component Cooling System			
	Type: Shell and tube; No. of Units		1[e]	2
	Heat transfer area		4990 ft^2	9980 ft^2
	Heat transfer coefficient (overall)		206 Btu/hr-ft^2-°F[f]	206 Btu/hr-ft^2-°F[f]
	Flow rate:	(sump water side)	1250 gpm	2500 gpm[d]
		(component cooling water side)	$8.96x10^5$ lbm/hr	$1.79x10^6$ lbm/hr
	Operating point (time)		4175 sec[g]	1920 sec

TABLE 14.20-6

ENGINEERED SAFETY FEATURES PERFORMANCE FOR LOSS-OF-COOLANT ACCIDENT CONTAINMENT ANALYSES

(a) For the hot leg break, the entire SI flow rate is injected into the core. For the cold leg break with minimum SI, the entire pre-RAS SI flow rate is assumed to flow to the reactor, with no spillage directly to the sump. This is conservative in that it maximizes the rate of energy transfer from the reactor to the Containment.

(b) For the cold leg break, 25% of this flow is assumed to spill from the broken loop directly to the containment sump. For the hot leg break, this entire flow rate is assumed to be injected into the core.

(c) Of the 8000 gpm, 2,000 gpm are spilled to the sump after being uniformly mixed in the vessel.

(d) Operation of two trains of spray is assumed for the initial 1.12 days (9.65×10^4 sec). By then, containment vapor pressure has decreased to 4.75 psig or less. After that time, it is assumed that one train of spray is manually turned off, and the flow rate decreases from 2500 gpm to 1250 gpm.

(e) Although only one SDCHX is credited, the system is operated such that both SDCHXs will receive component cooling water while only one SDCHX will have containment spray circulating through the tubes.

(f) This value is used for the initial 10,000 sec of the transient. Thereafter a value of 195 Btu/hr ft^{3}°F is used, taking into account the decreasing sump water temperature.

(g) For the Hot Leg Break with minimum SI, the operating point (time to RAS) is calculated to be approximately 4180 sec.

(h) This value represents the minimum volume available prior to RAS.

(i) 1400 gpm assumed pre-RAS, 1900 gpm assumed post-RAS.

TABLE 14.20-7

SEQUENCE OF EVENTS FOR DOUBLE-ENDED DISCHARGE LEG MINIMUM SI LOSS-OF-COOLANT ACCIDENT

TIME, sec	EVENT	COMMENT
0.0	Break occurs	Break area = 9.8 ft^2
	LOOP	RCPs begin coasting down
0.6	CSAS, Containment High Pressure analytical setpoint is reached, Reactor trip setpoint reached, Containment High Pressure.	Containment pressure = 4.75 psig
1.50	CSAS actuated, Main Feedwater, Condensate Booster, HDPs begin coasting down	0.9 sec signal delay time included
1.85	Turbine Stop Valves close	Includes a 0.25 sec valve stroke time plus a 0.1 sec signal delay time after reactor trip signal actuated
11.50	Main Feedwater rampdown completed	A 10-sec rampdown time was calculated
14.40	End of blowdown	
16.50	SI Pump Flow started	A 15 sec delay is assumed after SIAS on High Containment Pressure is actuated
36.50	CACs Full On	A 35.0-sec delay assumed after SIAS signal actuated
71.50	Containment Spray full on	A 70.0-sec delay assumed after CSAS signal actuated
200	Peak Containment Temperature	Vapor Temperature (F): 274.5
200	Peak Containment Pressure	Total Pressure (psig): 49.7
279.4	End of Post-Reflood	Long-term release model begins
1800.0	Time of RAS	SI pump flow switches from RWT to sump

TABLE 14.20-8

SUMMARY OF SIGNIFICANT ASSUMPTIONS FOR MAIN STEAM LINE BREAK MASS and ENERGY RELEASE CALCULATIONS

Sources of Energy

- Affected SG's metal, including the vessel tubing
- Affected SG's water (and steam) inventory
- Feedwater line inventory from MFIV to affected SG
- Unaffected SG inventory prior to closure of MSIVs
- Reactor power and decay heat
- Primary system metal

Primary coolant to affected SG during blowdown; No credit taken for cold SI flow or AFW flow to intact SG

Sources of Mass Release

- Affected SG steam and liquid
- Feedwater line
- Feedwater transferred to affected SG prior to closure of MFIVs
- Steam from unaffected SG prior to closure of MSIV
- Steam line inventory from ruptured SG outlet nozzle to MSIV
- The steam line volume from the ruptured side SG to the turbine and intact SG

Mass and Energy Release Calculations

- Break flow calculations were based on the MOODY critical flow correlation
- In accordance with the original NRC approved design basis assumptions for the Calvert Cliffs plants, a double-ended guillotine break was assumed for all cases
- No moisture carryover was credited in the MSLB analysis
- SG heat transfer calculations were based on nucleate boiling heat transfer
- Volumetric expansion due to pressure and temperature considerations was included in both the primary and secondary systems

Main Feedwater Flow

- Diversion of flow from the intact SG due to high differential pressure between intact and ruptured SGs was considered in the analysis
- Feedwater flashing in affected feedline up to the MFIV caused by reduction in SG pressure was considered in the analysis
- The MFW regulating valve was not credited in this analysis

TABLE 14.20-9

INITIAL CONDITIONS AND KEY ASSUMPTIONS FOR ANALYSIS OF MASS AND ENERGY RELEASE FOR MAIN STEAM LINE BREAK

	ITEM	VALUE/ASSUMPTION
1.	Methodology	
	Mass and Energy Code	RELAP5/MOD2-B&W
	Containment Response Code	CONTEMPT, Version 24
	Moisture Carryover from Ruptured SG	0%
	Break Type	Guillotine at SG nozzle, 1.9 ft^2 effective area due to SG flow restrictor
	Water in Feed Pipe	Considered
	Steam in Header Pipe	Considered
2.	Initial Nuclear Steam Supply System Parameters	
	Mode	1
	Power Level	102% 75% (limiting case), 50%, 0% also considered
	Initial Primary Pressure	2250 psia
	Initial RCS Inlet Temperature	550.0°F[(a)]
	Initial Secondary Pressure	888 psia[(a)]
	Primary and Secondary Volumetric Expansion Due to Pressure and Temperature	Considered
	Steam Generator Level	35.95' above tube sheet (Normal Water Level)
	Number of tubes plugged	None
	Number of tubes removed	None
3.	Reactor Shutdown	
	Reactor Trip	At 4.75 psig containment pressure
	Rod Drop Time	3.1 sec including holding coil delay
4.	Reactor Coolant Pumps	On throughout Event
	Total RCS flow rate	422,250 gpm
5.	Main Steam Isolation Valves	
	Delay Time from SGIS	0.9 sec
	Closure Time	7.0 sec
	Lift vs Time	Linear
	Single Failure	Considered
	MSIV Logic	High Containment pressure 4.75 psig + 0.9 sec delay + 7.0 sec closure

TABLE 14.20-9

INITIAL CONDITIONS AND KEY ASSUMPTIONS FOR ANALYSIS OF MASS AND ENERGY RELEASE FOR MAIN STEAM LINE BREAK

	ITEM	VALUE/ASSUMPTION
6.	Main Feedwater	
	Initial Flow Rate	102% of full flow[a] (Consistent with initial power level)
	MFW Enthalpy	425 Btu/lbm[a]
	SGFP, CBP HDP Trip Logic	High Containment pressure 4.75 psig + 0.9 sec delay + 1.0 sec trip delay
	MFW Flow Diverted from Intact High Pressure SG to Ruptured Low Pressure SG	Considered
	Contribution of MFW Flashing Between Shut MFIV and Ruptured SG	Considered
	Limiting Single Failure	Failure of SGFP to Trip on SGIS (CSAS) on Containment High Pressure
7.	Main Feedwater Isolation Valves	
	Response Time from SGIS	65 sec (for no LOOP case)
	Single Failure	Considered
	MFIV Logic	High Containment Pressure Temperature Setpoint of 4.75 psig + 0.9 sec delay + 65 sec step closure
8.	MFIV Leakage	A total leakage of 200 gpm (based on full power conditions) is assumed to the ruptured SG
9.	AFW Contribution	After 20 sec initial timer delay, 1550 GPM until isolation at 20 sec after high differential pressure block signal (actuated 0.9 sec after 250 psid is reached). AFW leakage to the ruptured SG, after isolation, is assumed at 80 gpm total. AFW enthalpy corresponds to the maximum AFW temperature of 100°F.
10.	Main Steam Piping	
	Total Equiv. K factor for Main Steam Pipe Line Losses	Based on steam line geometry
	Contribution from Steam in Pipe to Ruptured SG's MSIV	Considered

[a] Power Dependent Values.

TABLE 14.20-10

INITIAL CONDITIONS AND KEY ASSUMPTIONS FOR ANALYSIS OF CONTAINMENT RESPONSE TO MAIN STEAM LINE BREAK

Free Volume	1.989×10^6 ft^3
Containment Spray Actuation Setpoint (SIAS/CSAS)	4.75 psig in Containment
Spray Delay Time (after CSAS)	62 sec, with off-site power available plus 0.9 sec signal delay
Spray (RWT) Temperature	100°F
Containment Spray Logic	2 spray trains (1250 gpm per train)
CAC Capacity	See Figure 14.20-1, Four CACs operational, with service water flow rate = 1400 gpm
CAC Actuation Setpoint (SIAS)	4.75 psig
CAC Delay	10 sec, with off-site power available plus 0.9 sec signal delay
Initial Containment Temperature	125°F
Initial Containment Pressure	1.8 psig
Initial Relative Humidity	20%
Heat Transfer Coefficient Used for Passive Heat Sinks	Uchida Correlation
Credit for Condensate Revaporization	No credit taken
Credit for Heat Transfer to Water in Containment Sump	No credit taken

TABLE 14.20-11

ENGINEERED SAFETY FEATURE PERFORMANCE PARAMETERS USED FOR CONTAINMENT ANALYSIS FOR MAIN STEAM LINE BREAK

SAFETY FEATURES	ACCIDENT OPERATION
Containment Spray [(a)]	
Water sources (RWT)	360,000 gal[(d)]
No. of lines and headers	2
No. of pumps	2
Flow rate	2500 gpm
Containment Atmosphere Cooling Fans[(b)]	
No. of units	4
Total flow rate (air side)	220,000 cfm
Heat removal (Btu/hr)[(c)]	Figure 14.20-1

(a) The containment spray delay time after CSAS is 62.9 sec, with offsite power available.

(b) The containment fan cooler actuation analysis setpoint is 4.75 psig in Containment. The time delay is 10.9 sec.

(c) The heat removal rate is based on a service water flow rate of 1400 gpm per unit.

(d) This value represents the minimum volume available prior to RAS.

TABLE 14.20-12

SEQUENCE OF EVENTS FOR MAIN STEAM LINE BREAK INSIDE CONTAINMENT

TIME, sec	EVENT	COMMENT
0.0	Break occurs	Break area = 1.9 ft^2 (effective)
1.61	Reactor trip analytical setpoint reached, Containment High Pressure	Containment pressure = 4.75 psig
	SGIS/CSAS analytical setpoint reached, Containment High Pressure	
	Turbine Stop valves closed	TSVs conservatively closed at reactor trip setpoint
2.51	CEAs begin entering core	Reactor trip delay time = 0.9 sec
	SGIS/CSAS signal actuated	SGIS/CSAS signal delay time = 0.9 sec
3.51	SGFP, CBP, and HDP Coastdown Begins	Based on 1 sec response time for SGFP steam inlet valves closure
9.51	MSIV Closure	A 7.9 sec delay time after High Containment Pressure Reactor Trip analytical setpoint is reached
11.57	AFAS Block high SG ΔP analytical setpoint reached	SG ΔP = 250 psid
12.51	CACs full on	A 10 sec delay time after CSAS actuated
16.67	AFAS Low SG Water Level analytical setpoint reached	Ruptured SG level = 66.5" below normal water level
32.47	AFW to ruptured side SG isolated	A 20.9 sec delay time assumed after analytical setpoint is reached
64.50	Containment Sprays full on	A 62.0 sec delay assumed after CSAS signal actuated.
65.0	Containment peak temperature	Vapor temperature = 354.2°F
67.50	MFIVs closed	A MFIV stroke time of 65 sec assumed following actuation of SGIS on CSAS
250.0	Containment peak pressure	Total pressure = 49.1 psig

TABLE 14.20-13

INPUT PARAMETERS COMPARTMENT PRESSURIZATION ANALYSIS

Initial Conditions	
Containment Temperature, °F	120
Containment Pressure, psia	14.7
Containment Relative Humidity, %	50
Structure Geometries	
Main Containment:	
Net Free Volume, ft^3	$2.00x10^6$
East SG Compartment:	
Net Free Volume, ft^3	53,980
Long Sharp-Edged Nozzle Area, ft^2	356
Sharp-Edged Orifice Area, ft^2	770
Well-Rounded Orifice Area, ft^2	1,072
West SG Compartment:	
Net Free Volume, ft^3	51,500
Long Sharp-Edged Nozzle Area, ft^2	182
Sharp-Edged Orifice Area, ft^2	414
Well-Rounded Orifice Area, ft^2	1,072
Pressurizer Compartment:	
Net Free Volume, ft^3	3,394
Orifice-Type Relief Area (ventilation openings), ft^2	20.5
Orifice-Type Relief Area (available after baffle blows out), ft^2	85.2